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Mangrove Extinction: Anthropocene impacts, Ecological Risks and Conservation Strategies

Conservation priority for Mangroves

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Mangroves are one of the world's most fertile and ecologically significant ecosystems, supplying essential ecosystem services, products and supporting threatened/endangered species. Mangrove ecosystem degradation has become a matter of concern across the world. The present paper focuses on the importance of mangrove coastal biodiversity with respect to ecological and medicinal values. Severe anthropogenic impacts associated with organic matter, contaminants (pesticides and heavy metals), sediment specificity, redox properties, flora, and fauna (micro and macro) are highlighted in this paper. Knowledge about conservation as well as rehabilitation methods have been summarized with management approaches.

Key words: Anthropocene, Biodiversity, Contaminants, Conservation strategies, Mangroves.

Introduction

Mangroves are an assemblage of woody halophytes and the only humid coastal forests that are the foundational species of the dense inter-tidal forest ecosystem. Mangroves usually are found along tropical and subtropical coastlines, estuaries, creeks, bays, lagoons, and rivers (Friess, 2012). These Mangroves are prevalent along the intertidal regions of tropical and sub-tropical coastlines and are inimitable and dynamic ecosystems. These are the most productive, good bio-indicators of environmental quality and health of any coastal ecosystem and provides long-term carbon sink (Fan, 2002; Tam, 2006; Tang, 2008; Wang *et al*., 2009a; Devi and Pathak, 2016; Das *et al*., 2019). Mangroves provide habitats for marine species, protection from extreme weather conditions, and a resource base for sustainable tourism. They have unique ecological functions, services and socio-economic value for local communities and nations (Tam, 2006; Tang, 2008; Sukumaran *et al*., 2013; Devi and Pathak, 2016; Das *et al*., 2019). Mangroves are subjected to highly variable physicochemical conditions of salinity, flooding, light, and temperature that gives rise to the high diversity that characterizes the mangrove ecosystem (Kumar *et al*., 2017). Mangroves have enormous ecological and environmental importance, and it requires special attention for their protection and conservation (Amin *et al*., 2009; Yap *et al*., 2009; Ma *et al*., 2011; Yap *et al*., 2011). Threatening the mangrove ecosystems include toxins and persistent pollutants such as heavy metals and organic pollutants. Since heavy metals cannot biodegrade, they accumulate through the food chain of organisms (Pan and Wang, 2012). Heavy metals such as Cu, Zn, Mn, Cd, Cr, Pb, and Hg have been found in mangrove ecosystems due to their persistence, bioaccumulation, toxicity, and long-range transport. Organic pollutants in mangroves, including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dichlorodiphenyltrichloroethane (DDT), have also been a major problem. Both metal and organic pollutants have the potential to negatively impact flora and fauna as well as the stability of mangrove ecosystems and other ecological processes (Fu *et al*., 2003; Bayen *et al*., 2005).

Communities that live in coastal areas are dependent on local resources for their livelihood. Mangroves hold ecotourism as well as these are the sources of vastly treasured commercial products and fishery resources (Kathiresan and Bingham, 2001). More than 70 direct human activities, ranging from fuel wood collection to fisheries are found to be associated with mangrove forests (Kathiresan, 2012). Forestry products like firewood, charcoal, timber, honey and fishery products (fish, prawn, crab, mollusk, etc.) are supplied by mangroves. Mangrove twigs are used for making charcoal and firewood due to their high calorific values. Mangrove firewood produces high heat without generating smoke. 5 tons of Indian coal is equivalent to one ton of mangrove firewood (Krishnamurthy, 1990). Mangrove wood contains high contents of tannin which is used as timber for its durability. Varieties of bottle stoppers and floats are prepared from Pneumatophores. Some varieties of mangroves like Nypa leaves are used to thatch roofs, mats, and baskets (Krishnamurthy, 1990). For lime manufacturing, shells of mangrove mollusks are used. Mangroves facilitate apiculture activities as they attract honeybees in many areas (Krishnamurthy, 1990). Sundarbans account for about 90% of honey production in India. This delta provides employment to 2000 people through apiculture where approximately 111 tons of honey is extracted annually (Krishnamurthy, 1990).

