Causes of Deforestation and Degradation of Jhau (*Casuarina equisetifolia*) Plantation Along the Cox's Bazar-Teknaf Sea Beach in Bangladesh

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ABSTRACT: In this study, Jhau (*Casuarina equisetifolia*) plant degradation from the years 2006-2019 along the Cox's Bazar-Teknaf sea beach has been conducted by remotely sensed satellite image analysis from the Google Earth platform. According to the research, roughly 16.39% of Jhau patches were lost between 2006 and 2010, 30.59% between 2010 and 2015, and 43.38% between 2015 and 2019. Deforestation in the Jhau forest has mostly been triggered by anthropogenic and natural factors. The anthropogenic causes that have been found in the current study region include structural development, road construction, water logging, and agricultural land expansion. Coastal erosion and new channel development are natural causes. Among the natural causes, on average, 65% of deforestation has occurred due to coastal erosion processes, and less is due to anthropogenic activities from the years 2006 to 2019. Among the locations where coastal deforestation has occurred, Charpara region and the Teknaf peninsula were found to have the most notable deforestation. The Teknaf peninsula is highly unstable, and the Jhau forest has been deforested every year due to this instability. The selection of vulnerable zones in these regions is highly needed and the selection of suitable locations for future Jhau plantations is very important to these regions.

Keywords: Deforestation; Water Logging; Vulnerable; Anthropogenic; Coastal Erosion

INTRODUCTION

Jhau (*Casuarina equisetifolia*) is a fast-growing, prominent, environmentally suitable tree that is primarily found in coastal areas due to its ability to mitigate the effects of climate change and its high adaptability to a variety of environmental conditions (Kumar, 2016). It is generally grown in the tropical and subtropical regions and is native to the coastlines of Australia, Southeast Asia, Malaysia, Melanesia, Polynesia, and New Caledonia (Parrotta, 1993). The coastal zone of Bangladesh covers an area of 47,201 km^2 with a 710 km long coastline, consisting of 20% of the country's total area and 28% of its total population is living there (Islam, 2004). Bangladesh is considered one of the most vulnerable countries to the impacts of global climate change (IPCC, 2014). The coastal zone of Bangladesh is divided into three geomorphological regions, viz., western, central, and eastern (Ahmad, 2019). The eastern coastal zone, Cox's Bazar, is a flat to gentle slope with the world's longest uninterrupted (120 km) sandy sea beach (Zakaria et al., 2023). Cox's Bazars to Teknaf sandy sea beaches are increasingly vulnerable to a wide range of natural hazards such as cyclones, storm surges, sea level rise, floods, and landslides (Hossain, 2010). In order to reduce the impact of climate change, it needs to develop sustainable forests along the coastal belt of Bangladesh. Jhau trees have been proven to be suitable, climate-resilient, and promising species for the coastal sandy beaches of the open coast and off-shore islands (Hossain et al., 2008; Hossain, 2010). It has the potential to decrease tropical cyclone wind speed, establish a resilient saline environment, and adapt to heavy rainfall and extreme temperatures (Kumar, 2016). In Bangladesh, this species has been planted in coastal areas for decades and near beaches for the stabilization of sand dunes, reduction of coastal erosions, and other natural hazards. Established *C. equisetifolia* plantations in the sandy beaches are able to halt and reduce these climate change induced impacts and also provide benefits to the local livelihoods through aesthetic views to tourists, litter, and thinned forest. The government of Bangladesh initiated the Jhau plantation along the Cox's Bazar Sea Beach in the years 1972–73. The main reasons for this plantation were to stabilize the sandy

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beaches and to facilitate the development of the coastal greenbelt. But nowadays, Jhau plantation areas have been deforested and degraded due to many natural and anthropogenic causes. Among the natural and anthropogenic causes of coastal erosion, new channel development and road construction are the most destructive. The main objectives of this study are (i) to measure the amount of degradation of Jhau plantation (ii) and the causes of degradation.

