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Participatory Stakeholder Assessment for Drivers of Mangrove Loss to Prioritize Evidence-Based Conservation and Restoration in Bhitarkanika and Mahanadi Delta, India

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Abstract: In recent times, environmental stewardship of mangroves has provided the impetus to protect and restore these ecosystems for their inherent ability to protect coastal regions from climate change, sequester carbon dioxide as rich blue carbon, and support human well-being through a multitude of ecosystem services. Participatory stakeholder assessment, as a part of the present study, integrated local stakeholder perspectives in assessing drivers of mangrove loss in Bhitarkanika and Mahanadi delta, Odisha, providing empirical evidence through a mixed-method approach. The use of a Likert scale provided the methodology to develop a single composite variable as the best measure of central tendency. In total, 27.5% of the respondents were locals and were living close to the study area for generations, whereas the other 72.5% represented researchers, academics, and forest department officials. Stakeholder responses at the ground level indicated that Bhitarkanika and Mahanadi delta were facing increased frequency of extreme climatic events followed, by aquaculture and other land-use changes, which can be considered potential drivers causing mangrove loss. Co-development of future scenarios by integrating concerns of all the stakeholders emerged as a potential solution to effectively address the trade-offs arising from local anthropogenic interferences, as well as large-scale developmental activities. This study highlights the need for convergence of multi-disciplinary knowledge from diverse stakeholder groups, including traditional and indigenous knowledge, for the purpose of developing accurate plausible alternative scenarios. Interactive governance and incentivization approaches, along with alternative livelihood opportunities, are proposed as the means to improve conservation and restoration in the region based on the present study. Understanding of the coupled socio-ecological system and its relevance is found to be critical to improve bi-directional linkages of ecosystem health and human well-being.

Keywords: mangroves; mangrove loss; Bhitarkanika; Mahanadi delta; drivers; participatory survey; climate change; conservation; restoration



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1. Introduction

Known collectively as “Blue Forests,” mangroves, seagrass meadows, and salt marshes are among the most valued and productive coastal ecosystems, with the maximum densities of carbon reported from any ecosystem [1]. Mangrove forests are well-established as carbon-rich tropical ecosystems across the world that offer a variety of vital ecological and economic services to the coastal inhabitants in the area and beyond [2,3]. Mangroves stabilize shorelines by reducing the impact of cyclones, tsunamis, sea surges, etc. Further, they also regulate and support a multitude of ecosystem services which help in erosion control and protection of coastline, and also mitigate climate change [3–5]. This ability is dependent

on the size, location, and health of these mangrove patches [4]. However, degradation and deforestation have a significant negative influence on mangroves, with a 20–35% loss in global mangrove extent over the past 50 years [2]. More than 80% of the mangrove ecosystems across the world are experiencing human-induced pressures and interferences that have resulted in reduced regeneration of mangroves [5]. Hamilton et al. [6] reported a loss of global mangrove forest cover by 1646 km² (i.e., 1.97%) between 2000 and 2012 at a rate of 137 km², or 0.16%, per year. Due to land cover changes between 1996 and 2016, the global mangrove carbon stock reduced by 158.4 Mt, which was 1.8% of the stock present in 1996 [7].

According to the Intergovernmental Panel on Climate Change (IPCC) 2022 Climate Impacts, Adaptation, and Vulnerability report, significant changes in species and ecosystems are expected, including the failure of mangroves to slow the rise in sea level, the loss of species that depend upon them, and widespread tree mortality [8]. The Global Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reported that rapid habitat destruction in mangrove forests has already resulted in intense declines in biodiversity and ecological services, endangering billions of people globally [9]. Natural drivers of mangrove loss are emerging challenges to coastal adaptation [2]. The IPBES report identified the primary causes of biodiversity loss as pollution, invasive species, unsustainable use of wild species, climate variability, and associated vulnerabilities as direct drivers. However, humans' alienation and disconnect from nature, as well as our underestimation of nature's value and relevance, are two major indirect drivers that can lead to rampant loss of mangroves. More often, the tangible and intangible benefits offered by mangrove ecosystems can be unknowingly undervalued by almost all stakeholders, especially their potential as bio-shields [10–13]. Land use and land cover changes (LULCC) are predominant drivers of mangrove loss that have driven the conversion of natural patches of mangroves into aquaculture, industrialization, expansion of urban sprawls, etc. [14]. Globally, the decline in mangrove patches is of serious concern, as much of it is already in a severely degraded state. Remaining mangrove patches are under tremendous human-induced pressure due to clear and selective felling and encroachment for development, urbanization, agriculture, and aquaculture, followed by hydrological changes, extreme climate, and rising sea level [15–17]. More than 62% of the global mangrove ecosystems between 2000 and 2016 have been lost to land-use changes, predominantly due to conversion to aquaculture or agriculture [2]. The South Asian mangroves are facing threats from exponential population growth, rapid infrastructure expansion in the coastal areas and urban sprawling in its close vicinity despite only 2% of mangrove forests being diverted for establishing new settlements, as reported [18–20]. Aquaculture is considered a significant driver of mangrove loss across the Indian coasts and has degraded more than 35,000 ha, followed by construction of ports, roads, and coastal fisheries by mechanized machines, despite no fishing zones existing [21–23]. Fragmentation of mangrove patches in many coastal regions and degradation of mangrove ecosystems has jeopardized the ability of these sensitive habitats to support human well-being [4]. There are several extinction risks that are heavily stressing the Indian mangroves on a regional basis [22,23]. In the case of the east coast of India, a significant portion of mangroves of Odisha state has already been lost since India gained independence (after 1947). The loss of 42% of mangrove forests and the shrinking mangrove cover from 307.66 km² in 1944 to 179.00 km² in 1999 from Bhitarkanika, in the Kendrapara district of Odisha, is astonishing [24]. Construction of ports, jetties (Dhamra and Paradip), and road-broadening activities have further accelerated the pressure and stress on existing mangroves, which has significantly affected the habitat suitability for many threatened species [25].

While the analysis of existing LULC data provides a better understanding of ongoing land degradation and deforestation, the present study provides useful insights by engaging with local stakeholders to improve our understanding and to accurately assess the drivers of mangrove loss. Understanding the regional causes of mangrove decline is essential to developing accurate predictions and enforcing mangrove conservation policies in a

proactive manner. The major objective of the present study was to contribute to interdisciplinary mangrove conservation efforts in the region by accurately assessing the status and predicting the future of mangroves in coastal Odisha, via ground level assessments of the impacts of diverse drivers of mangrove loss. Resource managers, planners, and policy-makers also require this location-specific information on the key drivers responsible for the disappearance of mangrove forests. The present study is an attempt to understand evidence of the drivers from a comprehensive participatory stakeholder assessment to support ongoing conservation and restoration efforts in Bhitarkanika and Mahanadi Delta, India following the Asia Pacific Assessment of Biodiversity and Ecosystem Services by IPBES [26]. The results from this study will help to understand locally relevant causes of mangrove loss and to guide upcoming government policies and transformative efforts to meet global climate, conservation, and restoration targets.