Economic Importance of Mangroves

In addition to their nutritional value for animals like sheep, goats, buffaloes, and camels, many of the varieties of mangrove species, especially *Avicennia* genus, has been economically used as fodder. Extracts of mangroves are used in indigenous medicine, for example, leaves of *Bruguiera* species are used for reducing blood pressure and for the treatment of leprosy and epilepsy, *Excoecaria agallocha* are used for narcotizing the fishes whereas stems and roots of *Derris trifoliate* are used for the treatment of rheumatic disorders. Species of *Xylocarpus* exhibits antidiarrhoeal properties and species of *Avicennia* have tonic effect, whereas *Ceriops* shows hemostatic activity. *Rhizophora* species (barks) have astringent, antidiarrhoea and antiemetic activities. A beverage is prepared from the fruits of *Sonneratia* species whereas tender leaves of *Acrostichum* are used as vegetable.

Mangroves extracts have potential for human, plants and animal pathogens for the treatment of incurable viral diseases like AIDS (Kathiresan and Bingham, 2001). The mangroves are also beneficial for aquaculture industries as they provide seeds for it. Mangroves fix and store significant amounts of carbon. Mangrove forests contribute to the global carbon in large way while these unique forests constitute only 1% of world's plant biomes and only 0.7% of global coastal zone (Myers, 1997). The coastal vegetated habitats are considered as *'blue carbon sink'* such as mangrove, salt marsh and sea grass are large carbon sink. The vegetated coastal habitats of the seafloor cover only less than 0.2%, while 50% of the global burial of organic carbon in marine sediments they contribute (Kennedy, 2010).

Mangrove ecosystems are declining due to overexploitation and lack of adequate attention conversion. Mangroves possess a qualitative social value and quantitative economic value. They provide several ecological, economical services, social, and cultural benefits.

Ecological Importance of Mangroves

The roots of mangrove have a significant role in providing ecological balance and thus need to be protected. Mangroves provide protection against hurricanes, riverbank erosion, floods, reduction of shoreline and maintenance of biodiversity. Mangroves also provide utilitarian services. The species of mangrove named *Rhizophora* act as a protective force against natural calamities because of their unique physiological characteristics (Kathiresan and Bingham, 2001; Srikanth *et al*., 2016). The root system of mangroves is well developed and spread so that they control the flood and control sedimentation (Goodman, 2021). The conservation and restoration process of mangroves mitigate the impact of natural calamities like tsunami and controlstorms and rise in sea levels (Kathiresan, 2012). Roots of mangrove also provide other significant ecological services such as storage of carbon (Singh and Pathak, 2019).

Roots of mangroves serve as a nursery for juvenile fishes and provide them protection from their predators in shallow water environment. According to some researchers a great number of sharks and ray's fishes can also be found in the mangrove environment (Rö, 1999). They provide breeding grounds for several commercially important marine species for faunal ecosystem. Several Species of *Palaemonid* shrimps are linked with mangroves, which are associated commercially important freshwater shrimp. The crab found in mangroves are of major economic and ecological importance, which includes the mangrove mud crab that is of high priced. Roots of mangroves regulate the quality of water and this prevents the degradation of sea grass or the habitat of coral reefs. Rhizospheres or the habitat of coral reefs. Rhizospheres of mangroves provide the excellent habitat for the bacteria (Srikanth *et al*., 2016).

Mangroves- phytochemicals / medicinal importance of species is summarised in Table 1.

Anthropogenic Impacts on Mangroves

Organic matters

Organic matters are an important factor in mangrove ecosystems when determining the bioavailability and mobility of pollutants (Kristensen *et al*., 2008). The two sources of sedimentary organic

