

ASSESSING CHANGES IN ECOSYSTEM SERVICE PROVISION IN THE BIA-TANO FOREST RESERVE FOR SUSTAINED CARBON MITIGATION AND NON-TIMBER FOREST PRODUCTS PROVISION

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Assessing changes in ecosystem service provision in the Bia-Tano forest reserve for sustained carbon mitigation and non-timber forest products provision

The Millennium Ecosystem defined ecosystem services as “the benefits people derive from ecosystems”. Besides provisioning services or goods like food, wood and other raw materials, plants, animals, fungi, and micro-organisms, ecosystem services provide essential regulating services such as pollination of crops, prevention of soil erosion, water purification and a vast array of cultural services, like recreation and a sense of place. Forest ecosystems also provide numerous services, benefits, and goods that benefit human wellbeing and mitigate carbon emissions. In many developing countries, forest ecosystem services serve as a vital means of providing food, reducing poverty and creating employment. This study uses GIS and satellite images to assess the changes in forest ecosystem services in the Bia-Tano forest reserve from 1990 to 2020. The purpose was to ascertain how human interventions and activities have contributed to the decrease in the service provision of Bia-Tano forest reserve’s ecosystem services. We argue that LULC (Land Use Land Cover) changes affect the potential of the forest reserve to provide numerous products and services to benefit fringe communities and carbon mitigation. In all two sets of Classified Land Use Land Cover Images (CLULCI) co-vering the years 1990, 2000, 2011 and 2020 for the Bia-Tano forest reserve and surrounding areas and CLULCI for the actual forest reserve using the same years. The findings further revealed that the fringe community’s livelihood activities have contributed to the decrease in the quality and quantity of the forest reserve over the past 30 years, with closed forest decline, while built-up areas, barren areas, planted/cultivated areas and open forest continue to increase. Furthermore, the excessive exploitation of natural resources from the reserve, coupled with illegal encroachment, and frequent access to timber and fuelwood, threaten the conservation of the reserve’s biodiversity and sustainability of ecosystem services. The findings show inadequate forest governance mechanisms to conserve and protect the reserve from further degradation and depletion of the reserve’s resources. The livelihoods of fringe communities depend on the sale and consumption of NTFPs (Non-Timber Forest Products) from the reserve. Hence the changes in the forest reserves cover vegetation will reduce the NTFPs collected/harvested by fringe communities to support their livelihoods and wellbeing. Therefore, there is the need to tighten and strengthen the governance processes and mechanisms through participatory governance and enforcement of the rules and regulations to sustainably conserve and protect the reserve from deforestation and forest degradation.

Key words: Carbon mitigation, forest ecosystem services, service provision, non-timber forests products, Bia-Tano forest reserve, Ghana

INTRODUCTION

The Millennium Ecosystem Assessment (2005) defined ecosystem services as “the benefits people derive from ecosystems”; hence human wellbeing is highly dependent on well-functioning ecosystems (Burkhard and Maes 2017). The ecosystem products or benefits that users consume and experience are ones that people attach economic, social and personal values to (Maes et al. 2013). Besides provisioning services or goods like food, wood and other raw materials, plants, animals, fungi, and micro-organisms, ecosystem services provide essential regulating services such as pollination of crops, prevention of soil erosion and water purification, and a vast array of cultural services, like recreation and a sense of place. Encyclopedia Britannica (Johnston 2022) states that ecosystem services mean outputs, conditions, or processes of natural systems that directly or indirectly benefit humans or enhance social welfare. The concept of ecosystem services has provided the opportunity to show the linkage between ecosystems, their services and human wellbeing (Haines-Young and Potchin 2009). Ecosystem services can benefit people in many ways, directly or as inputs to producing other goods and services (Young et al. 2016). For example, the pollination of crops provided by bees and other organisms contributes to food production and is thus considered an ecosystem service. Another example is the attenuation of flooding in residential areas provided by riparian buffers and wetlands. Ecosystem services consist of functions and processes of ecosystems that yield benefits to humans, directly or indirectly, regardless of whether humans see them as benefits (Costanza et al. 2017). In order to scientifically classify, assess, account and value global ecosystem services, the European Environment Agency, through the Common International Classification of Ecosystem Services (CICES), divided the ecosystem services into three sections, namely: provisioning, regulating and maintenance and cultural services (CICES 2013). However, the capacity of an ecosystem depends on its ability to sustainably generate specific ecosystem services (Maes et al. 2018). The forest provides various services, benefits, products and goods to benefit human wellbeing and carbon mitigation. Tropical forests constitute the most productive terrestrial ecosystems that maintain and support life forms and vast global biodiversity (Yaduv et al. 2018). Although tropical forests cover only 12% of the global landmass, they provide 40% of the net primary production (NPP) and 25% of biomass carbon globally (Townsend et al. 2011). Forest ecosystems can sequester large amounts of carbon to avert greenhouse gases (GHGs) emissions to reduce global warming and climate change (DeFries and Nagendra 2017). In developing countries, tropical forests reduce poverty, ensure food security and achieve human wellbeing and progress (Bukoski et al. 2018). Generally, the forest provides a habitat for diverse plants and animal species (Yaduv et al. 2018). In particular, the forest provisioning ecosystem services provide the non-timber forest products (NTFPs) that sustain the lives of forest fringe communities in most developing countries. Globally, the contributions of NTFPs which benefit rural and urban livelihoods are widely recognized (Mahonya et al. 2019). For example, a study conducted in the Kededarnath valley, Garhwal in India, showed the important contribution of non-timber forest products to rural households (Dhyani and Dhyani 2016). Even in developed areas such as the eastern United States, people gather special forest products (SFPs) for consumption and sale to benefit their lives and livelihoods (Emery et al. 2003). Generally, the collection and harvesting of NTFPs significantly contribute to many households in the United States and boost their local economies (Greenfield and

