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Impacts and implications of anthropogenic activities on mangrove forests: A review

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Abstract

The purpose of this paper is to review and evaluate published literature on the causes, impacts, implications and mitigation strategies of anthropogenic activities on mangrove forests. A systematic method was utilized to access research works of literature on "Impacts and implications of anthropogenic activities on mangrove forests". A total of fifty-three (53) research papers published between the years 1975 to 2024 was accumulated and used for this review. A subjective approach was used to select the topics: impact and implications of anthropogenic activities on mangrove forests. In this paper, five (5) roles of mangroves were assessed and presented. Anthropogenic activities that threaten mangrove forests such as land conversion, mining and logging activities and household and industrial activities were also evaluated. Further, four (4) detrimental anthropogenic activities and the potential impacts they have on natural mangrove forests and the ecosystems they thrive in was also reported on. In addition, this paper reviewed some mitigation strategies for sustainable management and conservation of our mangroves, their ecosystems and the coastlines. The published works of literature established that reduced mangrove forests, altered mangrove composition, unequal species abundance, mass mangrove mortality, pollution in mangrove areas, rising sea levels, global climate change and coastal erosion or abrasion are all effects of anthropogenic activity that have a negative impact on mangrove forests and the ecosystems. This review highlights the fact that more studies on the impact and implications of anthropogenic activities on mangroves should be done in neotropical countries since there are paucity of such information on research and published data in these biodiversity rich regions.

Keywords: Impact; Mangroves; Anthropogenic Activities; Mangrove Ecosystems; Mitigation; Conservation; Management

1. Introduction

1.1. Mangroves and anthropogenic activities

Mangroves have frequently been thought of as marshy wastelands, but throughout time, many persons and communities have recognized their role as a diversified ecosystem and their value in protecting and maintaining the health of coastal zones. These woody halophytic plants can withstand high salinity, powerful tides, intense winds, elevated temperatures, and muddy, anaerobic soils. These amazing trees can be found growing along protected beaches in tropical and subtropical latitudes [22] [57] [65] [117]. Mangrove trees are often found on shifting sediments and are supported by special roots and pneumatophores, which are often submerged [22] [57].

The mangrove ecosystems, is a transitional habitat between terrestrial and marine ecosystems, and is greatly impacted by intertidal conditions. In contrast to beaches with steep, undulating topography and powerful tides, mangroves typically grow in muddy and sandy substrates on relatively flat or moderately sloping areas [3] [22] [57]. The flat areas give mangroves room to develop and increase the amount of mangrove vegetation. A variety of organisms that depend on mangroves can grow and flourish in the muddy and sandy mangrove ecosystem [1] [22] [57].

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The mangrove ecosystem provides a range of ecosystem services. Mangrove forests have a massive carbon stock stored in their above and below-ground biomass as well as in their soils. This carbon stock is five times greater than that of tropical and boreal forests per unit area, suggesting that mangrove forests play a significant role in mitigating the effects of climate change [22] [57] [80]. The shore is shielded by mangrove ecosystems from winds, waves, storms, and even tsunamis. Mangrove ecosystems supply the habitat and organic materials needed for food that marine biota needs to survive. Mangroves supply local communities with building materials, firewood, charcoal, food, and medication, among other household necessities [22] [57] [80].

The ecology of mangrove forests is delicate, very susceptible to changes in the surrounding environment and vulnerable to resource extraction, which results in deforestation and deterioration [22] [97]. Mangrove forest deterioration and deforestation are primarily caused by human activity, reported by Akbar *et al*. (2017). Anthropogenic activities, which include habitat destruction, land use conversion, alien species invasion, and exploitation of biological resources, are human actions that have the potential to alter the structure of landscapes. The mangrove ecosystem's trophic status changes as a result of these actions [22] [134].

According to Mappanganro *et al*. (2018), some examples of human-caused disturbances include clearing mangrove forests of trees and transforming them into plantations, villages, industries, irrigated or rainfed rice fields, and fish or shrimp ponds. In 2013, Athirah *et al*. stated that human activities reduce ecosystem stability and decreases biodiversity, particularly among mangrove organisms, degrading the mangrove environment. A serious threat to this ecosystem, whose inhabitants rely on coastal resources, is the reduction in the area and quality of mangroves. Schaduw (2015) asserts that disruptions to mangrove forest ecology will also affect its social and economic functions.

The objectives of this review paper were to examine the activities of humans that are impacting mangrove ecosystems, ascertain the effects of those activities on the ecosystems, and develop strategies to stop the deforestation and degradation of mangroves. It is anticipated that this research would offer a foundation and provide appropriate literature for improved mangrove ecosystem management and conservation in Guyana, the neotropics and other countries that utilize mangrove as a form of defense against the open ocean.

1.2. Mangrove forest ecosystems

Mangroves comprise less than one percent (1%) of all tropical forests and are present in 123 nations across the globe, covering an estimated area of 152,000 square kilometers [121]. Eighty species are found in eighteen families of mangroves but only the Pellicieraceae family is regarded as a mangrove exclusively [121], whereas, the other seventeen families are flowering plants that come in a variety of shapes, such as trees, shrubs, and palms [121]. These plants are extremely significant on an ecological, economic, social, and cultural level all across the world.

Mangrove forests are a type of tropical coastal vegetation communities that are dominated by common tree or shrub species that can grow in salty waters [88]. These plants are extremely significant on an ecological, economic, social, economic and cultural level all across the world and especially for local residents [22] [53] [57] [129]. According to Wang *et al*. (2021), mangrove forests are among the tropics and subtropics ecosystems with the highest carbon content on Earth and play a vital role as an atmospheric CO_2 sequester. In addition, through climate control, mangroves and the biodiversity they support provide products and services that are vital to food security, poverty reduction, and human well-being [27].

One of the complex ecosystems that interacts with other ecosystems, both onshore and offshore, is the mangrove environment. Because the mangroves' litterfall provides nutrients to the soil and water, it is regarded as one of the most fruitful ecosystems [22] [31] [57]. Additionally, mangrove ecosystems are regarded as one of the planet's most prolific and valuable coastal ecosystems [22] [51] [57]. Numerous biotic and abiotic elements, including wind, tides, sedimentation, nutrients, light, salinity, and human effects, control the growth of mangrove plants. The majority of a mangrove's physiological energy is directed toward responding to highly salinized environments. The pH of the soil and nutrients like N, P, and K control how available the nutrients are in mangroves [22] [34] [57].