Table 1 : Mangroves- phytochemicals / medicinal importance

S. No.	Mangrove plant species	Found in region	Phytochemicals detected	Active parts	Medicinal application	References
1.	*Acanthus ilicifolius*	Australia Southeast Asia, Bangladesh, Thailand and India	Alkaloids, carbohydrates, alcohols, steroids, Fatty acid, triterpenes, Steroids, phenol, terpenoids,	Leaves	Antifungal activity	(Rathod and Pathak, 2020; Andriani *et al*., 2020)
2	*Avicennia alba*	South and Southeast Asia, Australia and the islands of the South Pacific Ocean,	Lipids, naphthoquinones, flavonoids, hydrocarbons, alkaloids, phenolic groups, triterpenoids	Leaves	High anticancer activity, Antibacterial activity, Antifouling activity, Ichthyotoxic activity,	(Illian *et al*., 2019)
3.	*Avicennia marina*	Africa, Asia, New Zealand and Australia	Triterpenoids .Alcohols, carbohydrates, fatty acids, amino acids, carboxylic acids, hydrocarbons, tannins, triterpenes, steroids, vitamins, phenolics, alkaloids, flavonoids,	Leaves and bark	Anticancer, Antidiabetic ,Antibacterial, Antifouling activity	(Selvin *et al*., 2009; Dawane *et al*., 2016; Dawane and Pathak, 2020)
4.	*Avicennia officinalis*	Bangladesh, Cambodia, Brunei, India, Malaysia, Indonesia, Papua New Guinea, Myanmar,	Tannins, carbohydrates, Alkaloids, flavonoids, lipids, polyphenols, saponins, glycosides, proteins	Leaves	Antibacterial activity, Cholinesterase inhibitors to treat Alzheimer’s disease	(Lalitha *et al*., 2021)
5.	*Bruguiera cylindrica*	India and Sri Lanka, Malaysia, Thailand, the Philippines, Vietnam, New Guinea and Indonesia,	Alkaloids, phenolic compounds, triterpenoids, tannins, flavonoids, fatty acid,	Leaves	Ichthyotoxic activity, Antimicrobial activity, Antifouling activity, Brine shrimp cytotoxic activity,	(Selvin *et al*., 2009; Bandaranaya ke, 2002)
6.	*Bruguieragym norrhiza*	Asia,Australia, Indian Ocean, western Pacific Ocean and the South China Sea,	Anthocyanins, carotenoids, carbohydrates, catechins, fatty acids, flavans, lipids, phenolic compounds, steroids, proteins, triterpenes, carboxylic acids,	Leaves	Cytotoxic, Anti-hemolytic, Antibacterial activity	(Karim *et al*., 2020)
7.	*Ceriopsdecan dra*	India and Bangladesh, Burma	Flavonoids, proteins, polyphenols, tannins, steroids, alkaloids, triterpenes,	Leaves, wood, roots and bark	Antibacterial activity a	(Simlai, 2012)
8.	*Excoecariaag allocha*	Asia,Australia, Africa	Alkaloids, proteins, saponins, polyphenols, sugars, steroids, triterpenes, tannins, fatty acid	Leaves	Antibacterial activity	(Bandaranay ake, 2002)
9.	*Heritiera fomes*	Indo-Pacific region	Polyphenols, tannins, proteins.	Leaves	Antimicrobial activity, Antifouling activity and Ichthyotoxic activity	(Selvin *et al*., 2009; Bandaranaya ke, 2002)
10.	*Lumnitzera racemose*	Kenya, western Indian Ocean, tropical , western Pacific	Cyclitols,tannins, sugars	Leaves	Antibacterial activity	(Rollet, 1981; Premanathan *et al*., 1999)
11.	*Nypa fruticans*	Asia, Pacific Islands, Japan's Iriomote Island	Ethanol,Acetic acid, sugars	Leaves	Antibacterial activity	(Rollet, 1981)
12.	*Rhizophora stylosa*	Japan, Taiwan, China, Vietnam, Cambodia, Australia, Malesia,	Anthocyanins, steroids, anthocyanidins, triterpenes, tannins,	Leaves	Antibacterial activity	(Mouafi *et al*., 2014)
13.	*Sonneratia apetala*	India, Bangladesh	Sucrose, fructose, glucose, tannins	Leaves and bark	Antibacterial activity	(Bandaranay ake, 2002)
14	*Xylocarpus granatum*	Indo-Pacific region, Asia	Alkaloids, carbohydrates, amino acids, fatty acids, hydrocarbons, flavonoids, polyphenols, limonoids, saponins, sugars, steroids	Leaves	Antibacterial activity	(Bandaranay ake, 2002)

matter (OM) are mangrove litter and imported suspended organic matter (Prasad *et al.*, 2010). Composition of OM in mangrove soils under *Avicennia schaueriana* and *Rhizophora mangle* differs significantly in terms of amino sugar, sugar and amino acid content. Organic matter is also influenced by changing environmental conditions and weather. Mangrove pore water Dissolved Organic Matter (DOM) in Brazil had a greater content of high molecular weights as compared to estuary DOM nearby, indicating UV degradation of such compounds during seaward transmission (Prasad *et al.*, 2010). Mangrove sediments have a high OC concentration, bearing 2.2% of median Particulate Organic Carbon (POC) (Kristensen *et al.*, 2008). POC content varies widely within different sites, with stated values (Domínguez, 2010); India (0.52 to 3.02 %) (Fernandes and Bharathi, 2011); China's Deep Bay (2.69% to 5.96%) (Zhang *et al.*, 2004); Brazil (1.16% to 13.41%) (Marchand *et al.*, 2011; Kumari *et al.*, 2020). The geographical distribution of OC in sediments has been described in a variety of ways: the OC in sediments underneath *Rhizophora* stands was determined to be greater as compared to *Avicennia* stands, attributed to *Rhizophora's* more developed and complex root arrangement (Marchand *et al.*, 2011; Kumari *et al.*, 2020). Crabs scavenging leaves were also found to be linked to OC in sediment (Chen *et al.*, 2016). OM affects both Lipophilic organic pollutants and trace metals which affect their bioavailability and mobility (Bayen and Buffle, 2009). The significance of OM in mangroves was demonstrated by the total organic carbons (TOCs) (Lee, 2014). To further evaluate pollutant bioavailability, a meticulous study of quantitative as well as qualitative specificities of OM in mangroves is required which is often missing. Range of detectable level of contaminants in mangrove plants is explicated in Table 2.