Davis 2003 and Frey et al. 2020). Thus, the NTFPs harvested from the United States forests are numerous, including plant materials and fungi, which are collected for personal enjoyment, commercial benefits, and spiritual and cultural importance (Chamberlain et al. 2018). The collection of NTFPs such as forest honey, mushrooms, or berries serve as additional household income and consumption in many parts of Europe (Kilchling et al. 2009). According to Shrestha et al. (2017) while the better-off households have access to forest resources that provide higher income, such as timber, the poorest households only rely on low forest resources such as NTFPs. A quantitative review and analysis of non-wood forest products (NWFPs) in Europe showed that mushrooms, resin, cork and other forest fruits were the common ones being collected and harvested for consumption and sale purposes (Sacchelli et al. 2021). In South Africa, over 85% of households benefit economically and domestically from NTFPs such as fuelwood, wild spinaches, wooden utensils, edible fruits, grass hand-brushes, and twig hand-brushes (Shackleton and Shackleton 2004). In Ghana, NTFPs play a major role and contribution to the lives and livelihoods, especially in rural and peri-urban areas. The NTFPs serve as an important source of household food security and health and nutritional requirements (Ahenkan and Boon 2011). However, land use factors and human activities destroy natural habitats through deforestation and forest degradation, bushfires, poor farming practices, increased rural populations, and poor forest governance policies continue to hinder the sustainable provision of NTFPs. Similarly, the unsustainable collection and harvesting of NTFPs could lead to the degradation and extinction of important forest resources and species.

The forest cultural services provide (recreational, religious, spiritual, aesthetics and nature studies) regulating services (carbon storage and sequestration, flood and erosion control and water/air quality) and supporting services (nutrient cycling, soil formation, oxygen production, and primary production). Globally, the supportive services are the bedrock upon which the provisioning, regulating and cultural services underpin (Costanza et al. 2017 and Melnykovich et al. 2018). However, despite the numerous benefits forests provide, global environmental challenges, including biodiversity loss, changes in the climate system and forest ecosystem degradation, affect ecosystem services (Barnaud et al. 2018). Coupled with land-use changes, deforestation and forest degradation account for 12% of global GHG emissions (Aggarwal 2020). Moreover, tropical deforestation has been causing higher global carbon emissions (Locatelli 2016), leading to the accumulation of CO₂ between land and the atmosphere (Pan et al. 2011). In addition, tropical forests face various anthropogenic disturbances such as logging, fire and agricultural sources of deforestation and forest degradation (Abalo et al. 2017 and Owusu and Essandoh-Yeddu 2018).

Deforestation is the biggest direct anthropogenic driver that causes forest ES degradation and loss (Sukhdev et al. 2008); according to the Food and Agriculture Organization (FAO), between 1990 to 2020, nearly 420 million ha of forests have been converted into other forms of land uses (FAO and UNEP 2020). Between 2015 and 2020, the global forests experienced an annual deforestation rate of 10 million ha through deforestation, forest degradation and agriculture expansion, driving global biodiversity loss (FAO and UNEP 2020). Deforestation causes forest cover changes by converting forests into other land use types (Nasi et al. 2011). Similarly, Land Use Land Cover Change and Forestry (LULCCF), excessive pollution and exploitation of forest resources reduce forest ecosystems' capacity to enhance carbon stocks to mitigate carbon emissions (Locatelli 2016). For instance, in