Seawater tides have an impact on the mangrove ecology, which provides a suitable habitat for avifauna, especially migratory birds. Significant variations in the environment, particularly in temperature and salinity, are brought about by the tides of seawater in this ecosystem. Because of this, organisms that can thrive in this ecosystem need to be exceptionally resilient to drastic shifts in their surroundings. An estimated 150 to 250 different bird species can be found in mangrove environments; of these, 65 are classified as endangered or at risk of extinction [17] [22] [57].

1.3. Ecological importance of mangroves

Mangroves help to preserve the clarity and quality of the water by filtering different contaminants and sediments that runoff from the land. As a result, they help keep seagrass meadows and coral reefs from being stifled by terrestrial sediment runoff and inland rivers are protected from seawater intrusion by mangroves [40].

Mangroves offer a distinct environment that serves as a vital habitat and nursery area for several species, such as fish, birds, mammals, algae, invertebrates, fish, reptiles, and amphibians [117]. In addition to providing abundant food supplies, mangrove ecosystems shield animals from harm. Globally, mangroves sustain several vulnerable and endangered animal species, such as crocodiles, otters, tigers, monkeys, and birds [17] [40] [54].

Mangrove habitats are among the most prolific in the world. They have great potential for export or even storage of carbon through biochemical interactions since they produce copious amounts of carbon in the form of leaf litter [6] [121]. The tides force some of the carbon created to flow into neighboring systems, even though the mangrove ecosystem retains most of the carbon. Furthermore, species that migrate into mangroves during high tide to graze on the food sources there indirectly contribute this carbon to the food web. Thus, a range of species that are present in adjacent habitats benefit from mangroves' increased growth and productivity [121] [132].

Mangroves are a major worldwide sink and store of carbon; they help to mitigate climate change. Of all terrestrial and marine ecosystems, they accumulate the biggest average carbon reserves per unit area [7]. Although mangrove environments have damp, anaerobic soil conditions, the death of roots and the growth of new ones cause a considerable amount of organic matter, or buried carbon, to accumulate and degrade slowly [26]. Including soil carbon, the average worldwide carbon stock of mangroves is around 1,000 tons of carbon per hectare [58] [121]. According to Erickson-Davis (2018), mangroves are thought to be the carbon storage powerhouse, able to sequester four times as much carbon as rainforests. Therefore, safeguarding these carbon sinks and keeping them from releasing carbon dioxide back into the atmosphere is a practical and economical way to contribute to slowing down global warming.

1.4. Economic importance of mangroves

Mangroves are home to an abundance of fish, which are essential to both commercial and leisure fishing. In addition to providing a significant amount of food for many coastal communities, mangrove fisheries also provide a means of subsistence by producing a revenue stream [52]. Mangrove trees are widely used as a renewable resource. They are cut down for their sturdy, water-resistant wood, which is used to construct furniture, pilings, boats, and homes. Charcoal is also made from the wood of buttonwood and black mangrove trees. Mangrove barks are also used to extract tannins and other pigments [40].

Mangroves provide a variety of natural resources that are also used for subsistence, such as fishing bait, small mollusks, dye, honey, firewood, wood poles, herbs, and natural cures. Although subsistence agriculture does not produce cash revenue, it does play a significant role in reducing poverty [41] [121]. These products have little or no market value and might not be used by "far superior off" homes. The products give those persons with the fewest resources a supply of food during times of economic hardship [41]. Mangroves help manage coastal areas by acting as natural barriers against severe weather and natural disasters. This reduces property loss and increases the resilience of coastal populations. Because of their distinctive interwoven root systems, they stabilize sediments and halt erosion. The mangroves that both the United States and Mexico have are thought to prevent damages to residential and commercial property worth an estimated US $57 billion annually. Mangroves shield more than 12 million people from floods in nations including China, Vietnam, and India [15].

1.5. Hazards and threats that affect mangroves

Mangroves are becoming increasingly vulnerable to degradation and destruction globally, despite their critical role and immense significance. Approximately nineteen percent (19%) of the mangroves worldwide were lost between 1980 and 2005 [15]. Approximately two percent (2%) of the world's mangrove forest (1300 square miles) was destroyed during the years 2000-2006 as reported in a study that was conducted in South East Asia. According to Merzdorf (2020), human activity accounted for sixty-two percent (62%) of the lost mangroves, with natural factors like erosion and extreme weather occurrences accounting for the remaining percentage.

Mangrove productivity and quality are continuously declining due to human activity throughout the world. Coastal and urban growth, pollution, and the conversion of mangrove lands for agriculture and aquaculture are some examples of these activities. As a result, more than 25% of the earth's original mangrove cover has been destroyed [121].

The construction of roads, canal systems, and buildings as part of urban growth is to blame for the complete destruction of mangrove habitat. These upland and coastal operations result in increased erosion as well as a decrease in nursery habitats that support game and commercial fisheries. Human activity away from mangroves in the uplands may have an effect on runoff and water quality [68].

Mangrove habitat flooding has been linked to infrastructure-related dredging and filling operations. It is difficult for oxygen to reach their subterranean root systems and specialized roots because standing water covers their aerial roots. Mangrove trees eventually die as a result of these stressors [68]. In a 2014 report, the United Nations Environment Programme stated that the consequences of climate change pose a threat to mangroves as well, with the potential loss of an additional 10-15% of mangroves by 2100. Mangrove destruction is currently occurring at a rate three to five times faster than the average rate of forest loss [121].

In 1996, Ellison & Farnsworth conducted research that revealed that the Caribbean region has been losing mangroves at a rate of one percent (1%) year. The rate on the Caribbean mainland is 1.7% annually, while on the islands, it is 0.2% annually [36]. The majority of these mangrove losses were caused by vulnerability brought on by the loss of coastal protection and rising coastal development. The majority of conventional methods for coastal defense, such as constructed infrastructure, were used to exacerbate mangrove stress. As a result, the opportunity to preserve these trees for their worth as coastal defense was overlooked [15].