2. Study Area

The mangrove forests of Odisha along the Indian east coast are situated between the latitudes $19^{\circ}12'$ and $21^{\circ}36'$ N and $84^{\circ}51'$ and $87^{\circ}29'$ E. The area includes the Talsari coast in Baleshwar District to Gopalpur in the Ganjam District [27]. The region's major rivers, including the Mahanadi, Brahmani, Baitarani, Budhabalanga, Subarnarekha, Rushikulya, Devi, and Bahuda, have created a variety of estuarine ecosystems and deltas that support a variety of genetic resources for mangroves. The distribution of mangrove forests greatly varies across the six coastal districts of the state. The delta of the Brahmani–Baitarani and the Mahanadi in the Kendrapara District is where the majority of the state's mangrove cover is located (Figures 1 and 2). The forest ecosystem and wetland area of the delta are known as the “Bhitarkanika mangrove forest,” which is second-largest mangrove forest in India, after the Sundarbans, spanning 225 km^2 .

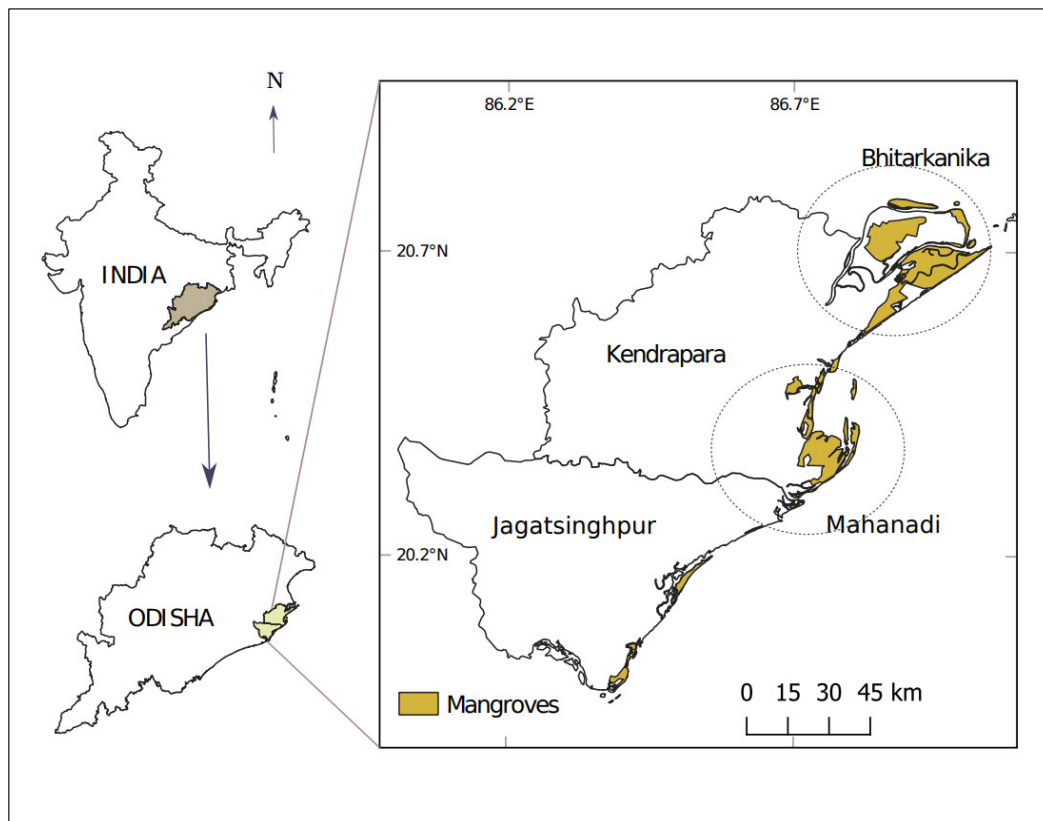


Figure 1. Map showing mangrove patches in Bhitarkanika and Mahanadi delta on the east coast of Odisha [16].



Figure 2. An overview of mangroves and drivers of mangrove loss: (a) riverside mangrove with mixed species; (b) an old patch of monospecific *Rhizophora mucronata*; (c) women engaged in fuelwood collection; (d) exposed degraded patch due to clearing of mangroves; (e) aquaculture; (f) brick kilns and agriculture expansion.

Major portion of Mahanadi delta mangroves are situated in coastal districts such as Kendrapara and Jagatsinghpur, formed by Mahanadi River and its tributaries (Figure 1). Approximately 80% (201.49 km²) of the total mangrove cover in the east coast of Odisha State is found within the boundary of the coastal district of Kendrapara [22]. Remaining, small, degraded, or newly generated mangrove areas are found distributed in other coastal

districts such as Puri, Jagatsinghpur, Bhadrak, and Baleshwar. Together, they host only 49.15 km² mangrove cover, which is either moderately dense (10.77 km²) and/or the open mangrove type (38.38 km²). Except for the mangrove ecosystems at Bhitarkanika, other regions are habitats to open, sparse, and sporadic patches of mangroves. Mangroves in the Rusikulya and Bahuda estuaries of Ganjam are fully lost. There are four significant protection classifications for Bhitarkanika mangroves, providing it strong legal protection. It was designated as a Wildlife Sanctuary in 1975; a Marine Sanctuary in the Gahirmatha region in 1997; a National Park in Bhitarkanika in 1998 under the Wildlife Protection Act, 1972; and a Ramsar Wetland in 2002 under the Ramsar Convention of 1971. Bhitarkanika is not only home to the highest diversity of Indian mangrove flora, but also the largest known rookery for the olive ridley sea turtles (*Lepidochelys olivacea*) in the world, the last of the three remaining populations of saltwater crocodiles (*Crocodylus porosus*) in India, the largest known population of king cobra (*Ophiophagus hannah*), and the water monitor lizard *Varanus salvator* [16,25]. The Bagaghana heronry of Bhitarkanika Reserve Forest is one of the largest heronries of India. Besides the environmental and ecological significance, Bhitarkanika forests provide significant ecosystem provisions to local livelihoods in terms of forestry and fishery products. Details of multiple values of Bhitarkanika mangroves for human well-being can be referenced in our recent publication through a detailed synthesis of contemporary scientific knowledge, as well as field-based observation for mainstreaming ecosystem services in policy planning [16].

3. Methodology

The present empirical study is based on the participatory stakeholder responses on the drivers of mangrove loss in Bhitarkanika and Mahanadi delta. The primary information was collected based on an inexpensive stakeholder survey technique. This approach integrates the conventional notion of drivers of mangrove loss with a participatory survey. A mixed research approach was used, followed by the collection of qualitative and quantitative data, which was used for further analysis. Participatory Rural Appraisal (PRA) initially included a short questionnaire survey with relevant diverse stakeholder groups in the study areas (n = 153). This was later followed by Focused Group Discussions (FGD) and detailed interviews with key informants. Three exploratory FGDs and several Key Informant Interviews (n = 40) were initially conducted from March to August 2019, and later, from June to August 2020. Important aspects and key points of the drivers of mangrove loss that emerged from the participatory survey on mangrove habitats were based on the relevant open-ended questions asked during our FGDs and Key Informant Interviews (Supplementary Materials).