LITERATURE REVIEW

Numerous studies have explored various aspects of *Casuarina* trees, including their development and livelihood implications (Kumar et al., 2014; Zhong et al., 2014), interactions, nutrient dynamics (Mohan and Manokaran, 2014; Saravanan and Rajendran, 2014), biotechnologies, socio-economic and industrial applications, responses to climate change, and their crucial role in safeguarding coastal communities (Pinyopusarerk and Nicodemus, 2014; Devaraj, 2014; Uma et al., 2014). Kumar et al. (2014) studied the improvement of the *Casuarina* for the security of livehood in India and found it is crucial for Indian farmers, meeting industrial, environmental, and livelihood needs. It's integrated into farmlands, providing fuel, poles, and pulpwood while protecting habitations and enriching soil. It offers a stable income source for farmers facing challenges with traditional crops, creating jobs for landless laborers. Zhong et al. (2014) studied with *Casuarinas*, which have been crucial for coastal ecosystems and local lives in southern China for over a century, are now under threat because of the infrastructure development and economic progress, the planted area has decreased from one million hectares in the late 1970s to 300,000 hectares today. Current restrictions include decreasing production, impaired ecological function, and overexploitation. Fish and shrimp farms, mining operations, and tourist resorts all cause damage to *Casuarina* plantations, underscoring the persistent tension between coastal environment protection and economic development. Devaraj, (2014) evaluated the protective role of *Casuarina* during cyclone. *Casuarina* shelterbelt plantations reduced damage from tsunami waves and cyclones. Individual trees, along with various species, offered life-saving shelter during tidal waves. New shelterbelt plantations, featuring *Casuarina* and multipurpose trees, were established as coastal bio-walls, providing protection and resources like fuel wood, minor timber, and oil seeds. Hossain et al. (2016) studied about growth and development of *C. equisetifolia* in the open sandy sea coasts of Cox's Bazar, Bangladesh. This study evaluates *Casuarina* plantations' survival, growth, and development in stabilizing sandy beaches and improving the environment. Bangladesh is a pioneer in coastal afforestation programs that limit damage from cyclones, tidal surges, and tsunami. Jhau (*C. equisetifolia*) is the sole suitable, climate-resilient, and promising species in coastal sandy beaches of the open coast and offshore islands. The longest uninterrupted beach (120 km) in the world, Cox's Bazar, is damaged by cyclones and tidal surges. A green-belt of *C. equisetifolia* is the best way to mitigate natural disaster losses. In 1997-2012, 415 ha of *C. equisetifolia* were planted along the seashore in three forest areas. Establishing plantations is encouraged to develop coastal green-belts and boost coastal community resilience. Chowdhury et al. (2007) conducted a study on the Effects of height on physical properties of wood of jhau (*C. equisetifolia*). *C. equisetifolia* is a useful low-maintenance shelterbelt shrub that is often utilized for windshields and coastal stabilizing. It is commonly planted as a windbreak in sandy soil due to its root suckering habit, large foliage that slows wind velocity, and capacity to recover soil under high salinity conditions (Torrey, 1976). Normally, the majority of the sand removed by storms from beaches in coastal locations builds up offshore and is transported back to the beach by waves. Sand is kept in place on beaches by *Casuarina* roots. The idea behind wind threshold velocity reduction by the tree-belt is how moving sand dunes are stabilized. More durable than mechanical mulching and chemical fixation methods, plant species can stabilize sand dunes (FAO, 1989; De Zoysa, 2008). The present study deals with the natural and anthropogenic causes of Jhau (*Casuarina*) plantation degradations using remote sensing techniques, the importance of coastal protections, and future recommendations.

MATERIALS AND METHODS

Study Area

The study was conducted from Cox's Bazar (Charpara) to Teknaf (Dakhinpara) beach, which is located in the south-eastern coast of Bangladesh, extending between 20º 45' 05"N- 21º 27' 50"N and 91º56' 50.47"E - 92º 20' 46.2"E (Fig. 1). The study area covers an area of

approximately 200 square kilometer landmass. It is popular mostly for its long natural sandy beach which consists of loose sand. The coastline consists of sand dunes which are preferable for Jhau plantation because the Jhau tree thrives best on loose sandy soils (Kumar, 2016).