1.6. Mangrove in coastal management for combating impacts of rising sea level

The length of the coastline on Earth is approximately 504,000 km, or 20% of the total surface area [24]. However, these coastal regions are home to over 50% of the world's population, which is concentrated in large cities and communities that are focused on ongoing development and significant economic sectors like fishing, industry, trade, transportation, and tourism [24]. Extreme weather events like storms and hurricanes, as well as long-term concerns like increasing sea levels and coastal erosion, pose a persistent threat to these populated coastal areas and their shorelines [77].

The mangrove ecosystem's biggest area worldwide is found in Indonesia. A significant portion of Indonesia's coastal regions are covered in mangrove forests, which vary in breadth from a few meters to several kilometers away from the coast [61]. On the other hand, Indonesia's mangrove forest deterioration and deforestation are concerning and are getting worse every year. As a result, the function of mangrove forests is continuing to diminish, with consequences for carbon emissions, biodiversity loss, increased risk of abrasion and ground subsidence, and decreased livelihood opportunities for communities [125].

The global average sea level has increased by eight to nine (8-9) inches since 1880, with around a third of the gain occurring in the last 25 years, according to a statistical analysis on climate change by Lindsey (2021). Additionally, reports indicate that between 2006 and 2015, the average worldwide water level in the ocean increased by 0.14 inches each year. This amount is 2.5 times the average annual rate of 0.06 inches per year that was recorded throughout the majority of the 20th century [64].

There are reports that the sea level is rising more quickly in Guyana than it is on average for the world [120]. Sea level increased at a rate that was almost six times faster than the global average between 1951 and 1979 and roughly three times faster than the yearly average between 1993 and 2009 [120].

Mangroves and reefs shield shorelines from wind-generated waves by absorbing from 70 to 90 % of the energy, according to a 2006 report by the United Nations Environment Programme - World Conservation Monitoring Centre. Another 2012 study by The Nature Conservancy and Wetlands International discovered that mangroves lower wind and swell wave heights over short distances, with wave heights decreasing by 13% to 66% across a 100-meter radius around mangroves [72]. Additionally, it was observed that as the waves start to pass through the mangroves, they reduce in height at the fastest rate per unit of distance close to the mangrove edge [72]. According to the data represented in these papers, mangroves are quite successful and have a significant impact on protecting and managing coastal areas and their ecosystems [22].

Historically, two main alternatives for coastal management have been used to combat these dangers and maintain the world's coasts: hard engineering choices and soft engineering options. Hard engineering solutions include groynes, rock armor, and boulder barriers in addition to seawall construction. These solutions are costly to construct and have immediate consequences, and need expensive upkeep. Additionally, it could not be environmentally friendly and sustainable [14]. In contrast, soft engineering options including mangrove and reef planting, beach reprofiling, beach nourishment, managed retreat, and living shoreline barrier. Soft engineering alternatives are more affordable, long-lasting, environmentally friendly, and sustainable [14] [30].

2. Material and Methods

The topic of "impact and implication of anthropogenic activities on mangroves" was the subject of a systematic review using "Google Scholar," a web-based search engine which provides a quick and easy way to search and access published literature from articles, journals and books. Thematic search terms such as impact, mangroves, anthropogenic activities, mangrove ecosystems, mitigation, conservation and management were used in the search.

The areas that were evaluated in this research were chosen using an approach that involved assessing at the related works of literature. Publications between the years 1975 to 2024 were acquired for this review. However, not all of the articles that were reviewed, were used in this study because the major objective was to assemble data from recent research (past 10 to 20 years) on impact and implications of anthropogenic activities on mangroves. However, papers that contained relevant literature from as far back as the 1900's and the 2000's were also utilized for this review. Seventy-seven (77) research articles were retrieved and included in this review and literature from fifty-three (53) papers published between the years 1975-2023 were presented in this paper.

The search yielded different results: Some articles had all the thematic keywords and some were obtained that were specific to mitigation, conservation and management approaches to protect mangrove forests and their ecosystems, while others were directed to specific anthropogenic pollution by various pollutants. Additionally, some were specific to mangrove biology and mangroves in biomonitoring and environmental assessment.

3. Results

When searching "Google Scholar" for information on impact of anthropogenic activities on mangroves, a total of 10,900,000 was retrieved. Among the results obtained from the search, a total of 9,980 were published within the years 2000-2023, 10,100 were published between the years 2010-2023 and 10,600 were published within the years 2015-2023. 35,300 publications between the years 2010-2023 reviewed the causes, impacts, implications and mitigation of anthropogenic activities on mangrove forests.

However, not all the results retrieved for this research focused on the impact of anthropogenic activities on mangroves. While some focused solely on anthropogenic activities on mangrove forests, others examined the mitigation, conservation and management approaches to protect mangrove forests and their ecosystems. Others were directed to specific anthropogenic pollution by various pollutants. Whereas, some were specific to mangrove biology and mangroves in biomonitoring and environmental assessment.

4. Discussion

4.1. Role of mangrove forests

According to Eddy *et al*. (2014), mangrove ecosystems provide a range of services, including provision, regulatory, cultural, and supporting functions. Mangrove ecosystems preserve and safeguard global biogeochemical processes, tropical and subtropical marine biodiversity, and climate change in terms of regulatory and supporting functions [22] [127].

When compared to other coastal ecosystems, the mangrove forest environment has the highest productivity level and it provides organic materials to the aquatic biota, which is necessary for the life cycles of different kinds of fish, mollusks, and shrimp [22]. Table 1. provides details on the roles of mangrove forests.