The PRA exercises were particularly focused on the villages viz. Gupti, Dangmal, and few small settlements close to the Paradip port. In total, we carried out four FGDs that included local forest department staff (10 participants), local farmers (45 participants), women, and boat owners and operators (28 participants), who were also part of this exercise. The number of participants who were women was lower because of the barriers of language in communicating their responses, and also because most of them were busy with household chores. FGD provided us information about potential informants who were included in the key informant interviews. Among the participants, 40 people were involved in further interviews, and they represented diverse backgrounds viz. government employees, academics, scientists, homestead owners, farmers, teachers, and businessmen. The first author, along with other authors, carried out these interviews. Of the total respondents, 88% were male and 12% were female. The respondents were majorly in the age bracket of 36–40 years (48%) followed by <35 years (42%), while only 10% of the total respondents were >51 years old. The diversity of representation of the stakeholders for these surveys was considered critical to understanding the dimensions of their engagement with the mangrove ecosystem services, directly or indirectly. These diverse stakeholders were questioned about their socio-economic status followed by their awareness and understanding of the drivers of mangrove loss in Bhitarkanika and Mahanadi delta [26]. The

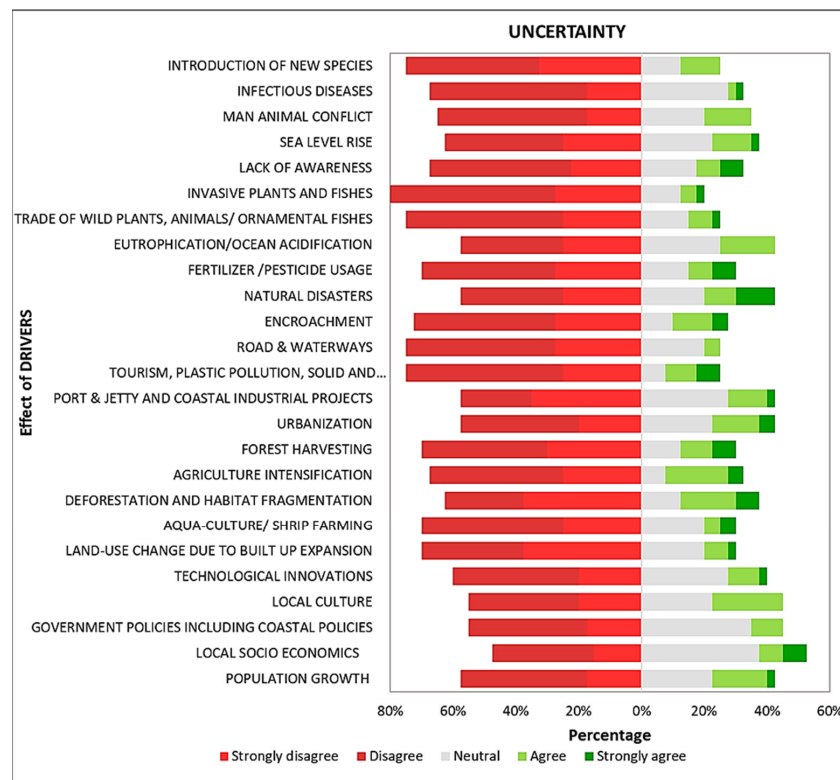
drivers of mangrove loss were segregated into direct and indirect drivers. The direct drivers included LULCC, aquaculture, deforestation, agriculture intensification, unsustainable harvesting, urban sprawl, tourism, natural disasters, and invasive species. The indirect drivers included population growth, local socio-economics, local culture, technological innovations, coastal policies of government, etc. We asked the respondents to categorize the drivers with appropriate justification about their impacts on the structure and function of mangroves in Bhitarkanika and Mahanadi delta. A score between 1 and 5 was chosen to express the impact and uncertainty of the discussed drivers, where (1) indicated no impact; (2) very little impact; (3) moderate impact; (4) high impact; and (5) very high impact. Similarly, for uncertainty, the scoring was as follows: (1) indicated very low uncertainty; (2) low uncertainty; (3) moderate uncertainty; (4) high uncertainty; and (5) very high uncertainty.

During the interviews, while the informants attended to the descriptions cautiously, the authors encouraged conversation through related and probing questions. Based on the focused analysis of the content and maximum repetitions, the potential drivers of mangrove loss were listed. These were further confirmed by field surveys and observations. Empirical data were collected in each of the steps, and a local language translator maintained careful and on-the-spot interpretation from the local Odiya language. The summary of the stakeholder responses was analyzed to identify specific drivers contributing to (a) forest management practices; (a) loss of mangroves; and (c) local understanding and efforts to reduce disaster risks (Table 1). Supplementary supporting evidence from existing scientific papers and government reports, was referred to in order to reinforce the confirmation resulting from the stakeholder survey.

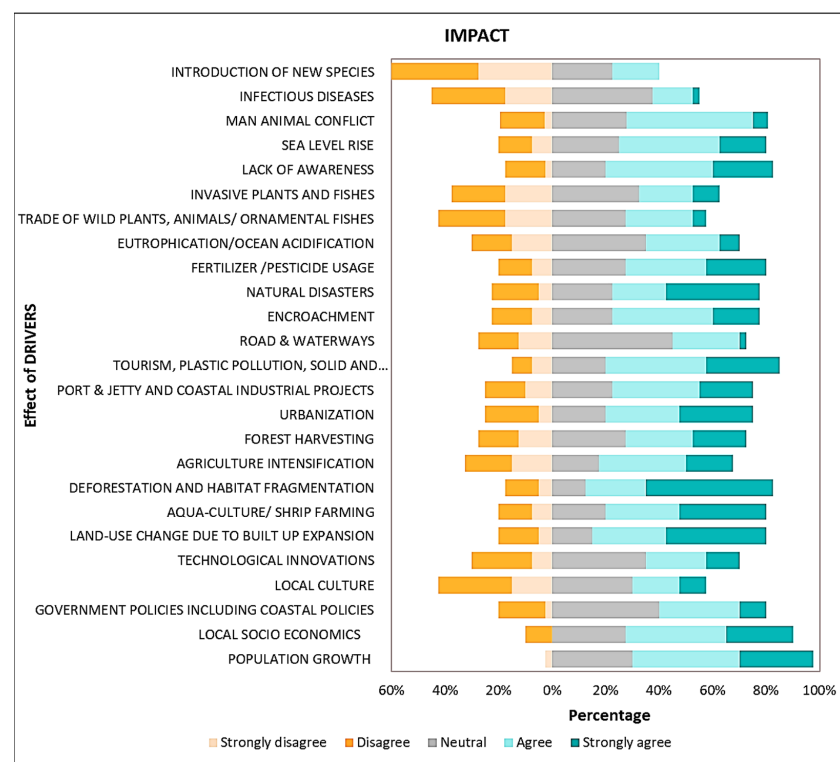
Table 1. Summary of the drivers that emerged from the participatory survey on mangrove habitats.

Major Drivers of Urbanization and Anthropogenic Impacts on the Mangroves	
Economic development	Increase in build-up, aquaculture, agriculture, pollution, tourism
Conservation measures	Avoiding deforestation and habitat fragmentation
Socio-economic factors	Poor education, lack of awareness, alternative resources, less forest dependency
Use of technology	For monitoring and coastal protection

To further understand the respondents' perceptions associated with the impact and the uncertainty of the drivers of change in the mangrove ecosystems, twenty-five statements representing interpretations of the concept (Table 1), pertaining to either impact or uncertainty, were put forth. The Likert analysis is based on a psychometric response scale which provides a comprehensive overview of the impact and uncertainty of potential drivers, as perceived by the respondents. This method is adopted to provide a quantitative value for qualitative data. Respondents indicated the degree to which they agreed with the statements on a 5-point Likert scale ("strongly disagree," "disagree," "neutral," "agree," or "strongly agree,") which was further analyzed in MS Office Excel, treating the Likert scale answers as continuous variables from 1–5 for the identification of potential drivers. The items were plotted as 100% stacked bar charts (Figure 3a,b).