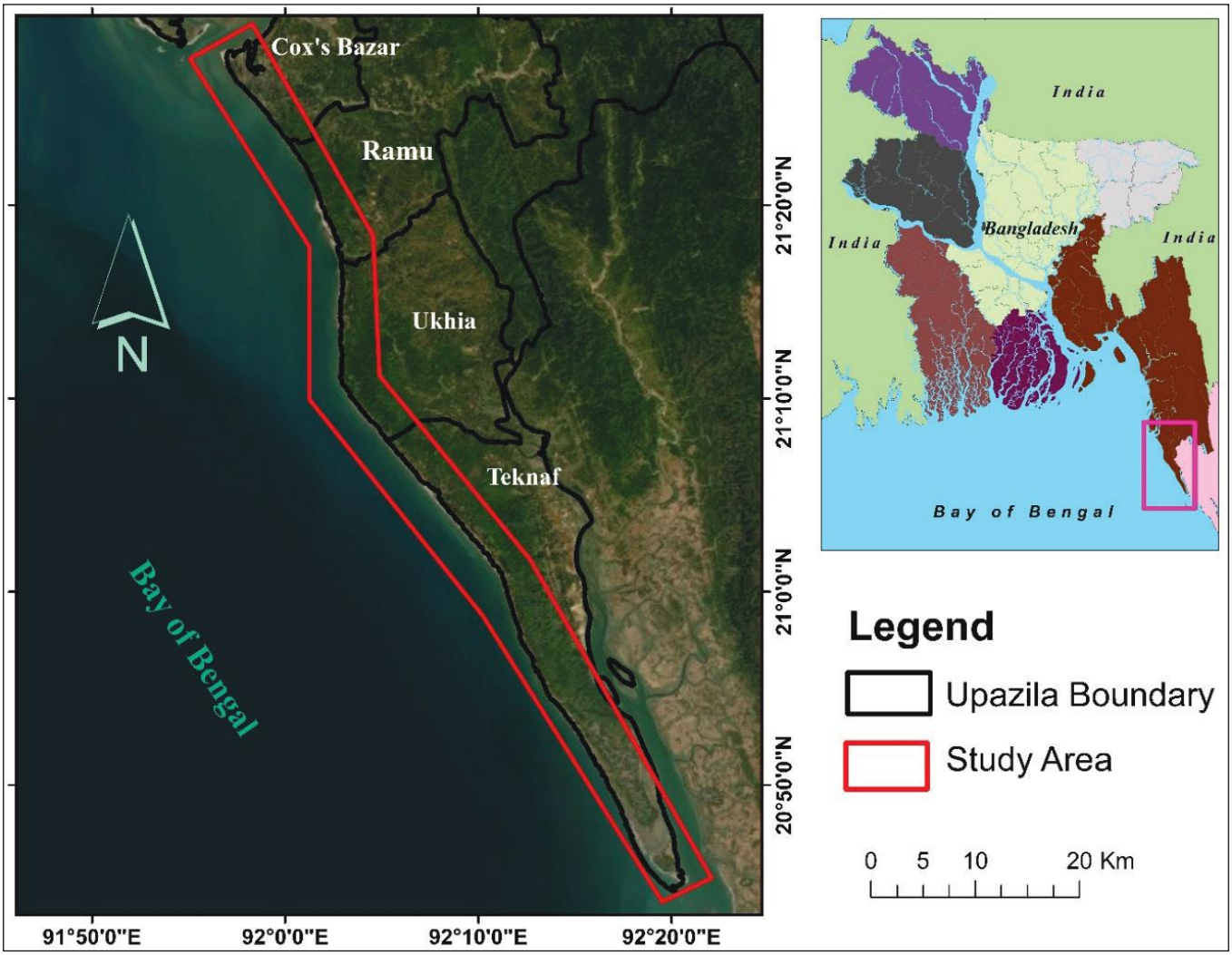

Figure 1: Map Showing the Location of the Study Area from Cox's Bazar to Teknaf

Sources of Data

The data was extracted from the Google Earth platform over the period 2006, 2010, 2015, and 2019. Such high-resolution satellite data is suitable for time series analysis of small areas such as forest cover. The area of the Jhau patches along the coast was demarcated using visual interpretation. With manual digitization, data was collected in KML (Keyhole markup language) format for displaying geographic data in the Google Earth browser. For time series analysis, data were taken out from different years in several year intervals.

Satellite Image Processing

At first, the data were taken from Google earth during the years 2006, 2010, 2015, and 2019. The high-resolution satellite image (0.5m resolution) available in Google Earth in KML format was converted to vector files. After topology testing, digitized patches were projected from WGS (World Geodetic System) to BTM (Bangladesh Transverse Mercator) Coordinate System. Finally, the change analysis of Jhau patches area was performed using GIS overlay analysis (Fig. 2). The hectares (ha) unit was used for measuring the Jhau forest area.

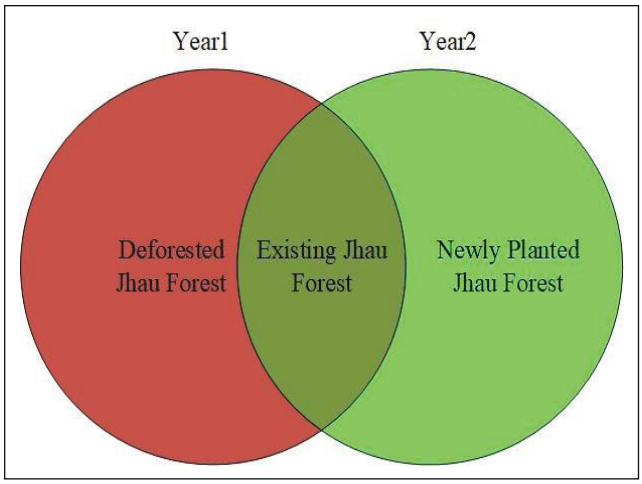

Figure 2: Overlay Analysis to Classify Total Forest

Shoreline Change Detection

Shoreline change (erosion and accretion) were detected taking the marine drive as reference line applying for the following years. Shoreline erosions and accretions were determined using GIS geo-processing tools. This was determined mainly for the measurement of deforested Jhau plantation cover due to coastal erosion.

Cause Factor Analysis

Causes of the Jhau patch degradation was identified by visual interpretation. The causes were divided into two- i) Natural Causes ii) Anthropogenic Causes. Coastal erosion due to wave actions and development of the channels were included in natural factors. On the other hand, structural development, road construction, agricultural land expansion, and water logging are included in the anthropogenic causes of the Jhau forest deforestation. Existing Jhau plantation coverage has been categorized into four according to the Jhau patch health conditions. The categories are i) Degraded, ii) Healthy, iii) Sparse Healthy, and iv) New Plantation.

i) **Degraded area** does not imply a reduction in forest area, but rather a decrease in forest quality.

ii) **A healthy area** does not face any kind of natural and anthropogenic pressure.

iii) **Sparse health** faces somewhat pressure from natural or anthropogenic**.**

iv) **New Plantation** means newly planted Jhau area.

Software and Tools

The study was performed using ArcGIS 10.3 software. ArcGIS is a powerful software that deals with vector and raster data sets that have been used extensively for geospatial analysis. The basic ArcGIS geospatial tools were used to calculate the area of the Jhau forest and to identify the causes of deforestation in Jhau forest.

RESULTS

Jhau Plantation Distribution

Jhau plantations patches have been delineated through different time series satellite image analysis from 2006 to 2019 (Fig. 3). The Jhau plantation area of 2006 was compared with 2010, 2010 was compared with 2015, and 2015 was compared with 2019. Three classes such as “Deforested Jhau Plantation Area”, “Existing Jhau Plantation Area” and “New Jhau Plantation Area” were identified from the change analysis of land use of the study area. The area of the Jhau plantation observed in 2006 but not observed in 2010, observed in 2010 but not in 2015, and observed in 2015 but not in 2019 was identified as “Deforested Jhau Plantation Area”. The “Existing Jhau Plantation Area” is those areas which was observed in both set of years and the area of Jhau plantation found in 2010 but was not observed in 2006, found in 2015 but was not in 2010, and found in 2019 but was not in 2015 is identified as “New Jhau Plantation Area”. From the satellite image analysis, the total Jhau plantations cover represents about 241 ha, 303 ha, 360 ha, and 300 ha in the years of 2006, 2010, 2015 and 2019, respectively.