Table 1 Role of mangrove forests

Role	Description of role	Author(s)
Mangrove as carbon stocks	Mangroves play a vital role in lowering carbon emissions for mitigating climate change because of their capacity to absorb and store vast amounts of carbon, which is essential for regulating CO_2 levels in the atmosphere. Mangroves store carbon in their stems, roots, leaves, and soil. More than 84 % of the total carbon in	(Heriyanto & Subiandono, 2012); (Purnamasari *et al*.,

	the mangrove ecosystem is found in the soils, which are the primary source of carbon stock. The dimensional scale of mangrove forests affects their capacity to sequester carbon stored as biomass. The capacity of mangrove trees to store biomass and absorb CO_2 increases with tree diameter. The absorption rate is also influenced by the mangrove stand's age and height.	2021); (Trettin *et al.*, 2021); (Cahyaningish *et al.*, 2022)
Pre-treatment of domestic waste	In tropical coastal areas, using mangrove swamps as natural wastewater treatment systems has been suggested as a viable and affordable alternative. Nedwell (1975) proposed using mangroves in the last stage of sewage treatment since their ability to reduce eutrophication stems from pre-treated wastewater. In 2011, Herteman *et al.* discovered that the home wastewater discharges raised the leaf pigment level in *C. tagal* and *R. mucronate* after studying the impacts of pre-treatment waste on mangroves. In addition, there was a notable rise in transpiration rates and photosynthetic activity. The affected mangrove stands also had a notable increase in branch length and leaf area. Waste nourishes these plants when grown in regulated environments, but like with any plant, too much fertilizer can be harmful. Therefore, more research would be required in addition to preserving tabs on how mangroves respond to these pollutants.	(Nedwell, 1975); (Herteman *et al.*, 2011)
Biological function	Mangrove forests are made up of special biotic and abiotic elements. Things that live near mangroves, like shrimp, fish, crabs, birds, and mammals, mostly eat the biological components of mangrove forests. Mangroves are home to a variety of living things, including young fish, shrimp, and other marine biota, which use them as gathering and hiding places. Additionally, mangrove forests offer a great location for marine biota spawning. The canopy of mangrove vegetation like other trees provide a useful habitat for a variety of arboreal faunas, including insects, birds, bats, and mammals such as primates. The surrounding ecosystems are impacted by the presence of mangrove forests, which serve as coastal green spaces. The ecosystem of the mangrove forest has been shown to provide benefits, including protecting against seawater intrusion, stabilizing the coastline, acting as the primary hub for the circulation of sulfur and nitrogen, collecting mud, and forming new land. Mangrove forests also neutralize hazardous compounds produced by chemical wastes and they are also valuable as an organic waste processor. By allowing litter to break down and release organic matter into the soil, mangrove root systems can enhance the physical and chemical characteristics of the soil. This process can also lower salinity levels. Mangrove leaves that fall into the water will be broken down by microbes, which will then produce food for small aquatic animals, thus beginning the food chain. Fish and other invertebrates that inhabit the mangrove ecosystem eat the roots of mangrove trees.	(Kustanti, 2011); (Pontoh, 2011); (Samosir & Restu 2017); (Cahyaningish *et al.*, 2022); (Bhagarathi & Maharaj, 2023); (Bhagarathi *et al.*, 2024)
Physical function	Mangrove ecosystems have the capacity to regulate seawater intrusion by storing mud, trapping sediment, and inhibiting $CaCO_3$ deposition by their roots. The towns that surround it gain from this physical protection against hazards like as large waves, powerful winds, coastal erosion, tsunamis, mudslides, sediment traps carried by surface water flows, and prevention of intrusion.	(Ahnanto *et al.*, 2014); (Utomo *et al.*, 2017); (Cahyaningish *et al.*, 2022)
Social and economic function	Coastal populations gain socially and economically from the mangrove ecosystem. The monetary benefits that resources provide to humans can be used to determine their economic value. Mangrove forests offer both direct (such as timber and fisheries commodities) and indirect economic value. Mangrove forests yield a range of forest products that meet community requirements and enhance the social and economic conditions of the surrounding populations. These are the direct advantages of mangrove forests. The provision of nutrients, the potential to build islands and maintain beaches, and the resistance to seawater intrusion and abrasion are some of the indirect benefits of mangroves for human life, according to Riwayati (2014). The roots, bark, leaves, tree trunks, and blossoms of the mangrove tree can all be advantageous to people. The community can use the wood and nontimber produced by mangrove forests for fuelwood, food, medicine, handicrafts, animal feed, and industrial raw materials. Mangrove tree bark has several uses, including building materials, natural remedies, and preservatives. Numerous economically significant fish, shrimp, and crab species can be found in	(Setyawan & Winarno 2006); (Ritohardoyo & Ardi, 2011); (Gumilar, 2012); (Saprudin & Halidah, 2012); (Ariftia *et al.*, 2014); (Riwayati, 2014); (Jumaedi, 2016); (Sondakh *et al.*, 2019); (Sondakh *et al.*, 2019);

	the mangrove habitat. By securing ropes to the mangrove trunks or roots, boats and ships can be kept safe. A few examples of mangrove plants that can be turned into food are Jeruju (*Achantus ilicifolius*), Api-api (*Avicennia alba*), Lindur (*Burguiera gymnorhiza*), Pedada (*Sonneratia spp.*) and Nipah (*Nypa fructicans*). In addition, mangroves have higher levels of calories and carbohydrates than a variety of other food kinds, including rice, corn, and cassava. It is also possible to use some mangroves as organic coloring agents. Waste or underutilized plant parts from mangrove species, such as those of the *Rhizophora* species, which can provide the hues black, brown, dark brown, light brown, and pink, can be used as dyes. Mangrove forests also serve as a location for the construction of salt farms, ponds for rearing fish and shrimp, and a supply of raw materials for premium charcoal. Mangrove forests have indirect benefits such as supplying the marine biota with natural food, preventing saltwater incursion onto the land, and preventing land from expanding towards the sea. Additionally, mangroves can be created for educational and ecotourism purposes. The goals of ecotourism are to protect the environment and uphold or enhance the well-being of the neighborhood. For example, floating among the mangroves and taking in the beauty of the flora and fauna are two ways to improve the ecotourism and education function of mangrove forests.	(Cahyaningish *et al.*, 2022)

4.2. Anthropogenic activities that threaten natural mangrove forests

Situated between the terrestrial and marine domains, the mangrove ecosystem is vulnerable to alterations brought about by both natural phenomena and human endeavors, including urbanization and economic growth [22] [127]. The resources found in mangrove forests are subject to continuous modification as a result of human activity in a variety of ways [63] [83]. Fishing, agriculture, plantations, settlements, mining, aquaculture, and other anthropogenic activities are among the causes of declining mangrove forests [22] [61] [110]. However, human activities including illegal logging, unsustainable use, and the construction of shrimp ponds cause mangrove deterioration [13] [22]. According to Konom *et al*. (2019), the rate of mangrove deforestation and degradation increases with the size of the population living nearby the mangrove forest region. Coastal populations and the mangrove environment coexist. One example of this is the use of mangrove wood for construction materials [22] [47]. Mangrove forests are prone to being exploited and disturbed because the majority of them are under government control (though some people consider these areas to be open access) and because they are situated in an easily accessible coastal area surrounding the estuary [22] [49]. Table 2. shows various anthropogenic activities that threaten natural mangrove forests.