Redox properties

Redox potential is generally dogged by quantifying the potential difference (Voltage or EMF) between an inert electrode usually made up of platinum in the soil and Ag/AgCl as a reference or calomel electrode at the surface of the soil (Rowell, 1981). In natural soil systems, heterogeneity and thermodynamic instability produce a mixed redox potential that does not reflect the ion oxidation states of present minerals, according to the Nerst equation (Rowell, 1981; Bartlett and James, 1995). An aerobic (oxidized) soil has an Eh value greater than +300 mV, while anaerobic (reduced) soils have an Eh value between +200 mV and –400 mV. In oxidizing environments, redox measurements are less stable and reproducible than in reducing environments. When soil is well aerated, redox couples are usually low in concentration (Veneman *et al.*, 1983). There is, however, a close relationship between the soil redox potential and oxygen concentration in the soil atmosphere even in well-aerated soils (Farrell *et al.*, 1991).

Redox conditions in mangrove sediments are dependent on the quantity and reactivity of bioturbation activity, organic matter, and sediment grain size, similar to marine sediments. It is also dependent on forest age, physiological activities of the root system, crab burrowing, and extent of water logging (Marchand *et al.*, 2011; Kumari *et al.*, 2020). Inundation of mangroves causes decrease in oxygen level in organic-rich sediments in several cases. Sulfidic conditions were degraded because of sulphate ions rich in huge quantities (Raven *et al.*, 2019). The co-precipitation of trace metals with other sulphide minerals (*e.g.* iron sulphide) in sulfidic zones is identified as a major step leading to metal immobilization in mangroves (Clarke and Wai, 1998). The fate of trace pollutants is also influenced by micro fauna closely tied to redox conditions. Anaerobic sulphate-reducing bacteria are well known to persuade mercury methylation (II), representing mangroves as a potential leading source of methyl-mercury (Kehrig *et al.*, 2003).

Mangroves vegetation

Several impacts of pollution have been observed in biological responses like biomass production, photosynthesis, defoliation, appearance of

Table 2 : Range of detectable levels of contaminants in mangrove plants

Pollutant	Range	References
Cobalt	7–42 nmol.g−1	(Marchand *et al.*, 2006b)
Cadmium	0.01–3.1 µg/g dw	(Peters *et al.*, 1997; Lewis *et al.*, 2011)
Chromium	0.2–347 µg/g dw	(Lewis *et al.*, 2011)
Mercury	106–4300 ng/g dw	(Marchand *et al.*, 2006b; Agoramoorthy *et al.*, 2008; Ding *et al.*, 2011)
Copper	0.1–207 µg/g dw	(Peters *et al.*, 1997; MacFarlane *et al.*, 2007; Lewis *et al.*, 2011)
Manganese	0.42–2472 µg/g dw	(Peters *et al.*, 1997; Lewis *et al.*, 2011)
Nickel	0.4–108 µg/g dw	(Lewis *et al.*, 2011)
Lead	0.02–225 µg/g dw	(Peters *et al.*, 1997; MacFarlane *et al.*, 2007; Lewis *et al.*, 2011)
Tin	354.2–1769.8 µg/g dw	(Agoramoorthy *et al.*, 2008)
PAHs	30.83–62.73 ng/g dw	(Lu *et al.*, 2005)
HCHs	4.478–10.475 ng/g dw	(Shete *et al.*, 2009)
DDTs	1.173–15.399 ng/g dw	(Shete *et al.*, 2009)
Endosulfans	0.633–1.542 ng/g dw	(Shete *et al.*, 2009)
Aldrin	0.177–0.256 ng/g dw	(Shete *et al.*, 2009)