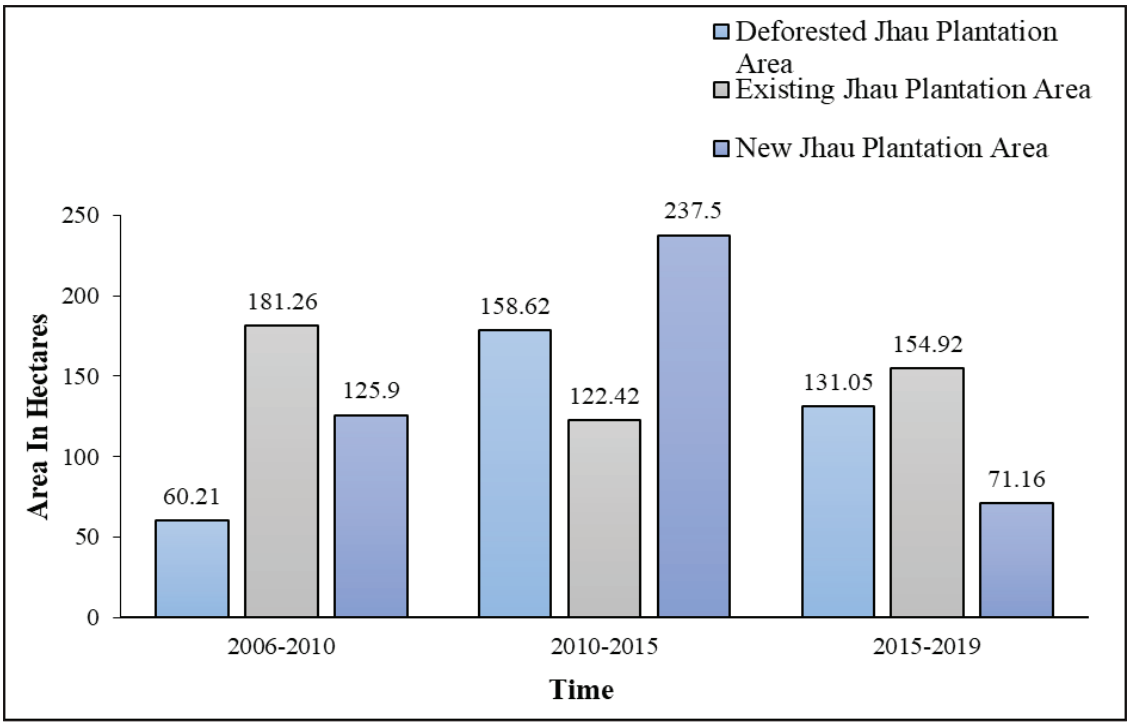

Figure 3: Time Series Analysis of Jhau Plantation Area from 2006-2019

Status of the Existing Jhau Forest

Among the four categories of existing Jhau forest coverage, it can be observed that degraded Jhau forest coverage was decreasing and newly planted forest coverage was increasing. Degraded Jhau forest area coverage was about 15.8% between 2006 and 2010, about 9.09% between 2010 and 2015, about 8.77% between 2015 and 2019, and 15.83% between 2006 and 2019 respectively. Healthy forest coverage was about 21.9% between the years of 2006 and 2010, after which it was somewhat decreased to 7.30% between the years of 2010 and 2015, and again it reached up to 34.91% between the years of 2015 and 2019 and 21.86% between the years of 2006 and 2019 (Table 1).

Table 1: Area Statistics of Existing Jhau Forest

Status of Existing Jhau Forest	2006-2010		2010-2015		2015-2019		2006-2019	
	Area in Ha	**Area (%)**	**Area in Ha**	**Area (%)**	**Area in Ha**	**Area (%)**	**Area in Ha**	**Area (%)**
Newly Planted	125.9	41	237.51	65.99	71.16	31.48	156.72	40.99
Degraded	48.63	15.8	32.70	9.09	19.82	8.77	60.54	15.83
Healthy	67.16	21.9	26.27	7.30	78.92	34.91	83.60	21.86
Sparse Healthy	65.47	21.3	63.44	17.63	56.18	24.85	81.50	21.31
Total	307.2	100	359.92	100	226.08	100	382.36	100

After analyzing the Jhau forest coverage from the year of 2006 to 2019 it can be noticed that much area has been deforested due to some natural and anthropogenic causes. Among the areas that have been studied in this research, the Jhau patches deforestation near the Charpara was much more significant (Fig. 4). The Jhau patches conditions is decreasing day by day.