Table 2 Anthropogenic activities that threaten mangrove forests

Activity	Description of activity	Author(s)
Land conversion	Several land uses have been implemented on mangrove forests. A total of nearly 100,000 hectares of mangroves are estimated to have been cut over a ten-year period between 2002 and 2012, with an average annual loss of 0.18%. The growth of oil palm plantations, rice farming expansion, and aquaculture are the main forces behind conversion of mangrove forests, for example, Kalimantan and Sulawesi are the primary places where mangrove forests are converted into aquaculture. This is problematic because the government often encourages the growth of aquaculture to boost fisheries productivity. Mangrove forest conversion, for instance, has happened in the mangrove forests of Takalar District, South Sulawesi, Indonesia. This irresponsible use of resources causes deterioration and deforestation. Over the 33-year analysis period, the mangrove area has declined by 66.05%, with land conversion for aquaculture being the primary driver of this reduction. However, removing mangroves to make way for the seaweed and shrimp farms in the region creates jobs and brings in money for the locals. In Java, the southern coast of the island has seen the conversion of river mouths into ponds, and the majority of the mangrove habitat into rice field villages. In Rembang, Central Java, Indonesia, for example, land is converted from mangrove forests to ponds. To make ponds predominate along the shore, many of the mangrove ecosystems in this area have been opened for use as saltwater, shrimp, and milkfish ponds. Unfortunately, extensive and intense	(Setyawan *et al.*, 2002); (Setyawan *et al.*, 2003); (Setyawan & Winarno 2006); (Setyawan *et al.*, 2008); (Rimmer *et al.*, 2013); (Richards & Friess 2016); (Malik *et al.*, 2017); (Puspitasari *et al.*, 2017); (Ulumuddin & Setyawan, 2017); (Kadarsah *et al.*, 2020); (Cahyaningish *et al.*, 2022)

	aquaculture operations have altered hydrological conditions, introduced endophytes, and contaminated the ecosystem, which has left the ponds barren, neglected, and degraded. There is currently no remaining natural mangrove environment in the area. Fish ponds, salt extraction, and rice fields are among other land conversions in Central Java. The remnant vegetation in this location, which displays canopy gaps and open space, is indicative of the effects of human activity. Oil palm plantations in Kalimantan are accountable for 70% of the island's degraded coastal areas, which leads to the conversion of mangroves. Plantations that grow oil palm have proliferated and pose serious environmental threats to coastal areas. The oil palm business, which is a major factor in the devastation of the mangrove ecosystem, generates trash that can damage mangrove plants and lower the pH of waterways and sediments. It also contains heavy metals like Pb, Cd, Fe, Cr, Zn, and Ni. The function of the mangrove ecosystem is impacted by pollution in numerous rivers and coastal estuaries in Kalimantan, which is caused by an overabundance of oil palm mills.	
Mining and logging activities	Other human-caused activities that alter mangrove ecosystems include coastal reclamation for infrastructure development and human habitation. The coastal region is highly dynamic and heavily impacted by human activity. The primary objective of coastal reclamation is to manage floods inside urban areas. The mangrove environment is one of the ecosystems that may alter as a result of coastal reclamation. Mangrove forests may be cleared to make way for settlements as, if there is no owner, the land is deemed open access. The amount of land conversion, sedimentation, reclamation, and environmental contamination are all impacted by the increasing population pressure. Another human activity that devastates the mangrove ecosystem is the logging of mangrove trees. Furthermore, the environment of mangrove forests is severely impacted by illicit logging. The locals use several kinds of mangrove plants for building materials, charcoal, and firewood. Mangrove species including *Rhizophora*, *Xylocarpus*, and *Bruguiera* are the principal species used in mangrove logging in Dumai, Riau, Indonesia. In Central Java, logging operations also negatively impact a number of mangrove regions. The vegetation in the mangrove ecosystem of Central Java is experiencing secondary succession, and there are a lot of empty spaces, which suggests quite extensive logging activities. It appears that the stands do not reach a climax based on the composition and structure of the vegetation in areas where the significance index of young plants is rather high. The environment is dominated by immature mangrove trees with numerous canopy gaps, as evidenced by the vertical and horizontal vegetation.	(Setyawan *et al*., 2005); (Setyawan *et al*., 2008); (Mulyadi & Amin 2016); (Malik *et al*., 2017); (Kadarsah *et al*., 2020); (Anwar *et al*., 2021); (Cahyaningish *et al*., 2022)
Household and industrial activities	Mangrove ecology in places like Dumai, Riau, Indonesia, is also threatened by human activity, including household and industrial activities. The ecosystem around the mangrove area is contaminated and polluted as a result of these coastal activities. The garbage coming from homes, hotels, and restaurants is the source of the pollution. Wastes are generated that are solid, liquid, or gaseous, as well as organic and inorganic, and frequently include heavy metals. Due to domestic activities, the population also affects potential sources of pollution in coastal areas, particularly for those without access to equipment for waste management. A high population will lead to more economic activity and more waste being produced. Water will transport the trash that people discard into the river, where it ends up in the mangrove forest. Years passed in this manner with no thought given to developing trash disposal, which led to an increase in the amount of waste that accumulated. Plastic is another kind of waste that is becoming more and more problematic. van Bijsterveldtwe *et al*. (2021) looked into the extent of the plastic waste issue in the mangroves on Indonesia's north coast near Java. Plastic was widely distributed across the field, covering up to 50% of the mangrove bottom in different locations with an average of 27 plastic fragments per m^2. The study also showed that plastic was frequently buried in the upper sediment layers, where it remains immobile and can cause extended anoxic conditions. Large plastic objects are reported to be found in mangroves more often than on beaches, according to surveys of anthropogenic waste	(do Sul *et al*., 2013); (Mulyadi & Amin, 2016); (Martin *et al*., 2019); (Numbere, 2019); (van Bijsterveldtwe *et al*., 2021); (Cahyaningish *et al*., 2022)

	carried out in these habitats. A mangrove serves as both a land-based waste disposal site and a marine trash landfill. Mangrove forests collect plastic debris, which can be found in significant amounts in the sediments and on the forest floor. Large plastic waste is retained in the filter by the mangrove air roots. Mangroves generally maintain high rates of sediment accretion and effectively remove plastic from their sediments. In the mangrove forests of *Avicennia marina*, microplastics smaller than 0.5 mm dominated the mangrove sands. Since the 1930s, tons of plastic waste are said to have been buried in the mangrove sediments. Additionally, it demonstrated how long-term plastic reservoirs mangrove sediments serve and how long mangroves may hold onto marine plastic trash.	