Metallothioneins (MT), activities of enzymes (*e.g.*, GSH, Peroxidase, CAT, and SOD), mutation frequency and lipid peroxidation products. Mangroves plants have been researched in connection to trace metals (Mercury, Copper, Cadmium, Manganese, Zinc, and Lead), oil residues, raw wastewater and herbicides. Trace pollutants have been linked to causing reduced photosynthesis in mangrove plants in controlled conditions (Kumari *et al*., 2020). It lowers biomass and growth and eventually causes mortality (MacFarlane and Burchett, 2001). Under field observations, mangrove degradation in Australia has been found to be caused as an after-effect of pesticide pollution, notably Diuron which acts as a photosynthesis inhibitor (Du *et al*., 2021). An LC50 of 580 microg/g zinc was found for *A. marina* seedlings (artificial sediments cultured with Zinc (II) for 2 weeks), which is similar to the highest limit of total Zinc recorded in certain mangrove sediment samples (MacFarlane and Burchett, 2001). Such a comparison might indicate that some mangrove plants are at risk. To advance the risk assessment, the procedures used for other plant systems and pollutant speciation triggered in mangrove sediments must be explicated for identification of bioavailable proportion (Bayen, 2012).

Mangrove microorganisms

Polyaromatic hydrocarbons (PAHs), heavy metals (Cu, Mn, Hg, Pb and Zn), crude oil, fluoranthene, bisphenol and wastewater have all been proven to be harmful to some mangrove microbes (bacteria, microalgae and fungi) as well as to the whole mangrove ecosystem (Ružičková *et al*., 2018). Microcosms are known to be influenced by the presence of trace pollutants, not only because microbes compete for substrates for respiration or carbon production and also because harmful impacts occur (Gomes, 2007; Wang *et al*., 2010; Liebezeit, 2011). Bioremediation methods are based on these processes (Kaur and Kanwar, 2021). In mangroves, microbes are observed to be responsible for the degradation and transformation of oil wastes and heavy metals (Ding *et al*., 2009). Mangrove leaves and wood contain lignocellulose components that are degradable by microorganisms (Alongi *et al*., 1989; Moran and Hodson, 1989). The decay of fallen mangrove vegetation begins immediately after it is colonized by fungi and bacteria living in the sediment, and can last for 2–6 months (Newell *et al*., 1984; Steinke *et al*., 1990). In Goa's mangroves (India), heterotrophic bacteria produce cellulolytic, pectinolytic, amylolytic, and proteolytic products (Matondkar *et al.*, 1981). Decomposing mangroves requires fungi with pectinase, protease, and amylase activities, as well as the capacity to degrade lignocellulosic compounds (Findlay *et al*., 1986). Mangrove vegetation decomposes into detritus, a form of organic matter in active decomposition. In addition to being rich in energy, it is also home to a large number of microbial populations that live both attached and free in the environment (Odum and Heald, 1975a; Bano *et al*., 1997). Detritus may also be formed by organisms other than bacteria and fungi colonizing vegetative matter (D'Croz *et al*., 1989). Mangrove leaf decomposition reveals a complex microbial community that includes fungi, bacteria, protozoa, and microalgae (Odum and Heald, 1975b). In most cases, the microbial biomass is substantially less than 1% and never exceeds 1.2% of detrital mass. Therefore, detritivores (organisms that feed on detrital particles) cannot obtain their energy solely from microbes (Blum *et al*., 1988). Odum and Heald (1975b) determined that newly fallen mangrove leaves contained 6% protein. After six months, the leaf protein content increased to 20%, probably due to the transformation of fats, carbohydrates, and vegetative proteins into microbial proteins. Mangrove leaves and wood accumulate nitrogen as they decompose (Newell *et al*., 1984). During the initial two months of the decomposition, the nitrogen content in the fallen trunks of *Rhizophora* spp. has increased by 500% (Robertson and Daniel, 1989a). In the Bay of Panama after 27 days of involvement, the degraded red mangrove leaves showed 50% loss in dry weight. Within the mangrove ecosystems the activities of microbes are responsible for most of the nutrient transformation (Alongi *et al*., 1993; Holguin *et al*., 1999). According to several surveys, 91% of the total biomass are made up of bacteria and fungi in the tropical mangroves while algae and protozoa represent only 7% and 2% (Alongi, 1988). In tropical mangrove sediments, the bacteria are responsible for major carbon flux. They act as the carbon sink and process most of the energy flow and nutrients. Instead, as the bacteria naturally die and lyse, they are converted by the next generation of cells into new bacterial biomass. The bacteria are converted by the next generation of cells into the new bacterial biomass or they naturally die and lyse after a period of time (Alongi, 1988; Alongi *et al*., 1993).