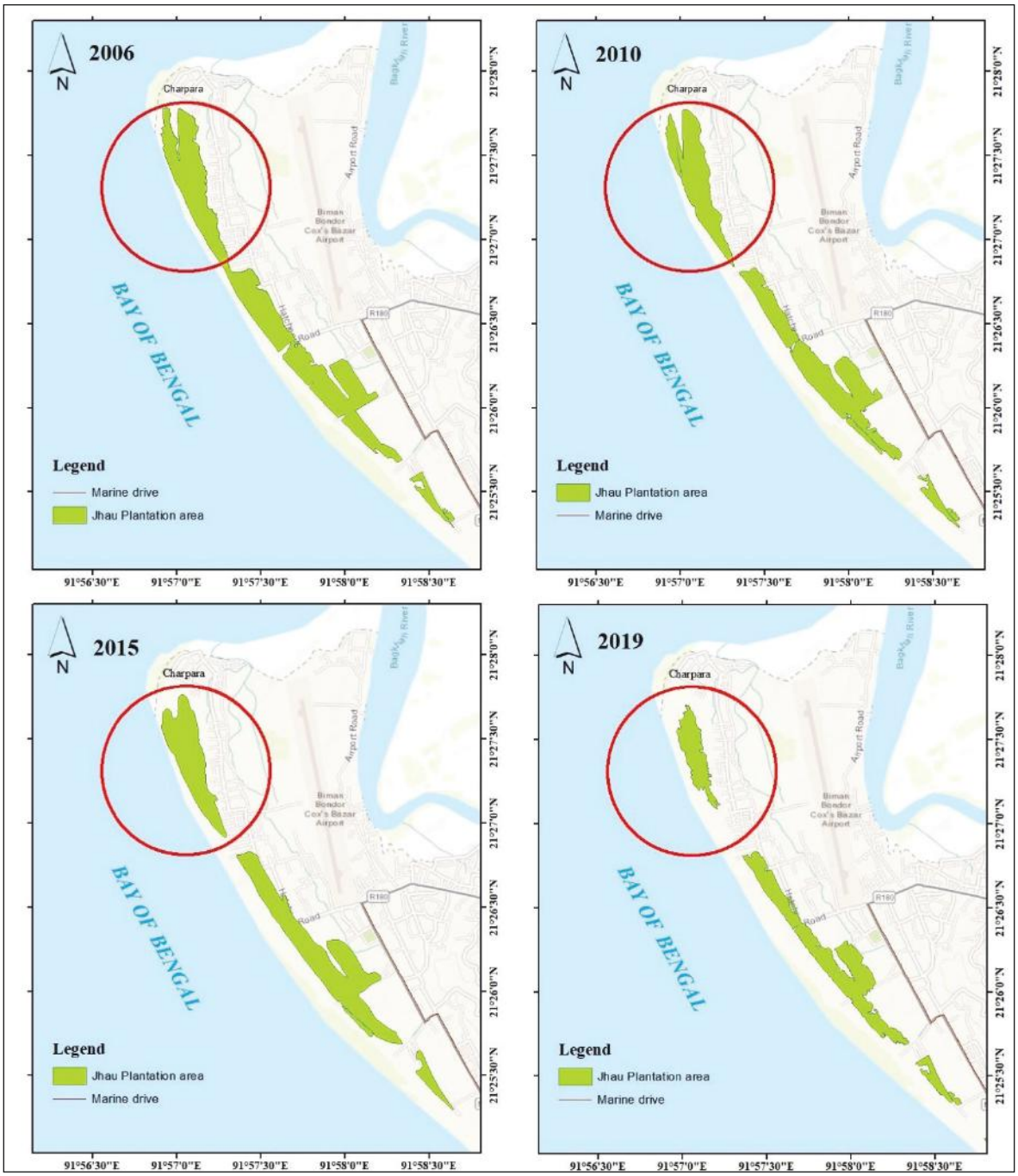

Figure 4: Deforestation of Jhau Plantation Area Near Cox's Bazar City Within the Year 2006 to 2019

Factors Causing Deforestation of Jhau Plantation

There are numerous causes behind the degradation and deforestation of Jhau plantation along the coastline of the study area. The Jhau Plantations of the study area have been degrading and deforested due to two major factors, natural and anthropogenic Causes.

Change analysis revealed that about 60 hectares of Jhau plantation area were deforested due to natural and anthropogenic over the period 2006 to 2010; about 178.63 hectares of Jhau plantation area were deforested due to natural and anthropogenic causes over the period 2010 to 2015; about 131 hectares of Jhau plantation area were deforested due to natural and anthropogenic causes over the period 2015 to 2019

Natural Causes

There exist many natural causes of Jhau forest deforestation in the present study area (Table 2). Two main causes are coastal erosion due to wave actions and another is channelization due to upstream water flow. During the year 2010-2015 around 72.74% Jhau forest were deforested due to coastal erosion which was the largest from 2006-2019. Least amount of Jhau forest were deforested due to new channel development about 27.26% during 2010-2015.

Table 2: Area Statistics of Deforested Jhau Forest Due to Natural Causes

Natural Causes	2006-2010		2010-2015		2015-2019		2006-2019	
	Area in Ha	**Area (%)**	**Area in Ha**	**Area (%)**	**Area in Ha**	**Area (%)**	**Area in Ha**	**Area (%)**
Coastal Erosion	20.72	52.84	60.30	72.74	44.32	69.66	41.78	67.49
Channelization	18.49	47.16	22.60	27.26	19.30	30.34	20.13	32.51
Total	39.21	100	82.90	100	63.62	100	61.91	100

Coastal Erosion

Coastal erosion is the main cause of deforestation of Jhau Forest. The rainfall runoff and stream flows from upland areas fall in the sea through the foreshore area. As the sandy soil has coarse sand particles and having weak bondage between the particles, and therefore, runoff force easily changes the drainage path and wash away the forest floor. About 87% of the deforestation caused for channelization due to water runoff which has been considered as the main cause of afforestation. Around 53% of deforestation between 2006 and 2010, 73% of deforestation between 2010 and 2015 and 69.66% between the year 2015 and 2019, and 67.49% between 2006 and 2019 has occurred due to coastal erosions. A part of the Jhau plantation near Laboni Beach was uprooted due to beach erosions during lunar perigee last year. Kinetic energy of sea waves attack during the perigee washed away the forest floor while returning the seawater (Mitra, 2014). Cyclonic storms in different times caused degradation of Jhau plantations specially, during the Cyclone Mora in the year 2017 (BMD, 2017). But this evidence is not very significant immediately at the time of the storm by visual observation. In most of the cases, a number of Jhau trees have been twisted or broken branches in different places of Jhau forest patches was observed (BMD, 2017). So, it is not possible to indicate the location of degradations of Jhau plantation. Wind speed and direction are important phenomena that affect the Jhau forest plantation in the coastal region. The Jhau trees are vulnerable to tidal surges and high winds. Wave has the most predominant effect on plantations in the coast. Wind acts as the main force in wave generation. The wave has complex characteristics on coastal area. Though complexity of the most coastal problems varies widely with location, time, and design parameters, the proper solution of any specific problem requires a systematic and thorough study (SPM, 1984).