(a)



(b)

Figure 3. (a) Respondents’ perceived reasons for changes in Bhitarkanika mangrove ecosystems. (a) Responses pertaining to the uncertainty of the effects of drivers; (b) responses pertaining to the impacts of the potential drivers. The numbers in the center and on the right indicate the proportion of responses for “Disagree/Strongly Disagree,” “Neutral,” and “Agree/Strongly Agree,” respectively, for each driver.

4. Results and Discussion

The participatory survey was conducted among the diverse stakeholders of the region to find out the major concerns of the locals regarding mangrove degradation. All the respondents were either living in or involved in activities contributing to local economy education or administration connected to Bhitarkanika and Mahanadi delta. Of the respondents, 27.5% were local residents and had been living there for generations, whereas the other 72.5% had been working and living there for >5 years. Out of the total respondents, 12.5% were female, whereas the other 87.5% were male. A total of 42.5% respondents were <35 years old, whereas 47.5% belonged to the 36–50 year age group and 10% were >51 years of age.

Based on the results of the Likert analyses, the key drivers (uncertainty) perceived by the respondents for change in the Bhitarkanika mangrove ecosystems were natural disasters, deforestation and habitat fragmentation, urbanization, changes in local socio-economic dynamics, etc. (Figure 3a). A majority of the respondents also strongly agreed with the view that population growth, tourism, deforestation, aquaculture, and fertilizer usage have high impacts on the changes in mangrove ecosystems (Figure 3b). The responses indicated that there was low uncertainty amongst the respondents regarding the effects of drivers, while the respondents strongly agreed regarding the potential impacts of these drivers on the mangroves.

4.1. Demographic

From the FGDs and personal interviews, the “human–environment interaction” emerged as one of the mega drivers that has resulted in the loss of fringe mangrove habitats in the study area. Respondents had low uncertainty regarding the impact of population growth, which has severely affected mangrove degradation in the region (Figure 3a,b). According to them, pressure on the natural mangroves has enhanced manifold due to the exponential population growth, especially due to rural–urban migration. More than 9 lakh people from around 900 revenue villages are presently living close to Bhitarkanika, while 410 villages are inside the protected area boundaries. These demographic changes reduced the agricultural land use and led to an increase in land used for settlements, from 27.33 ha to 38.01 ha (39.07%), in the period of 2000–2006 and from 38.01 ha to 46.19 ha in the period of 2006–2015 [28,29]. According to the respondents, Bhitarkanika is sparsely populated, and most of the settlements are far from coasts due to frequent and extreme cyclones. However, it was shown that the population growth in nearby urban sprawls such as Kendrapara is increasing. People living close to the coasts and mangroves were observed to live in more harmony with nature than those living in nearby urban sprawls. Marine fishers mostly utilize non-motorized or small motorized boats for their enterprises. An influx of immigrants from Bangladesh and migration from other states (for instance, West Bengal) in the last three or four decades (since the 1980s) has contributed to an increase in the existing population. It was also observed during the field survey that the key issues were encroachment and conversion of mangroves for settlements, agriculture, and homestead by immigrants, as well as their conversion into common homestead and agriculture land. Enhanced demographic pressure was evidenced in restricted natural growth of mangroves and clearing of mangrove forests for shrimp farms in fringe areas. Respondents attributed expansion of agriculture and blocked tidal creeks in the encroached areas to population growth in the region. One of the respondents emphasized the Population Control Bill, which had some serious clauses to limit population growth.

4.2. Local Socio-Economics

Respondents agreed, with low to medium uncertainty, that local people are directly as well as indirectly dependent on the mangrove forests, and that local socio-economics have a high to very high impact on mangroves (Figure 3a,b). The eco-sensitivity of the area has deterred domination of marine fishing activities in general, and there was a cessation during the fishing ban periods [30]. Respondents indicated that local poverty and socio-economic

factors have significantly affected the mangroves' health in the region, and that agriculture expansion, along with the pressure of fuelwood, is tremendous. Changes to the hydrological and geomorphological conditions have resulted in a decline in farming opportunities (due to salinity ingress, cyclones and disasters, etc.). Reduced farming opportunities for livelihood, in turn, have led towards the dependence of local communities on mangroves, resulting in their further loss [31]. With the increase in economic development, an increase in the human interference has been registered in natural mangrove patches. Increasing tourism, especially through homestays, contributes to the issue of loss of mangroves, as it enhances illegal fishing opportunities in the region, mostly as a recreational activity. Surveys have indicated that improving socio-economic conditions of local people by providing them with alternative livelihood options can help to reduce exploitation of the mangrove resources. Bhitarkanika and Mahanadi delta are an open platform for such activities, especially Mahanadi delta, as it does not have the required legal protection.

4.3. Conservation and Coastal Management Policies

The creation of coastal protected areas has helped in reducing the losses of mangrove ecosystems, especially in countries with insufficient regulatory governance. However, countries with better regulatory quality ensured a higher level of conservation for mangroves, even outside of the protected areas [32]. Human-induced pressures that threaten the natural ecosystem of Bhitarkanika and Mahanadi delta vary across small spatial scales; however, they are likely driven by diverse large-scale drivers such as national policies and governance frameworks. In response to the growing need for conservation efforts, the Government of Odisha declared the core area of Bhitarkanika a "National Park" in 1998. The resultant gain of 24.4% of dense mangroves could be attributed to increased protection and consequent regeneration. On the other hand, 70% of the total dense mangroves, again, changed into open mangroves from 2004 to 2017 in the area [33]. As per the stakeholder responses received from our survey, the respondents believed that government policies have ensured the conservation of mangroves in the region. According to the respondents of the present survey, government policies have moderate to high impact, with low to medium uncertainty. Especially, efforts of the state forest department have ensured mangrove protection and habitat protection for sea turtles, brackish water crocodiles, and many other threatened species along the east coast of Odisha by ensuring strict enforcement of government policies. The efforts of the state forest department in implementing regulatory policies have also ensured that the overall negative impact on the mangroves has been lowered. However, the respondents stressed, upon their observation, that a lack of strictness and enforcement on regulating illegal fishing in the region continued to have strong negative impacts on the provisioning ecosystem services.

Respondents further believed that although coastal zone regulation policies have helped coastal zone management to some extent, the violations are quite frequent and ongoing, to the detriment of the mangrove conservation efforts. The FGDs revealed that the lack of local stakeholder awareness on the importance and sensitivity of coastal zones is a key issue among the stakeholders. A lack of alternative livelihood sources other than fishing and mangrove-dependent livelihoods for coastal peoples has emerged as a major gap which is not adequately addressed in the existing policies. On the other hand, recent ecotourism policies have helped to grow mangroves, with no specific negative impact.

It was observed that in certain cases, in which the rights of locals for settlement procedures under Forest Rights Act, 2006 were followed, locals were deprived of their ancestral rights. Few respondents believed that government policies had a high impact on habitat conservation and mangrove conservation, as they ensure a secure future for Bhitarkanika mangroves through effective conservation, management, and functioning. A few respondents emphasized the fact that existing coastal zone regulation and mangrove conservation policies were not being sufficiently and appropriately exercised for the improvement of coastal zones, especially in the Mahanadi delta region. Hence, a common observation is that there are gaps in the existing policies, necessitating the need for new, progressive, and

inclusive policies catering to diverse stakeholder needs, which will be useful to address local socio-economical requirements that are culturally advanced and environmentally sustainable in nature.