4.3. Impacts of anthropogenic activities that threaten mangrove forests

The destruction and disappearance of half of mangrove acreage is primarily due to human anthropogenic activities. According to Majid *et al*. (2016) and Hartati & Harudu (2011), the main causes of mangrove deforestation and degradation include population growth, changing labor demands, and people's attitudes toward mangrove forests. Humans are supposed to maintain the mangrove environment by understanding the effects of their actions. Table 3. address several issues regarding the impacts of anthropogenic activities that impact mangroves.

Table 3 Anthropogenic activities and their impacts of mangrove forests

Effect	Description of impact	Author(s)
Impact of Pollution	Pollutant levels in the atmosphere are rising due to anthropogenic activities, especially atmospheric CO_2 and tropospheric O_3, which are vital to the health of forest ecosystems. Elevations of CO_2 and O_3 have an impact on the growth, metabolism, and chemical makeup of trees. Modifications in the chemical composition have the potential to impact ecosystem processes by trickling down through the trophic levels. The mangrove ecosystem is frequently contaminated by heavy metals, oil, garbage from tourism, aquaculture (ponds that create liquid waste), roadways, industry, residential areas, mining, and agriculture. Pollution has a number of negative effects on the mangrove ecosystem, including diminished and damaged mangrove ecosystems, the extinction of certain plant and animal species because they cannot adapt to the pollution, and the disruption of the fish and shrimp life cycles. These effects will eventually upset and have an impact on the balance of the mangrove and coastal ecosystems. Oil spills from tanker accidents, oil loading and unloading, port operations, and other sources are among the common forms of pollution that endanger marine life. These spills can cause physical disruptions to mangrove vegetation, such as falling or yellowing leaves, mangrove death from oil covering mangrove roots, and permanent damage to mangroves that destroys the nursery ground for marine biota.	(Couture & Lindroth, 2013); (Prasetyo *et al*., 2017); (Cahyaningish *et al*., 2022); (Numbere, 2023)
Impact of Land conversion	There is a growing demand for employment opportunities due to the growing human population. The employment opportunities for those who live along the shore are limited to agriculture, fisheries, fishponds, ports, salt farms, and other sectors requiring huge areas of land, suggesting that land conversion and mangrove deforestation are inevitable. These land conversions, however, disregard development designation and capacity, which has numerous detrimental effects. These include water intrusion, marine pollution, shallow beaches from sedimentation, and the threat to fish and shrimp regeneration in offshore areas. Mangrove forest degradation is impacted differently by anthropogenic activity. The primary causes of mangrove degradation to date have been land conversion activities, such as those for the establishment of shrimp ponds and agricultural lands. The area of mangrove forests is shrinking as a result of these human activities. There isn't much consensus regarding the size of mangrove forests. Ninety percent (90%) of the recorded loss of mangroves is attributed to land modification, such as the construction of shrimp ponds in tidal areas and coastal agricultural land. Mangrove forests suffer from oil mining operations, as is the case in Balikpapan, East Kalimantan. Because the roots of mangrove trees are vulnerable to oil exposure, oil spills can destroy them by	(Rusdianti & Sunito, 2012); (DasGupta *et al*., 2013); (Hadayatullah & Pujiono, 2014); (Rasyid *et al*., 2016); (Kadarsah *et al*., 2020); (Rudianto *et al*., 2020); (Anwar *et al*., 2021); (Cahyaningish *et al*., 2022);