Macro benthos and fish biodiversity

Research on macrobenthos is crucial as a tool for ecological and environmental monitoring, especially for coastal locations that have suffered from degradation.). According to (Parsons *et al*., 1984) benthic biotas, which include Gastropoda, Bivalvia, and other macrobenthic creatures, play a crucial role in the mineralization and breakdown of organic materials as well as holds a key place in the food chain. Moreover, macrobenthos serves as food for a variety of species, particularly demersal fishes (Platell *et al*., 2006; Nasi *et al*., 2020). There has been many research on the importance of macrobenthic organisms for benthic and environmental monitoring in the Java Sea, Indonesia (Ruswahyuni, 2008; Pamuji *et al*., 2015; Sihombing *et al*., 2017; Sahidin *et al*., 2018).

The mangrove habitat is inhabited by a wide range of fish species, including Liza, Mugil, Lates, Polynemus, Ilisha and Etroplus. The Mollusca varieties of Crassostrea, Meretrix, Tefescopium, and Cerethedia are frequently found in the mangrove habitat, which is significant for fish and fisheries, and are found in crustaceans like Penaeus, Metapenaeus, and Scylla (mudcrab). Tanin, which is released by the mangrove vegetation, hardens the egg cases of fin and shellfishes and improves hatchling survival, while wax from the leaves of mangrove trees and the hives of hymenopterans regulates predatory aquatic insects. The cellulose and hemicellulose found in mangrove litter and the pectin found in the shells of deceased crustaceans, respectively, are broken down by yeast's enzymatic activity, making the carbohydrates, protein, and other nutrients easily available to developing prawns and fish that eat detritus. In the aquatic environment, macrobenthos serves as a bio-indicator of the degree of pollution (Tweedley *et al*., 2012). These macrofauna include a wide range of species, including gastropods, mollusks, echinoderms, bivalves, and annelids (Gray, 1981; McLusky and Elliot, 2004; Lu *et al*., 2008). Macrobenthos, sessile, walking, or hole-digging seafloor animals, are crucial to the dynamics of coastal ecosystems (Bartels-Hardege *et al*., 1996; Platell *et al*., 2006). Tolerance and sensitivity to environmental changes have a significant impact on abundance and variety (Hong and Yoo, 1996; Gray *et al*., 2002; Kon *et al*., 2012). These organisms play important roles in the breakdown of organic matter and mineralization of organic material in coastal waters (Bengen, 2000; Leung, 2015). Mangrove rotifers, crustaceans, crabs, and fishes have all been tested for toxicity. *Killifish* and *K. marmoratus*, the fish species found in mangrove has been used as a new model of aquatic toxicology for carcinogenicity and endocrine disruption spawning a large body (Lee, 2008). The mangrove fauna, in laboratory tests, exposed to some specific trace pollutants was found to be associated with biological responses including enzyme activity inhibition, activity/behavioural alteration (Alves, 2002; Saha *et al*., 2009), as well as enhanced vitallogenin in fish species, thereby leading to mortality (Lee, 2008). Pollution in mangroves is linked to deformities in oyster embryos (Paixão *et al*., 2011), snails (Roach and Wilson, 2009), genetic alterations in crabs (Penha-Lopes *et al*., 2011), parasitism noticed in shrimps (Penha-Lopes *et al*., 2011) or abnormalities found in some fish species (Kruitwagen *et al*., 2010). Crabs appear to have an unusual capacity to digest certain pollutants among the mangrove macrofauna. A lowered bio-water accumulation factor for Polyaromatic Hydrocarbons (PAH), interpreted as a sign of crabs' capacity for biotransformation of PAH into polar metabolites, allowing for easier defecation was also reported (Nudi *et al*., 2010).

Conservation and Management Strategies

A brief description of anthropocene activities and strategies for mangrove conservation is shown in the Fig. 1.