4.4. Land-Use Change Due to Build up Expansion

LULCC is one of the major drivers of mangrove loss in coastal Odisha, especially in and around Bhitarkanika [28,34,35] (Table 2). One of the earliest long-term studies on mangroves, conducted between 1944 and 1999 by Das and Vincent [24], shows that mangrove cover in Odisha dropped almost to half of 307.66 km² in 1944 and further to 179.0 km² in 1999. One of the longest monitoring periods of LULCC for mangroves in the region, carried out by Thakur et al. [36], reported a significant decline in mangrove cover during the last four decades (1973 to 2017). In Bhitarkanika, a dense mangrove cover of 35.23% in 1973 declined to 22.43% by 2017. Cross-verification of the reported data by ground truthing also reported a loss of 0.644 km² of mangroves, which corresponds to a 1.52% loss, with 1.12 km² of mudflats corresponding to a 30.6% loss. Several degraded open mangrove patches of previously dense mangroves also vanished from Bhitarkanika. Respondents had very low uncertainty about the high impact of land use change, especially due to built-up expansion owing to industrialization, which has severely affected mangrove degradation in the region (Figure 3a,b). During the stakeholder survey, respondents indicated that the increasing pressure of tourism affected the mangroves in the region. Construction activities were observed to have largely increased, especially in the Mahanadi delta region, during the survey. New priorities (aquaculture ponds) and sand bunds were clear reasons stated for changing land use and loss of mangroves. Most of the expansions in the region occurred after the introduction of different government policies (focused on economic development in a “Business-as-Usual” perspective), and it was also stressed that expansions prior to the area being declared as protected were negligible. Monitoring of land use change in the area was suggested by the respondents as a better approach to keep an eye on these land use changes, an approach which can improve future land use changes, and also help to monitor and map land use change and expansion inside protected area boundaries and mangrove patches.

Table 2. Change pattern of the area (ha) of LULC classes of Bhitarkanika National Park from 2000 to 2020.

Sl. No.	LULC Classes	2000	2006	2015	Change in Area 2000–2006	Change in Area 2006–2015	Change in Area 2000–2015	% of Change from 2000– 2015
1	Agricultural Land	970.157	939.392	893.127	−30.76	−46.26	−77.03	−7.94%
2	Aquaculture Pond	26.85	24.991	61.691	−1.85	36.7	34.84	56.47%
3	Drainage	345.135	350.391	351.761	5.25	1.37	6.62	+1.882%
4	Grass Land	33.18	35.298	35.129	2.11	−0.16	1.94	5.52%
5	Mangrove Forest	4489.076	4545.914	4421.685	56.83	−124.22	−64.40	−1.52%
6	Road	18.673	20.525	20.525	1.85	0	1.85	9.9%
7	Scrub Forest	123.533	79.404	203.823	−44.12	124.41	80.29	+64.39%
8	Settlement	27.328	38.017	46.191	10.68	8.17	18.86	40.83%

Source: [28].

4.5. Aqua-Culture

Aquaculture in Indian coastal areas contributed to more than 1.1% of the GDP of India. Odisha State exports 26% of its aquaculture products to foreign countries [37]. Increasing aquaculture is clear evidence that aquaculture is facilitating socio-economic developmental of coastal communities; however, it is a major driver of mangrove loss. Gradual decline in agriculture land of 3.17% (9.70–9.39 km²) between 2000 and 2006, followed by a 4.92% decline (9.39–8.93 km²) between 2006 and 2015, reflects a decline of 7.94% in a short period of fifteen years (from 2000 to 2015). Bhitarkanika is also facing slow but significant land use

changes due to conversion of agriculture fields to aquaculture ponds/gheris (Figure 2e). This was due to the gradual conversion of agriculture to aquaculture, which has resulted in a rampant 129.76% increase in aquaculture in the region, having grown from 0.27 km² to 0.62 km² [28]. The increase in aquaculture was observed more in Bhadrak District than Kendrapara. The increase was significantly high, from 0.36% to 0.79%, in the 15-year period of 2002 to 2017, and has been further increasing in the recent years. The cumulative increase in mangroves and loss due to aquaculture in Bhitarkanika, Mahanadi delta, and Devi estuary was reported to be a marginal gain of 16.16 km², but a significant loss of 23.35 km² was also reported [38]. Respondents had low uncertainty about the very high impact of aquaculture expansion in the region that has severely affected mangrove degradation (Figure 3a,b). According to local respondents, aquaculture is seriously affecting mangroves in the region, and there is a low uncertainty regarding this factor. Aquaculture farmers utilize mangrove areas for the production of fish and prawns, thereby disturbing the nearby ecosystem.

Presently, the mouth of the River Devi (a tributary of the Mahanadi River) at the interface of the Puri and Jagatsinghpur district boundaries have healthy and well-established mangrove habitats. This area is home to quickly regenerating mangroves that are also rich in species diversity. However, human-induced interference, especially aquaculture, is rapidly altering the habitat and also reducing the land availability for the regeneration of forests. The siltation due to aquaculture is observed to significantly affect the breeding and spawning of many native and threatened fish species, followed by many other mollusks and marine fauna that are used as food by migratory birds visiting the Ramsar site of Bhitarkanika. Reports of large areas of agriculture land close to rivers and creeks converted into aquaculture were also a common observation during the field visit. There was low uncertainty about the high impact of encroachment on the degradation of mangroves in the region (Figure 3a,b).

During the present study, it was observed that stakeholders supported the strict enforcement of Coastal Zone Regulation Guidelines. Bhitarkanika, is a National Park under the Wildlife Protection Act, 1972, which reduces the largely nonexistent chances for land encroachment and land grabbing. Many locals exhibited positive stewardship practices, denying shrimp farm owners and land from infiltrators, and preventing encroachment on the mangrove forests of Bhitarkanika; they suggested regular monitoring to control such incidences. The nature of encroachments of mangrove patches, especially open mangroves, by the emigrants is observed to be via their conversion into common home gardens or agriculture initially, and later into aquaculture or brick kilns when crop yields reduced, as reported by locals during the discussions. Respondents also reported that there has been a rise in the purchase of private lands along the coast and creeks by non-natives for aquaculture. Hence, it is revealed that a decline in the ownership attitudes is counter-productive to the conservation efforts led by the administrators. Swampy areas are being cleared for this purpose, or the mangroves become lost due to the extensive use of chemicals to enhance productivity; most of these are emerging contaminants and endocrine-disrupting hormones. Extensive use of chemical fertilizers is being practiced, and the nutrient-laden run-off drains to the sea through rivers as well as coastal feed channels. A majority of the respondents agreed that the degradation of water quality and deterioration of mangroves were due to the increasing chemicals used in shrimp farming. They attributed the same to the loss of many native varieties of fishes due to widespread usage of fertilizers by farmers in agriculture and aquaculture. Local informants also mentioned the frequent use of private lands in aquaculture.

However, a few respondents also stressed that regulation by forest department partially constrained the practice of aquaculture in areas surrounding Bhitarkanika. However, ground level surveys revealed that denudation of mangroves for shrimp farms is quite common, and the location of new aquaculture expansion will decide the impact and future of mangroves in the region. By converting degraded land into aquaculture instead of buffering the mangroves and other eco-sensitive habitats, the damage due to rampant

aquaculture expansion degrades the mangroves in the region. In the last few decades, new species of fish/shrimp have also been introduced illegally for economic gains, which was confirmed by locals. A few respondents highlighted that traditional fish farming was observed not to affect the environment adversely, since chemicals were not used in the traditional fishing ponds.