	introducing oil deposits that are carried by the tides and flooding. However, it takes a while for the effects of oil spills to fade. In addition to killing the mangroves, it can deteriorate the water and soil quality, which makes it harder for mangroves to grow back naturally. As in South Kalimantan, numerous environmental changes in mangrove forests have resulted from coal mining sites and oil palm plantations. The pH of the waterways is now more acidic (5.76–6), the organic matter content of the sediments is higher (0.61–6.59%), and the concentration of heavy metal Pb in the waters and sediments is higher. *Avicennia alba*, *Acanthus ebracteatus*, *Nypa fruticans*, and *Rhizophora apiculate* are examples of real mangrove species that can still survive; however, this has an impact on the decline in the population of mangrove species as a result of mortality. Mangrove forest composition may shift as a result of timber harvesting, with low-value commercial species probably taking their place. The ecological and economic benefits of mangrove forests as a habitat for diverse marine biotas with significant economic value and as a location to locate food are lost as a result of these vegetational changes. Further, due to alterations in their composition, mangroves can no longer effectively absorb ocean waves and are unable to tolerate seawater erosion and abrasion. Mangroves are frequently illegally harvested for lumber, as was the case in the mangrove forests of East Java. Because illegal logging reduces the average carbon sequestration and storage in East Java's mangrove forests, mangrove forests naturally act to lower carbon dioxide concentrations.	(Numbere, 2023)
Impact of domestic and industrial activities	Both juvenile and adult mangrove trees are impacted by the numerous household and industrial activities that generate a variety of solid, liquid, and gaseous pollutants. For instance, contaminants from industrial activities such solid waste, the processing of organic and inorganic liquid waste, and generator residues have an effect on the mangrove regions in Dumai City, Riau. In addition to industrial activity, home-generated solid waste and wastewater have an impact on mangrove vegetation. A decline in the amount of dissolved oxygen in the waterways of the mangrove ecosystem is a clear sign of pollution, according to Budiastuti *et al*. (2016). The discharge of liquid waste by nearby industries into the mangrove forest environment is typically the cause of this contamination. When there is anoxia, the amount of oxygen decreases. Anaerobic decomposition of organic matter results in the production of ammonia and sulfides, both of which are poisonous to the aquatic biota in the mangrove ecosystem. The accumulation of plastic garbage in mangrove ecosystems is also detrimental. When plastic waste builds up in mangrove areas, a layer is formed above the air roots of the trees, which inhibits root formation and ultimately causes the mangrove to die. Kinanti *et al*. (2014) claim that because river estuaries in mangrove areas turn into trash disposal sites, organic contaminants frequently enter these estuaries at high concentrations. Chemical pollution can drastically diminish mangrove biodiversity and show altered biogeochemical cycles with a dramatic decline in organic carbon in sediments. This is especially true of metal buildup and biotransformation. Mass mangrove mortality may result from damage to mangroves. This is caused by a sharp rise in salinity, a rapid rate of sedimentation, and a decrease in water level. The fundamental source of these changes in river nature is human conduct, which includes things like throwing trash into rivers, using bombs to fish, and restricting rivers to make room for human settlements. Beaches near rivers or river deltas will have an abundance of mangroves because the river flows provide sand and mud, which serve as the primary growth substrate for mangroves. The habitat of the fauna and benthic species, whose lives are largely stationary at the bottom of the ocean, will also be harmed and disturbed by the activity of fishing or shrimp catching that involves spread nets and moving from one location to another. Such factors put mangroves at risk of dying, which could have detrimental effects such coastal erosion, flooding, fewer catches, worse quality fishery products, and decreased community revenue as a result of depleted fisheries resources.	(Wardhani, 2011); (Maiti & Chowdhury, 2013); (Kinanti *et al*., 2014); (Budiastuti *et al*., 2016); (Mulyadi & Amin 2016); (Carugati *et al*., 2018); (Martin *et al*., 2019); (Cahyaningish *et al*., 2022); (Numbere, 2023)
Impact of sea-level rise	Human activity is a cause of climate change because greenhouse gas (GHG) emissions, primarily from CO_2, disturb the ozone layer in the atmosphere and lead to global warming. Global climate change can impact sea-level rise and result in floods, harm to populated areas, damage to freshwater supplies from coastal aquifers, and inundation of a coastal area further inland beyond the coastal border, according to the IPCC's	(Nandini & Narendra, 2011); (Anggraini *et al*., 2012);

	Special Report on Emission Scenarios (SRES). Waves, storm surges, tidal conditions, tsunamis, and global warming are all indicators of sea level rise. The amount of sediment will drop as a result of sea level rise, which will restrict the mangrove vegetation's ability to spread landward. Naturally, this will eventually jeopardize the continued survival of mangroves and disturb their distribution. Climate change also causes a decrease in rainfall, which raises the salinity and salt sulfate levels in seawater and reduces the growth of mangroves. It also reduces the biophysical ability of mangrove forests because some plant species cannot adapt to the drastic changes in climate, and it raises air temperatures, which in turn leads to the extinction of marine animals that cannot adapt. Finally, it reduces the availability of water in forested areas. Furthermore, a protracted drought brought on by climate change can result in the death mangrove plants and prevent mangroves from growing.	(Subardjo & Pribadi, 2012); (Cahyaningish *et al.*, 2022); (Numbere, 2023)

4.4. Mitigation strategies for sustainable mangrove management and conservation

Mangrove forests play a variety of roles in preserving the equilibrium of an ecosystem. Developing and implementing mangrove management plans that benefit both people and mangroves can help stop the deforestation and degradation of mangroves brought on by human activity [22] [106]. Poverty, a lack of care for the ecological significance of mangroves, a sectoral viewpoint while observing mangrove forests, and poor community participation are the main barriers to mangrove management and protection. The lack of understanding regarding possible applications, regeneration strategies, and silvicultural techniques exacerbates these management issues [22] [102]. Overcoming anthropogenic disruptions to mangrove forests also requires educating coastal people about environmental conservation [5] [22]. An alternate approach to managing mangrove forests is sustainable mangrove management. While there are several choices for managing mangroves sustainably, a co-management strategy should to be the primary focus [22] [114].

4.4.1. Encouraging community participation

The sustainability of natural resource management often depends on community participation. In order for people to feel accountable for the long-term viability of the program and for its preparation, execution, and monitoring, community involvement is crucial for the conservation and rehabilitation of mangrove forests [22] [71]. Most importantly, people need to be aware of the need to protect mangroves by spreading knowledge [22] [113]. Environmental care initiatives are one way that the public is being educated. Mangrove management, including efforts to restore it if it is in a deteriorated state, requires the support and dedication of the local residents. If the community is motivated to restore themselves and receive personal advantages, such efforts will be more successful [22] [93]. Through appropriate maintenance of the mangrove environment, community involvement can contribute to the preservation of the diversity of mangroves. The community has a great deal to be concerned about the mangroves, much as it does for the mangrove areas on the coastlines. Here, the government organizes into groups and permits the communities to use the mangrove regions while preserving their sustainability. The environment and mangrove diversity are successfully preserved by this community involvement [22] [105].

4.4.2. Promoting mangrove conservation

According to Winata & Yuliana (2016), mangrove conservation calls for cooperation or accountability from the government and the community. The conservation of mangrove forests can be achieved through three primary strategies: the preservation of ecosystems and the diversity of flora and fauna, the protection of life support systems, and the sustainable use of biological resources [22] [133]. Regional development plans must guide the implementation of integrated strategies for mangrove conservation [22] [39]. In order to tailor the management approach to the specific requirements of the region that needs to be managed, the environmental management process should be carried out by paying more attention to the local situation and conditions [22] [74].

In order to address issues pertaining to mangrove conservation, deliberate and ongoing actions must be taken through community education and advice that emphasizes the value of maintaining the ecosystem. Local knowledge and wisdom can help with management and efforts to restore mangrove damage caused by human activity [22] [107] [108]. This article explains three indicators that can be used to promote mangrove conservation. Firstly, attitude; this encompasses societal ideals, a deep concern for the preservation and sustainable use of natural resources, a drive to engage in conservation initiatives, and involvement in those efforts. The community must be inspired to create a sense of enthusiasm and the ability to alter individual or human behavior in order to raise ecological awareness in coastal communities [22] [111].