Channelization

Channel development is one of the causes of Jhau forest deforestation. Forty seven percent deforestation between 2006 and 2010, 27.26% deforestation between 2010 and 2015, and 30.34% deforestation had occurred between 2015 and 2019, and 32.51% between 2006 and 2019 due to new channel development. The areas that were deforested due to new channel development are Baharchara, Sabrang, Jalia palong etc.

Anthropogenic Causes

There also exist many anthropogenic causes of Jhau forest deforestation in the present study area (Table 3). They are described in the following subsections.

Agricultural Land Expansion

Agricultural land expansion by local people is another anthropogenic cause of Jhau forest deforestation. 24.23% deforestation between 2006 and 2010 and 15.17% of total jhau forest deforestation between 2006 and 2019 has occurred due to agricultural expansions. The area is deforested due to agricultural land expansion are Jalia palong and Baharcchara.

Table 3: Anthropogenic Causes of Jhau Forest Deforestation Were Calculated by Visually Observing Time Series Satellite Data from Google Earth of the Jhau Plantation Area

Anthropogenic Causes	2006-2010		2010-2015		2015-2019		2006-2019	
	Area in Ha	Area (%)	Area in Ha	Area (%)	Area in Ha	Area (%)	Area in Ha	Area (%)
Agricultural Land Expansion	1.923	24.23	19.27	38.34	10.86	16.11%	12.05	15.17
Structural Development	0.972	12.24	1.17	2.33	22.32	33.10%	23.32	29.37
Water Logging	3.065	38.62	6.91	13.75	8.23	12.21%	17.22	21.68
Road Construction	0.61	7.684	22.90	45.57	26.02	38.59%	26.82	33.77
Illegal Forest Cutting	1.367	17.22	-	-	-	-	-	-
Total	7.936	100	50.25	100	67.43	100	79.41	100

Structural Development

Lands surrounding the Cox's Bazar Sea Beach are highly valued for construction of hotel, motel, shrimp hatcheries, and other infrastructural developments. As a result, some portions of Jhau plantation at Char Para, Samiteepara, Cox's Bazar Paurashava and Jhilwanja area have been deforested during last few decades.

Water Logging

Waterlogging is the main suspected cause which was induced due to creation of drainage obstacle for civil construction of Bangladesh Army Rest House. Previously, an amount of rainfall runoff used to pass in sea through this forest passage which is currently blocked by the approach road and foundation of the Army Rest House causing 7-8 months' water logging condition at the nearby forested land. Wastewater from nearer hotels mixed with rainfall runoff has been creating stagnant water at the forest floor during monsoon. The hotel used different chemicals for laundry and floor cleaning which may have caused catastrophic death of many Jhau trees at that location. At Baharchara, Lengurbari and near Teknaf R.F. mouza, waterlogging condition has been created due to change of stream and rainfall runoff channels and also developed dykes at braided areas.

Road Construction

Jalia palong, Baharcchara, Lengurbil, Teknaf and Sabrang areas are deforested due to construction of road. It has been estimated that 7.684% deforestation between 2006 and 2010 and 33.77% area between 2006 and 2019 has been deforested due to road construction.

Illegal Forest Cutting

As per local inhabitants, Jhau trees have been logged now and then at different Jhau Forest patches at Charpara and Samitipara under Khurushkul mouza. In addition to this, the local people at Inani Forest Range also have cut down the cyclone-affected trees. Overharvesting of Jhau tree's leaves and branches for cattle fodder are the cause behind the denude canopy at Charpara area.

Jhau Forest Replantation Plan

Vulnerable Zone Selection

Vulnerable Zone Selection refers to the process of identifying and selecting the areas that are most susceptible to hazards. The vulnerable zone selection process typically involves a combination of vulnerability assessments and risk analysis. Vulnerability assessments involve identifying and evaluating vulnerabilities in the areas. Risk analysis involves evaluating the likelihood of a hazard occurring and the potential impact of that effect on the environment. A vulnerable zone has been selected after the visual analysis of satellite data from the period of 2006–2019. Those areas, which have suffered extensive erosion, have been considered as vulnerable zones for future Jhau plantation. The present study has identified some vulnerable zones (Fig. 5) that are actually not suitable for future Jhau plantation program although future research should be required as well as more in-situ data should be collected to identify vulnerable zones for Jhau plantations.