4.6. Deforestation and Degradation

Upadhyay and Mishra [5] reported that mangrove forests degraded by 5–30% in Bhitarkanika and 20–60% in Mahanadi delta as of 2008. However, in another study by Ravishankar et al. [31] no significant change in mangrove cover was reported in Bhitarkanika between 1985 and 2004, and only a marginal increase of 561 ha of mangrove cover was reported, from 13,617 ha in 1985 to 14,178 ha in 2004. More than 64 ha (1.52%) of mangrove forest, followed by 112 ha of mudflats (30.6%), were lost in fifteen years (2000–2015) to increasing aquaculture, human habitations, and degraded and scrub forests [28]. Local respondents considered deforestation and habitat fragmentation as one of the major drivers that depleted the rich mangrove patches in the region. Respondents had low uncertainty about the very high impact of deforestation and degradation of mangrove loss in the region (Figure 3a,b). Deforestation for economic reasons was highlighted in the discussions with shrimp farm owners, and the establishment of small industries, fishing jetties, and settlements were said to be the major reasons for the loss. A few mangrove forests were also observed to be in the denuded state due to rapid reclamation of mangrove forest patches for human settlements to accommodate growing population, increasing paddy cultivation, aquaculture, and over-exploitation of timber and wood for various growing demands. However, aquaculture was observed and reported to be on rise in both the deltas; it can be considered as the prime factor behind the loss of mangroves.

Respondents showed their concerns that reducing fresh water supply to mangroves, except during monsoons, will severely affect the future forest health in the region. In the absence of regular freshwater and nutrient input from rivers, sediment texture has also changed from a marshy to a sandy habitat. This is a severe constraining condition for mangrove growth that has resulted in the decline of natural mangrove populations and stunted growth, with branches regenerating from the base of the tree. Our field-based observations also support halophytes dominating the natural mangrove stands and preventing natural regeneration of true mangrove tree species in almost all deltaic habitats of Odisha's coast. Enhanced field-based observations and monitoring were suggested to be undertaken by local respondents to reduce and halt deforestation and degradation of mangroves. The resilience of fragmented, degraded, and open mangrove forests is compromised. Hence, change in the ecological attributes of the mangroves will affect ecosystem functioning, and this will drastically affect resilience in long run. During the discussions, local stakeholders also appreciated the role of the forest department and acknowledged their efforts, especially for undertaking large-scale afforestation programs in the past few decades, which are helping in the restoration of degraded mangroves.

4.7. Agriculture Intensification

Agriculture around the mangrove ecosystem of Bhitarkanika and Mahanadi delta is in a vulnerable state, as the production of paddy is constantly declining due to climate variability, rampant use of fertilizers, and deteriorating soil quality. Respondents had low levels of uncertainty about the high impact of agriculture intensification, which has severely affected mangrove degradation in the region (Figure 3a,b). During the survey, it was also reported by locals that the mangrove patches close to the coasts were usually not very suitable for agriculture, due to the enhanced salinity close to the coast. Hence, according to locals, there is no significant impact on mangroves caused by extension of agriculture. A few other respondents also reported enhanced fertilizer and synthetic pesticides being used for paddy cultivation close to mangrove areas in private agricultural land for the purpose of enhancing productivity from saline soils.

Respondents also confirmed that embankments around 20.23 km² of aquaculture ponds on the riverbanks and coastal areas have resulted in the flow of river water to the sea restarting and flooding local crops. Effluents released by aquaculture ponds are heavily loaded with emerging contaminants and persistent organic pollutants into nearby fields, which contaminates and increases the salinity level in the soil, making it unfit for growing crops. It was also clear from a few important long-term land use monitoring studies that in the conversion of dense mangroves, they are first converted to open mangroves, then to degraded scrubs, and then to the preferred land use, which is, preferably, either agriculture or aquaculture [27–29]. Conversion of land use to aquaculture in the region is first converted to agriculture, and later, after the loss of productivity due to enhanced salinity, is converted to aquaculture. Locals expect changes to be made, and reducing the loss of mangroves requires expert guidance, especially from agriculture and forest experts who can generate awareness so that detrimental impact of agriculture on the local mangrove ecosystem can be reduced.

4.8. Biomass Harvesting and Local Culture

During the survey, respondents reported low uncertainty about the moderate impact of biomass harvesting and local culture on the degradation of mangroves in the region (Figure 3a,b). Locals confirmed that fuel wood collection has a moderate impact on natural mangrove patches, but in last few years, with increasing populations, harvesting pressure has also increased (Figure 2c). Due to government regulations and stringent measures taken by the forest department, fuelwood collection has reduced in recent times. Still, there was no denial that the collection of fuelwood still takes places. Locals have the perspective that fuelwood and other NTFP (non-timber forest products) collection has minimum impact on the loss of mangrove forests. Approximately 25% of the respondents denied the use of timber from mangrove trees for building houses and for domestic fuel, and they also consider it a prominent driver of loss of mangrove patches in the region. One of the respondents emphasized implementing rotational harvesting of biomass from mangrove forests, which will be a low-impact measure following sustainability principles for limiting disturbance. When asked about the impact of local culture during the survey, local respondents denied that local culture and beliefs had any adverse impact on the mangrove patches. Local stakeholders stressed that they were not involved in the felling of mangroves; however, they agreed that grazing is common and prevalent. They consider immigration of Bangladeshis in the region as the main reason behind the loss of mangroves. A few of them also mentioned that local culture has no role in protecting the mangroves, and it all depends on cultural underpinnings. It is important to mention here that the local inhabitants of Badakot, located at the fringes of Bhitarkanika, transformed 25 acres of degraded forest land into a dense mangrove patch with *Avicennia*, *Bruguiera*, *Rhizophora*, *Sonneratia*, *Kandelia*, and many other native mangrove species.

4.9. Urbanization

With aquaculture and agriculture expansion in Bhitarkanika and adjoining areas having significant effect on mangrove cover, urban sprawling due to exponential population growth has been an important driver of loss of mangrove cover in the state. During the survey, respondents reported low uncertainty about the very high impact of urban sprawling on mangrove harvesting (Figure 3a,b). However, during the stakeholder survey, most of the respondents stressed that urban sprawling might have a very insignificant direct impact on the existing mangroves, as no major urban center is in very close vicinity of Bhitarkanika and Mahanadi delta. The district headquarters of Kendrapara are located in a semi-urban area which is also not very close to the study area. However, the impact of urbanization on mangroves from far-off locations also cannot be ruled out, including the impacts of the influx of marine plastics, litter, and debris, which remains unexplored in the current context. Increasing tourism, collection of fuelwoods and NTFPs, and fishing do have impacts on the coastal mangroves, as they are used as a resource to fulfil the growing

demands of nearby urban sprawls. Fisheries, fast-expanding aquaculture, and brick kilns were also reported to be reasons behind the growing settlements; a recent shift towards perception of the use of mechanized boats as profitable ventures seems to be a matter of concern from the conservation and climatic change angles.

The development of ecotourism in the region in the last few years has also facilitated the establishment of new hotels, guest houses, lodges, shops, etc., which was further confirmed during the field surveys. Many local households close to Bhitarkanika have started homestay and local lodges. Thus, from the stakeholder survey, it was clear that the indirect impact of urban expansion in nearby areas is strong and hidden; however, does not specific direct impacts. It also confirms that many villages in the close vicinity of the Bhitarkanika and Mahanadi delta region are now dotted with *pukka* brick buildings, and many of the stakeholders' urban expansion due to increasing population will also bring significant changes to the local land use and will result in further opening and degradation of mangroves.