According to Ambo-Rappe *et al*. (2020), the extension must also be implemented in order for the community to be aware of the issues it faces, wish to address them, and take proactive steps to foster behavior change in people, groups, and communities. Second, expertise is required to address issues related to natural resource conservation. Third, involvement is required to cultivate a sense of accountability for a problem pertaining to the conservation of natural resources so that appropriate action can be taken in conformity with the circumstances [22].

Mangrove degradation can be avoided by implementing a number of strategies, such as comprehending the ecology of mangrove species and communities, identifying obstacles to succession, determining the location and hydrological suitability of plantings, determining the degree of community dependence, and comprehending customs, beliefs, and requirements of the surrounding community. To determine how ecosystem services are balanced between human usage and exploitable mangrove resources, analysis of ecosystem services in mangrove ecosystems is necessary [22] [45].

4.4.3. Practicing mangrove restoration

Mangrove restoration is currently being encouraged due to the deforestation and degradation of numerous mangrove ecosystems. In order to reduce seawater incursion onto land and coastal abrasion, degraded mangrove areas are being reforested. To address community needs while preserving biodiversity overall, mangrove restoration projects must adopt a more comprehensive strategy that integrates coastal area management and incorporates critical components including ecology, socioeconomics, and socio-culture [22] [103].

For instance, mangrove trees have been planted in Yogyakarta's Baros Village, Bantul. The local community can benefit greatly from the numerous ecological, economic, social, and tourism advantages that the restored mangroves can offer. Through this initiative, the agricultural regions surrounding the mangroves are protected from abrasion. In order for mangrove restoration to be successful and benefit the community's socioeconomic and environmental sustainability, the village government, tour guides, and community involvement are all necessary [22] [32].

Mangrove regeneration and afforestation can involve the community in a range of activities, including nursery preparation for seedlings, planting, upkeep, and utilization of conservation-based mangrove forests. Mangrove planting is possible in a variety of coastal sites, particularly in regions that were formerly mangrove habitats in ex-ponds that have been harmed by human activity or tsunami waves [22] [112].

For example, mangrove seedlings have been planted as part of restoration efforts in a number of areas along the north and south shores of Central Java, Indonesia. Numerous locations exhibit remarkable progress in boosting and refining the mangrove's functions. In this instance, the local community's support, active involvement, and careful evaluation of biotic, abiotic, and cultural variables have contributed to the success of mangrove restoration [22] [99].

4.4.4. Encouraging sustainable mangrove ecotourism

In recent years, even in mangrove areas, sustainable ecotourism is growing in popularity. Both humans and the mangrove ecology benefit from this strategy. The mangrove ecotourism sector serves as evidence that mangroves can be used for both nature-based tourism and mangrove protection. Community involvement is necessary to integrate local knowledge into the ecotourism plan and improve the sustainability of the mangrove ecosystem [22] [44]. Promoting community knowledge of the importance of mangrove forests is essential, especially for the communities that encircle them [22]. In order to prevent harm to the ecosystems of the mangrove forests and to improve community awareness of ecotourism-based mangrove forest management, counseling and training are also essential for the communities surrounding the mangroves [22] [79].

The main goal of managing mangrove ecotourism should also be to enhance the social and economic benefits for the local populations. This must be done to prevent the nearby residents from using the mangrove forest for non-environmentally friendly purposes. Therefore, in order to meet their requirements without damaging the environment of the mangrove forest, it is imperative that the people surrounding the mangroves improve their social and economic standing. This is a crucial topic because the main stakeholders in the preservation of mangrove forests are the local population [22].

4.4.5. Allowing the natural recovery of mangrove ecosystems

Mangroves have development techniques and adaptations that enable them to recover from natural disturbances, much like many other natural ecosystems. This particularly addresses contamination resulting from oil spills. Mangroves are resilient, so once the disturbance has subsided, they will naturally regenerate. If the stressor leaves no residual effect, they can return to their pre-stressed condition; if not, they are limited to becoming simpler than they were before if they continue to be impacted by residual stressors or a higher frequency of acute events [25]. Therefore, the extent of human involvement in mangrove stress restoration may be restricted to eliminating the stressors that are degrading the system and letting nature take its course. Additionally, if the stressors have not been eliminated or if any residual levels are present, any attempt to artificially restore mangrove regions would be futile [25].

5. Conclusion

In conclusion, although mangroves are a vulnerable species, they offer these coastal communities' significant benefits in terms of risk reduction and flood protection. Because they serve as natural barriers to waves and storm surges, coastal ecosystems like reefs and mangroves are essential in minimizing the harm that floods bring to people and property at large [116]. A wide variety of anthropogenic activities, such as domestic activities, land conversion, mining, and logging, are the main causes of mangrove deforestation and degradation in Guyana and other neotropical countries. Both the extent and the function of the mangrove ecosystem can be diminished by anthropogenic activity. Reduced mangrove forests, altered mangrove composition, unequal species abundance, mass mangrove mortality, pollution in mangrove areas, rising sea levels, global climate change, and coastal erosion or abrasion are all effects of anthropogenic activity that have a negative impact on mangrove forests and the ecosystems they thrive in. Mangrove forest conservation and restoration can be achieved by replanting mangrove forests, raising community knowledge of their value, and encouraging community involvement in the preservation of natural resources. The conservation of mangrove forests can be achieved through three primary strategies: the preservation of ecosystems and the diversity of flora and fauna, the protection of life support systems, and the sustainable use of biological resources. A significant portion of the published literatures that were examined included information regarding nations outside of the Neotropics. It is therefore necessary to conduct additional research on mangroves and the impact of human activities. Considering there is a dearth of information in this region rich in biodiversity, there is a need for additional comprehensive studies in the Neotropics regarding the impacts and implications of anthropogenic activities on mangroves and possible mitigation solutions to conserve and preserve the species along the coastline.

Compliance with ethical standards

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Disclosure of conflict of interest

The author certify that this submission is original work and is not under review at any other publication. The author hereby declare that this manuscript does not have any conflict of interest.

Statement of informed consent

The author declare that informed consent was obtained from all individual participants included in the study. All work utilized in this study was fully cited and referenced so authors of prior researches are given their due credentials for their work.

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