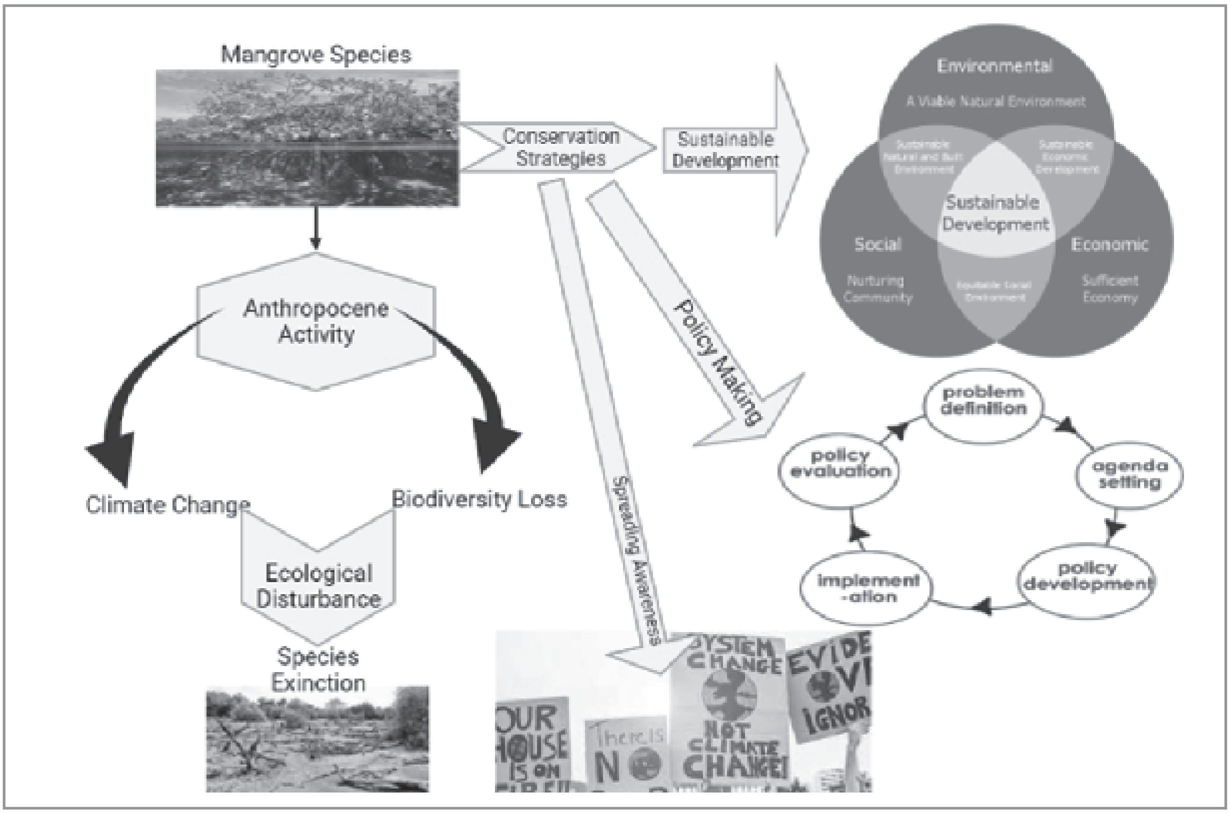

Fig. 1: Mangroves fate upon Anthropocene activity and conservation strategies

Management of Coastal activities through Policy Execution

The Ministry of Environment, forests and climate change, government of India (MoEFCC) in recognition of the destruction of the coastal environment and over-exploitation of the coastal areas of Indian subcontinent has issued a draft Coastal Regulation Zone (CRZ, 18th January, 2019), which invites suggestions and objections from the public. Tidal activity in coastal areas which tends to affect streams, rivers, bays, and waterbeds, that are part of the CRZ region. (Ministry of Environment, Forest and Climate Change Notification New Delhi, CRZ, 18th January, 2019). The classification of the CRZ areas is based upon the geomorphological features, ecological sensitivity and demographic distribution into four categories, CRZ-I (intertidal and sensitive zone), CRZ-II (developed and urban zone), CRZ-III (underdeveloped and rural zone), CRZ-IV (Lakshadweep and Andaman & Nicobar Island). For the developmental activities in CRZ area special permissions are required and also prohibition of certain activities. Withdrawal of groundwater, mining of sands, and other minerals, disposal of effluents and wastes, manufacturing and storage of hazardous waste, expansion of existing industries and setting up of new, industries, fish processing units. Such activities are strictly prohibited under the notification of CRZ rules. Only the developmental and construction activities related to defence needs for which coastal facilities are essential, construction of harbors and ports in specific areas are only permitted.

Establishment of Protected Areas

Protected areas are the zones in which the mangroves are treated as the replica and refugia. In such areas these vulnerable ecosystems are conserved. Communities that are more resistant to climate change stress, areas of mangrove which act as climate change refugia are covered under protected areas (Gilman *et al*., 2008). Recently established mangrove forests are less resistant and resilient to stresses than a mature mangrove community. In general, the refugia areas recover quickly after a disturbance.

Mangrove Rehabilitation

This is a matter of choice to rehabilitate the mangrove lands for conservation. Such choices should be committed by the socio- economic and ecological priorities of the communities tangled, while such choices are affected by the coercion from conservation organizations advising the nature's preservation. Sustainable production, land scaping, coastal protection and conservation are the four main reasons for mangroves rehabilitation. Out of this coastal protection is specifically applicable to climate change induced sea-level rise and subsequent erosion. By diminishing the factors that causes the mangrove loss mangrove cover can be enhanced and that can increase the resistance and resilience to climate change (Gijsman *et al*., 2021).