4.10. Port, Jetty, and Coastal Industrial Projects

Most of the respondents from Bhitarkanika felt that the construction of ports and jetties has comparatively less impact because it is a protected area, whereas those close to Paradip felt strongly about its impact on mangroves. Except the Dhamra port, most of the ports are beyond the boundaries of Bhitarkanika. On an average, respondents reported with very low uncertainty about the high impact of port, jetty, and coastal industrial projects on the degradation of mangroves in the region (Figure 3a,b). However, one cannot deny their significant impacts on these mangroves, as has been witnessed elsewhere, leading to the slow decline of mangrove patches [30]. There are small jetties operating from various ranges of Bhitarkanika, mostly for tourism purposes. The Paradip port has severely impacted the mangroves in the Mahanadi delta. Many stakeholders believe that the petroleum fuel used in local ships, boats, etc., as well as industrial effluents, also significantly affects the marine fauna and nearby mangroves, and spillage affects mangroves as well as the water and air environment. A few respondents also provided information about the proposed port at the Brahmani–Baitarani River, which they expect will have lasting impacts on the pristine mangrove patches of Bhitarkanika in the near future, thus noting their opposition to it. FGDs revealed the concerns of the local stakeholders that the location of the proposed port at Akhadasali and the fishing jetties at Jamboo, Kharinasli, and Talacua will further degrade mangroves in the region. During the survey, most of the stakeholders stressed that large developmental projects such as ports, jetties, and coastal industrial projects should not to be planned close to mangroves, and coastal zones should be declared as “No GO” zones.

4.11. Road and Waterways

Roadways construction was observed in the area at Paradip, where, for the purpose of broadening the stretch, mangroves had been cleared. However, within Bhitarkanika itself, no new roads or waterways were found to be under construction. Respondents reported, with low uncertainty, the moderate impact of road- and waterways on the degradation of mangroves in the region (Figure 3a,b). A few respondents reported that the construction of a dam 220 km upstream of Brahmani, at Rengali had, reduced the availability of fresh water as well as silt in the mangrove estuarine regions of Bhitarkanika. A lower influx of fresh water during non-monsoon months had caused the soil to be dry, while a reduction in silt deposition made the mangrove habitat sandier. The progressive reduction in sediment due to dam construction was largely considered to be a long-term threat to colonization of the new mangrove patches.

In general, the anthropogenic pressure on mangroves in the state was related to the provision of easy accessibility, roads, and composition of forests. However, the human habitations inside Bhitarkanika directly benefited from the easy accessibility of roads, which enabled market availability for locals to sell their forest NTFPs. At the same time, locals also expressed their concerns about the government approval for a 450 km-long coastal

highway that is expected to pass from the ecologically sensitive zone of the Odisha coast. Despite the lack of clarity on the projects proposed for realignment of the roads lying close to Bhitarkanika, the road project is still expected to be detrimental to the existing mangroves and the fragile ecosystem of the area. This was also further validated and confirmed by our field-based observation, where road construction and broadening resulted in the loss of a major chunk of forests in the coastal area. The local stakeholders also expressed the view that coastal highway construction has the potential to likely enhance flood incidences in the region. If these highways pass through different pristine mangrove patches of Bhitarkanika, the local stakeholders fear that the movement will jeopardize the mangrove ecosystem.

4.12. Sea Level Rise and Extreme Climate Events

Odisha, on east the coast, is highly vulnerable to extreme climate events that affect the coast every year, whenever a low-pressure zone is developed in Bay of Bengal. Other geological and geographical factors are also responsible for the increasing intensity and frequency of extreme events in the region. There has been massive loss and destruction of mangroves in the region in last few decades because of frequent cyclonic storms and extreme climate events, and this was also further validated and confirmed by local respondents (Das [39] also reported the same). The mangroves of Bhitarkanika have faced tremendous loss due to tropical cyclones, such as Amphan in 2020 and Fani in 2019. However, local respondents stressed that the nearby village settlements were comparatively less affected by the super cyclone in 1999 because of the dense protective cover of mangroves close to the coastline. During the survey, it was clear that there was low uncertainty in responses about the high impact of extreme climate events on the degradation of mangroves in the region (Figure 3a,b), corroborating earlier reports from Odisha (Sanathanam and Kundu, [30]; at Talasari). It has been well established that the especially rich mangroves of Odisha in the Kendrapara district have acted as a shield to reduce the intensity and impact of cyclones and tsunamis. Despite the damages during the cyclones, mangroves have the potential to recover naturally, although slowly. As per a preliminary estimation by the forest department, there was only a loss of some barbed wire fencing at the mangrove plantation area, which was found to be partially damaged. However, stakeholders perceived higher levels of risks associated with sea level rise, which might be devastating for coastal communities. However, it is also expected that this may bring more coastal area under mangroves due to enhanced soil salinity in the post-event phases. Many of the local stakeholders associated an increase in sea level with the degradation of mangrove ecosystems and many coastal villages viz. Satabhaya, Pentha, Sialia, and others facing sea erosion issues. Still, a few respondents were not aware of these impacts on the coastal areas near Bhitarkanika that were lost to rises in sea level, but were convinced that many coastal villages were displaced due to reducing livelihood opportunities and increasing extreme events. Locals who still have dense mangrove cover close to their village feel safe from the coastal disasters; however, villages that are losing their mangrove cover have shared their fear of the increasing cyclones, storms, and floods.

However, many locals who participated in the discussion were of also of the opinion that it is not only the extreme climate events, but also natural degradation, such as that caused by insect pests and other unknown reasons, which might be the cause for accelerating mangrove degradation in the region. However, these locals could not report any serious insect pest damaging the mangrove wood in their vicinity. There is also insufficient documentation on the impact of insect pests and borers on the loss of mangroves in the study area. Although diverse stakeholders understand that the impact of the rise in sea-level on mangroves, they still suggested a comprehensive scientific investigation for the purpose of understanding its broader implications for the region.

4.13. Invasive Species

Presently, a large part of Bhitarkanika and Mahanadi delta was observed to be covered by invasive and exotic halophytes viz. *Acanthus ilicifolius*, *Suaeda maritima*, *Caesalpinia crista*,

Ipomoea pes-caprae, *Heliotropium curassavicum*, *Fimbristylis ferruginea*, *Porteresiacarctata*, *Salvadora persica*, *Tamarix troupii*, *Sesuvium portulacastrum*, *Trianthema portulacastrum*, *Clerodendron inerme*, *Mimosa pudica*, *Parthenium histrophorus*, *Cleome viscosa*, and *Croton bonplandianum*. Many parts of Bhitarkanika are invaded extensively by *Suaeda maritima*, which is capable of tolerating salinity as high as 100 ppt. There was low uncertainty in responses about the high impact of exotic, invasive plants invading the mangrove patches and degrading them (Figure 3a,b). Respondents to the survey provided clear evidence of the presence of invasive species in Bhitarkanika in some areas; however, they were not very aware of the negative impacts of these species. A few local stakeholders were also unaware of the presence of invasive species in mangrove patches.