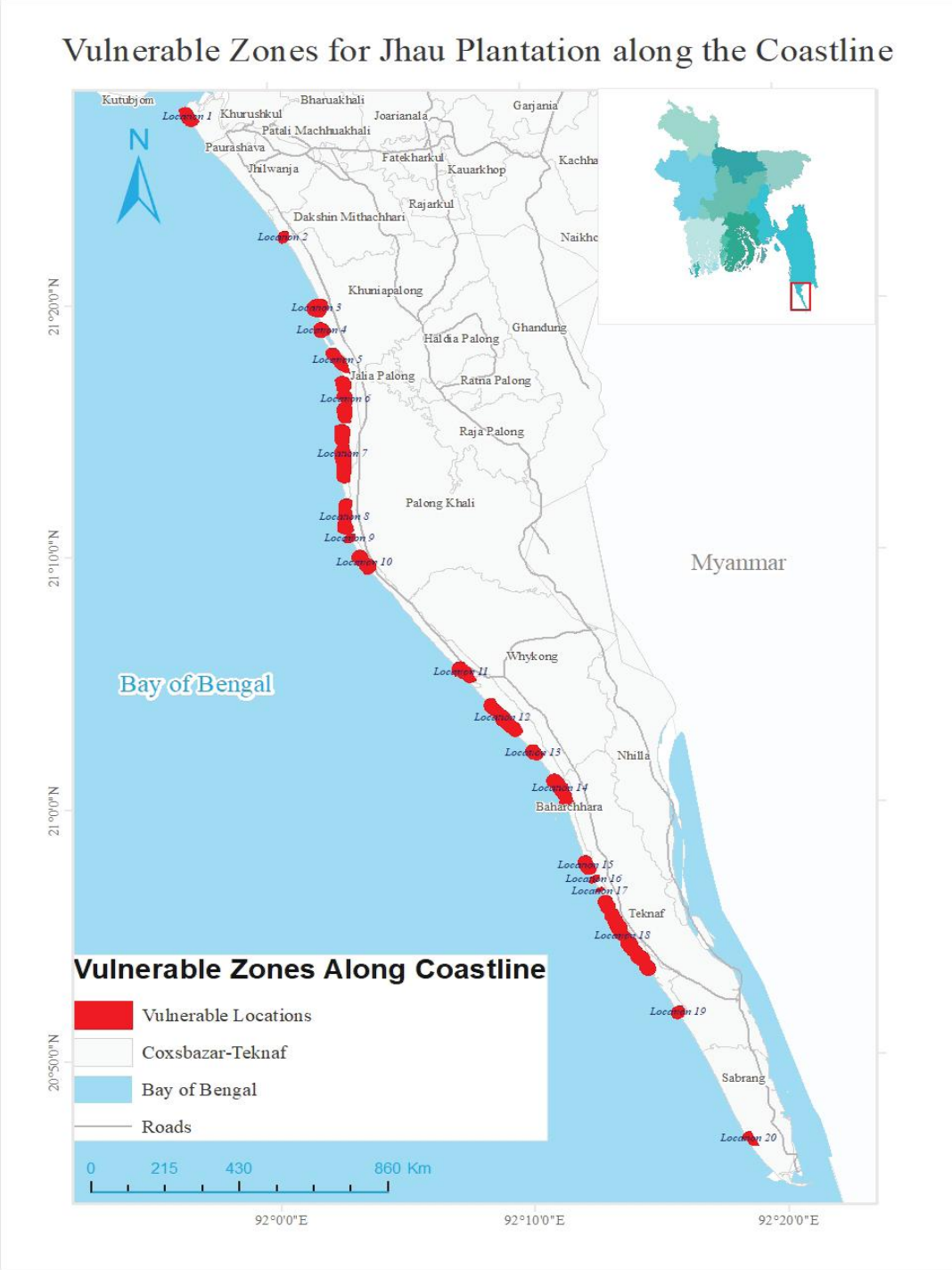

Figure 5: Vulnerable Zone Selection Along the Coastline

Suitable Areas Identification

Suitable area identification for Jhau plantation involves identifying areas that are well-suited for the growth and development of Jhau trees. To identify suitable areas for Jhau plantation, several factors should be considered, including: soil type, climate, suitability of the location, etc. The present study identified some location where Jhau forest conditions were healthy and free from any kinds of natural hazards like erosions, channelizations, and anthropogenic intervention through visual

observations (Fig. 6). Overall, suitable areas for Jhau plantations are those that have sandy soils, hot and dry climates, high salinity, access to water sources, and sufficient land availability. By identifying and planting Jhau trees in suitable areas, coastal protection and reforestation efforts can be enhanced, while also providing additional environmental and economic benefits.