Regional Monitoring Network

Compositional changes of the atmosphere are accelerated by human interventions that leads to change in ecosystems with respect to time. There is urgency to study the changes and monitor systematically due to uncertainties about climate change and mangroves and other coastal ecosystems (Giri *et al*., 2011). For better understanding of mangrove responses to sea-level and global climate change and also for the mitigation of adverse effects on mangrove ecosystem establishment of baseline studies and gradual monitoring through regional networks using standardized techniques should be used. In some studies, mangrove associates have also been mapped in addition to true mangroves (Duke *et al*., 2007). Among the most important parameters are area, extent, spatial distribution, species zonation, canopy closure, density, height, biomass, 3-D structure, mangrove health, disturbance, and recovery. Mangrove forests can be better characterized, mapped, and monitored through the use of remote sensing with higher spatial, spectral, and temporal resolutions. With the development of remote sensing data, image processing methodologies, information technology, and human resources development, it is now possible to observe and monitor mangroves on a consistent and regular basis at local and global scales (Ramachandran *et al*., 1998; Ajithkumar *et al*., 1998). Mangroves can now be observed and monitored with unprecedented spatial and thematic detail due to improved spatial and spectral resolution of remote sensing data. New remote sensing platforms, such as unmanned aerial vehicles, and emerging sensors, such as Fourier transform infrared spectroscopy and LiDAR, can now be used to monitor mangroves. Using cloud computing, large amounts of data can be stored and analyzed (Thanikachalam and Ramachandran, 2003; Nawar *et al*., 2014).

Awareness Programs

Local people or tribal communities are very effective supervisors of forest resources; recent environment conservation approaches suggest that these people have stewardship quality. To achieve the economic and environmental conservation goals management of mangroves and local restoration are broadly used as a wise decision and the best solution for sustainability. Now a day the sole stewards or primary supervisors of forest resources are not the governments but the local people of that area (Panda *et al*., 2020). The local people are enlisted as partners in the forest land management policies and programs. Outreach activities, webinars and educational programs are very effective to make this partnership stronger. "The urgent need for restoration set against a background of limited resources, clearly demands a more holistic approach" (Sheaves *et al*., 2014).

Conclusion

Mangrove ecosystems are one of the most productive ecosystems. Programs for rehabilitation may help reduce carbon emissions and slow down global warming. This will need resources, capability, and interdisciplinary strategies including teams with expertise relevant in ecology, economics hydrology and understanding of the cultural context. The review emphasizes the importance of Mangrove and urgent need to protect them. Administrative collaboration with different communities in order to establish policies and plans to attain best rehabilitation practices may be the best way to conserve and manage the mangrove ecosystem. Existing mangroves could be protected, and mangroves could be managed through community awareness and participation for mangrove conservation. Mangroves have evolved unique adaptations to thrive in the intertidal environment. This review provides the current scenario of developments for better understanding of mangrove adaptability and responses to environmental stresses. The findings of this review could be a baseline of knowledge to environmentalists for conservation and management of Mangrove as well as to develop adaptive management strategies to safeguard the mangrove ecosystem.

मैंग्रोव विलोपन : एंथ्रोपोसिन प्रभाव, पारिस्थितिक जोखिम और संरक्षण रणनीतियाँ

प्रियंका कुमारी और भावना पाठक

सारांश

मैंग्रोव दुनिया के सबसे उपजाऊ और पारिस्थितिक रूप से महत्वपूर्ण पारिस्थितिक तंत्रों में से एक हैं, जो आवश्यक पारिस्थितिकी तंत्र सेवाओं, उत्पादों की आपूर्ति करते हैं और संकटग्रस्त/ लुप्तप्राय प्रजातियों का समर्थन करते हैं। मैंग्रोव पारिस्थितिकी तंत्र का क्षरण दुनिया भर में चिंता का विषय बन गया है। वर्तमान लेख पारिस्थितिक और औषधीय मूल्यों के संबंध में मैंग्रोव तटीय जैव विविधता के महत्व पर केंद्रित है। कार्बनिक पदार्थ, संदूषकों से जुड़े गंभीर मानवजनित प्रभाव; (कीटनाशक और भारी धातु), तलछट विशिष्टता, रेडॉक्स गुण, वनस्पति और जीव (सूक्ष्म और स्थूल) पर प्रकाश डाला गया है। संरक्षण के साथ-साथ पुनर्वास विधियों के ज्ञान को प्रबंधन दृष्टिकोण के साथ संक्षेप में प्रस्तुत किया गया है।

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