4.14. Technological Innovations

Respondents representing academia and the forest department appreciated technological innovations, such as satellite-based monitoring of coastal and mangrove forests, which has yielded strong positive effects and ensured proactive conservation of existing mangroves. RS-GIS-based monitoring has helped in the identification of degraded coastal areas that are suitable for restoring the mangroves. Furthermore, this approach helped with the early and inexpensive detection of the conversion of forest land to aquaculture or any other negative land use change [40]. The present study revealed that the regular monitoring of mangroves had tremendously helped management and resource conservation efforts in coastal areas. According to locals' views, the establishment of geo-tubes reduced coastal erosion. The use of technology for monitoring, early detection of disturbances, and restoration, as well as for regulating the fishing activities close to mangrove regions, can be approached with significant positive outcomes. However, the use of motorized boats running on diesel and kerosene is a threat to the mangrove environment, and needs to be regulated [30]. In this context, marine police (as observed in Dhamra and Paradip) patrolling can be enhanced in order to monitor and regulate the fishing activities adjacent to mangrove areas. The usage of drones or unmanned aerial vehicles for aerial surveillance can be better options supporting environmental stewardship. Sensor-based monitoring of air and water quality using excellent artificial intelligence can provide quantitative information on the health of the forests in real-time, for the purpose of developing preemptive strategies. Use of the Nature-based solutions Aiding Technologies (NAT) for eco-technological approaches to conservation can help substantially.

5. Conclusions

The present study presents a detailed synthesis and analysis of the drivers of mangrove degradation based on participatory stakeholder assessment at Bhitarkanika and Mahanadi delta on the east coast of India. Field-based participatory interaction, group discussion, and personal interviews revealed that the changes in land use, expansion of built-up area, and large construction activities have largely affected and impacted the local hydrology. The effect of industries along the coasts, ports, and jetties have enhanced water pollution, which has disturbed the water quantity and quality in the estuaries and mudflats, which, in turn, are degrading the sensitive mangrove habitats in the region. The majority of the participants reported with high certainty that the expansion of aquaculture and agriculture have tremendously enhanced the degradation of mangroves. Many participants responded, with very high certainty, that deforestation and habitat fragmentation is a significant concern for mangrove habitat degradation. This raises concerns, especially because of illegal aquaculture mafias active in the region, and despite regular interventions by the government's line department, more enforcement of policies are required to ensure that agriculture intensification and aquaculture can be regulated and controlled.

Socio-economic and demographic factors of the local population residing in the fringes of the mangrove patches exert indirect but vital pressure on coastal mangroves. Although firewood collection, fishing, poaching, and extraction of medicinal plants support local subsistence demands, population growth is changing this dependency. In Bhitarkanika,

there is controlled harvesting as it is a protected area, but this is not the case for other mangrove patches. Many participants believed that the protective measures taken by the government are actually helping to check the degradation of mangrove habitats; still, a few respondents highlighted the lack of effective policy implementation as well as the instances of violation of coastal protection rules which resulted in the low conservation outcomes, especially in Mahanadi delta. Remarkably, the majority of the participants believed that the implementation of technology such as remote sensing and GIS-based surveys will benefit ecosystem monitoring, management, and resource conservation. In addition, certain coastal conservation structural measures are believed to be helpful in reducing the impact of storm surges and cyclones on the mangroves.

There was strong evidence that the core area of Bhitarkanika experienced tremendous loss and degradation in past 3 to 4 years (2018 onwards, to date). A few areas seemed to have naturally lost mangroves, without any human interference. The present study also brings into focus the roles of increasing intensity and frequency of extreme climate events as dominant causes of the loss in mangrove cover. This further points towards the immediate need to assess plausible alternative scenarios for improving conservation efforts, in synchrony with the local and national policies aiding forest conservation. A continuous decline in freshwater supply to the rivers from upper catchment areas, as well as an irregular saline water supply in many areas due to the construction of saline embankments in Bhitarkanika, has significantly affected the growth of mangroves. Species such as *Excoecaria agallocha*, *Ceriops decandra*, *Heirietira fomes*, and *Avicennia officinalis* are now dominating the mangrove patches in the region, whereas a lower tidal influx has affected other prominent mangrove species viz. *Sonneratia caseolaris*, *Sonneratia apetala*, *Sonneratia alba*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Xylocarpous granatum*, *Lumnitzera acemose*, *Kandelia candel*, and *Aegiceras corniculatum*, which are now present only near riverbanks and are showing a continuous decline in their population. There is a need for conservation and restoration efforts to ensure that the invasion of salinity-tolerant species is reduced and native mangrove species are promoted. This can help with conserving blue carbon in these patches for various climate promises by government of India.

The discharge of the Brahmani and Baitarani rivers is reported to bring heavily concentrated effluent discharge to the Bhitarkanika estuary from steel and thermal power projects, as well as from iron and chromite mines. The local respondents were not very aware of this important concern, and thus, they also stressed the importance of seasonal studies to monitor the same. This is important for the Odisha State Pollution Control Board (OSPCB) to regularly monitor these contaminants entering the estuaries and mangroves, and to ensure strict compliance by the industries under the polluter pay principal, to ensure no further damage is caused to the stretches.

Mangroves in the country are managed like any other forest type despite their unique nature and characters, and are guided by same kind of regulatory governance, policies, and guidelines. Strictly enforced protected area (PAs) status, under the Wildlife Protection Act, 1972, ensures the enforcement of Acts and other conservation policies to conserve the area from human-induced interference and other economic, socio-political, cultural, and demographic drivers. Flexibility and recognition of location-specific factors in the process of decision-making can improve coastal mangrove conservation. The role of national legislation and policies that acknowledge the role of mangroves as a “special forested zone” can produce a specialized set of management practices which differ from those implemented with respect to other inland forests. Enforcement of existing central and state government policies should be appropriately carried out to enhance conservation benefits. Mangrove-specific training of forest department officials can help to reduce the loss of mangroves in the region. The advice of domain experts and proper implementation strategies can accommodate conservation strategies in tandem with the changing environmental conditions, and can add value to ongoing restoration schemes. While there is awareness among locals about the mangroves and their services, enhancing awareness

among immigrants will significantly aid in the planning and execution of conservation efforts by providing them a sense of ownership of the mangrove resources.

This study also clearly highlighted the stakeholders' views on avoiding developmental projects which may result in significant impact on mangroves in the long term, although these may help to contribute to the SDG14 goals. Increasing aquaculture and agriculture-related pollution load in the Baitarani and Mahanadi deltas is rightly perceived to have long-term, irreversible, and unforeseen impacts on the natural mangroves. Hence, a proper assessment, followed by alternative livelihood opportunities, needs to be strengthened, especially with respect to SDG 14b. The present study illustrates the point that mangrove restoration is related to the achievement of other SDGs, including elimination of poverty and hunger (SDGs 1 and 2), ensuring decent livelihoods and economic growth (SDG 8), positive actions against climate change impacts (SDG 13), and nullifying the biodiversity loss (SDG 15).

The present study clearly indicates a huge dependency of the local livelihoods on mangrove resources, a dependency which was enhanced in the aftermath of frequent cyclones. The major limitations of the study include the pandemic, which, during the years 2020–2021, significantly reduced frequent travel to the field site and the ability to question more local stakeholders.

Our study acknowledges the human–ecosystem inter-linkages that are crucial and necessary to reducing vulnerability for the purpose of improving ecosystem resilience. Enhanced resilience and conservation of mangroves will reduce the intensity and impacts of cyclones, thus improving environmental integrity in the region. This will require efforts to upgrading social equity as a tool for enhancing “sustainable adaptation”.

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