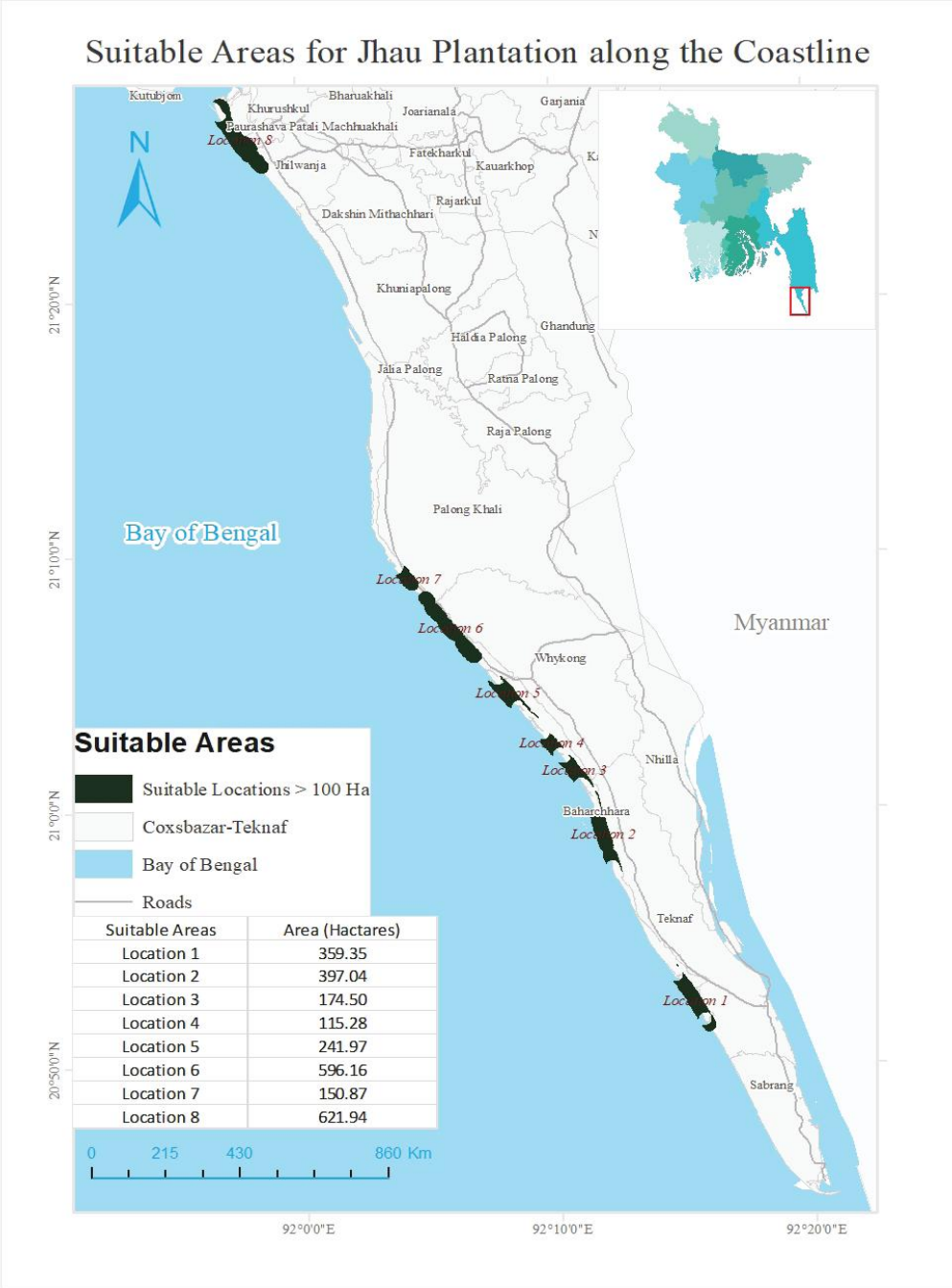

Figure 6: Suitable Area Selection Along the Coastline

Future Plantation Recommendations

Jhau is the only successor tree in the coastal sand dunes of Bangladesh. Dunes undoubtedly are one of the most well-known features of sandy beaches. Dunes can help protect coastal property from the destructive forces of storm surges, but human activities have had severe

impacts on coastal sand dunes as well. Moreover, sand dunes use to act as natural embankments to protect against tidal surges. When Jhau trees gradually grow on any sand dune, it stops the expansion of the dune and make it vulnerable due to erosion.

Followings are some of the recommendations in order to prevent the degradation of Jhau forest:

- Jhau plantation should be taken in places with sufficient sediment sources in addition to the present plantation program. Locations where no source of sediment is present nearby would eventually lead to an insufficiency of sediment input. As sediment supply is important to balance the longshore sediment transport, locations with no upstream supply will be susceptible to severe erosion.
- The off-take dynamics of adjacent rivers/khals should be carefully taken into consideration. Because the gradual progression of the off-take mouth into the sea restricts the growth of the plantation. Hence, Jhau plantation can be carried out considering some distance away from the nearby river/khal off-take.
- The portions of very gentle slope sand beach where width is narrow and having sea turtle nesting evidence shall be avoided for the Jhau plantations for fostering their undisturbed breeding.
- Cox's Bazar-Teknaf Beach is the most dynamic beach in terms of coastal morphology and the coastline has been changed frequently over times due to morphological changes and uncertain tidal surges during cyclones. Hence, it is difficult to demarcate any location which is stable for the Jhau plantations. However, under this study, assessing the time series satellite image analysis and considering sediment sources, Figure 4.1 presents the erosion prone sites that are vulnerable to Jhau plantation. The red marked portions have minimum upstream source of sediment supply and as a result, the balance between sediment input and output gets disrupted causing the retreat of the coastline towards the land. So, these portions of beach are considered most vulnerable sites and must be avoided for selecting the future potential locations of Jhau plantation. Except these most vulnerable sites, other portion of the sea beach is less vulnerable as there have been adequate sediment sources and future plantations can be implemented in those locations.
- Besides coastal morphological analysis, detailed plant pathological, physiochemical, and soil physico-chemical analysis are to be carried out for a better understanding of the causes of degradation of Jhau plantation.

CONCLUSIONS

Jhau plantation along the Sea Beach aims to protect coastal populations and their resources and to prevent the coastline from erosion. Accordingly, this tree has been selected which found successfully adapted in sandy beaches and perform its role to minimize wind actions during natural calamities. From the study, it reveals that coastal erosion is the prime cause of deforestation of Jhau plantations along the Cox's Bazar-Teknaf Sea beaches. Waterlogging, wave actions, and infrastructural developments also have been triggered partially in this case. However, the severe death of Jhau plantation at the location of Laboni Sea Beach was occurred due to water logging condition created by the encroachment of drainage path during infrastructural development activities in that area. Except some of the tiny unhealthy plantation patches, most of the patches are in healthy condition based on physical observations which revealed that the Jhau plantations within the study area are not degraded but it has been deforested.

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