Ghana, LULUCF caused 25% of GHGs emissions in Ghana (Forestry Commission 2016). Land Use Land Cover Changes (LULCC) pressures significantly drive deforestation and forest degradation resulting in GHGs emissions disrupting the climate system and affecting carbon sequestration potentials and the decline in ES quality and quantity (Sandbrook et al. 2010 and Khan et al. 2019). Forest land cover conversion reduces forest ecosystem structures, accounting for a 10% loss of global carbon stocks, leading to increased climate change as there is a close correlation between forest carbon storage and biodiversity conservation (Newton et al. 2016). Forest-fringe communities lack alternative livelihoods; hence they depend heavily on forest ecosystems, leading to ecosystem services degradation and loss (Fagariba et al. 2018). Thus, the activities of the forest-fringe communities, including LULCC, negatively impact forest ecosystem services, thereby reducing the benefits to local forest-dependent communities (Kogo et al. 2019). For example, human-induced drivers such as a rising global population, urbanization, habitat loss, unsustainable agriculture, legal and illegal logging, mining, fires and climate changes pose substantial risks and dangers to tropical forests (Yaduv et al. 2018). Ghana's forest reserves cover two hundred and eighty (280) forest reserves covering approximately 23,729 km² translating into 11% of the country's total land area, with 75% classified as production reserves, while 25% are regarded as protection reserves (Forestry Commission 2016). Notwithstanding, Ghana experiences an annual deforestation and forest degradation rate of 2%, comprising 135,000 ha/year of forest cover loss via mining activities, agricultural expansion, wildfires, illegal logging, and poaching (Forestry Commission 2016). Between 1990 – 2020 Ghana's closed natural forest went from 3,108,508ha to 1,204,372 ha. The open forest loss was marginal from 6,765,748 ha in 1990 to 6,484,336 ha in 2020 (FAO and UNEP 2020). The widespread deforestation and forest degradation threaten tropical forests' sustainability (Nasi et al. 2011) and reduce their ecosystems' sustainability and supply (Appiah et al. 2009). Given the rate of deforestation occurring in Ghana's forests, urgent forest governance and management strategies are required to reverse the trend. This study aims to assess and highlight how service provision has changed over time due to the use of resources and the effects of other human activities on the Bia-Tano forest reserve. This study was justified since earlier studies had indicated the presence of some human activities, both legal and illegal, which have resulted in the forest reserve's resources depletion and degradation (Abugre et al. 2019 and Lossou et al. 2019). Although their study offered a clue regarding some activities contributing to the reserve's degradation, they did not offer an empirical assessment of the level of depletion and degradation that has resulted in changes in service provision over time. This study seeks to fill this knowledge gap by assessing the level of deforestation and forest degradation that has resulted in changes in the availability of ecosystem services, benefits, goods and products that local people derive from the forest reserve. Key research questions posed for the study included (1) How has the forest cover changed over the past 30 years (1990 – 2020)?, (2) What land/resources-related drivers caused these changes?, (3) Have these cover changes affected the forest reserve's services, goods, products, and benefits?, (4) Is the reserve governed and managed well by the Forestry Commission officials? The qualitative and quantitative nature of the study required a combined GIS and satellite images and questionnaire interview to elicit empirical data to assess the research problem. It will be expected that the activities of the fringe communities coupled with lapses in governance and management have culminated in the changes in the availability of service provision from the Bia-Tano forest re-

serve. The study's empirical outcome will inform the managers to adopt appropriate governance and management options to safeguard the reserve's sustainability and resilience. It will also inform beneficiaries about the effects of their activities on the reserve's resources provision, which support most of their livelihoods needs. This study is structured to cover the introduction, methods and materials, results, discussion, summary and conclusions.

MATERIAL AND METHODS

The analysed maps and data were obtained through GIS tools from 1990, 2000, 2011 and 2020 to detect LULCC and trends in the surrounding areas of the Bia-Tano forest reserve. LULCC images and change detection statistics covered actual reserve and surrounding areas within 5 kilometres, where most fringe communities and their major farm activities occur. In the study, we use Google Earth Engine to search for the data; the selected data for 1990, 2000, 2011 and 2020 with a cloud cover below 10% acquired from USGS Earth Explorer. Scan lines were removed from the 2011 Landsat image to enhance the visual image appearance before calibration using `landsat_gapfill`. Data calibration performed in QGIS, followed by layer stacking involving colour rendition of the images using 7,4,2 band combinations, allows us to differentiate the various land classes. Samples were trained in Envi 5.7 after stacking calibrated bands in 7, 4, and 2 combinations (1990, 2000, 2011 and 2020). Classification, accuracy assessment and change detection statistics were also generated in Envi 5.7 for the (1990, 2000, 2011 and 2020) years selected for the study. It must be emphasized that appropriate data for 2010 could not be obtained to match the rest of the years. Hence our choice of 2011, which is the nearest to 2010, meets the rest of the years' requirements. The spatial resolution for LULC changes detection within the specific time horizons was $30\text{m} \times 30\text{m}$. The post-classification accuracy was assessed based on a common method that establishes the value of the information derived from the data (Firdaus 2014). The final maps for the years under study were generated in ArcGIS Pro 2.7.1. The overall accuracy and Kappa coefficient (K) were based on the formula below:

$$K = \frac{N \sum_{i=1}^r X_{ii} - \sum_{i=1}^r (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^r (x_{i+} * x_{+i})},$$

where r denotes the number of rows, x_i indicates the number of observations in row i and column i , x_{i+} and x_{+i} represent the marginal totals of row and column, and N is the observed total number (Jensen and Cowen 1999 and Rwanga and Ndam-buki 2017). The sample of 300 household heads selected through simple random sampling from the nine (9) communities fringing the Bia-Tano forest reserve answered a questionnaire we administered. The part of the questionnaire extracted to support this study was under the heading forest reserve sustainability. Under it, the respondents were asked to rate the key drivers responsible for the degradation of the Bia-Tano forest reserve (see Fig. 7 below). They represented 192 males (64%) and 108 females (36%). The communities fringing the Bia-Tano forest reserve within five (5) kilometres are Fianko, Dominase, Kokofu, Gambia No.1, Nsuta, Tokurom, Duase, Aboagyaa and Bediako. The case study area covers the Bia-Tano forest reserve in Goaso Forest District in the Ahafo region of Ghana, located between $6^{\circ}55'$ and $7^{\circ}05'$ north and longitude $2^{\circ}45'$ and $2^{\circ}30'$ West, with an average land elevation of 244m above mean sea level (Fig. 1). The green area in the map

below (Fig. 1) indicates the actual Bia-Tano forest reserve. The reserve covers 181.97 km² comprising 113 compartments of timber production, two swampy compartments (Elephant Pool), and 10 Convalescence spaces. The research area of the reserve comprises six compartments, while two compartments were demarcated for Provenance Trial (*Guibourtia ehie*) and Provenance Trial (*Chrysophyllum* spp), respectively. The reserve lies in a tropical humid climatic zone with forest Ochrosol as the primary soil type. The annual average rainfall ranges between 1200.9 mm and 1524.2 mm, while the annual mean temperature ranges from 28°C to 34°C.

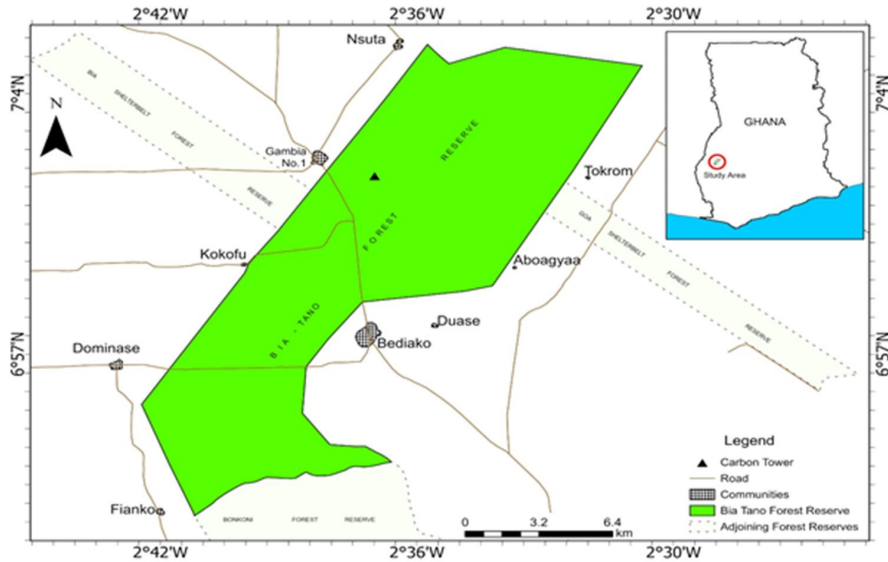


Fig. 1. A map showing the case study area of the Bia-Tano forest reserve

RESULTS

The study results are presented through classified LULCC images from 1990, 2000, 2011 and 2020 (Figs. 2a, b, c and d). The classified images covered six land classes: barren, built-up, closed, degraded, open, and planted/cultivated for the years. Table 1 describes the characteristics of the class as it pertains to the Bia-Tano forest reserve. The results of the LULCC are presented as a summary (Tab. 1) and choropleth maps (Fig. 2).

Tab. 1. Land cover types in Bia-Tano forest reserve

Classes	Description
Barren/Built-up	Bare land/built-up include settlements, unproductive topsoil, tarred and non-tarred roads, rocks, recently burnt surfaces, recently cleared agricultural lands and quarry sites
Closed forest	Include all lands with woody vegetation with canopy cover greater than 65 %
Degraded forest	Degraded areas all woody lands of canopy cover below 15 %, areas within the forest reserve that are experiencing regeneration due to overexploitation of timber or recent fire outbreaks or areas that have undergone illegal felling and logging
Open forest	Open canopy forest Include all lands with woody vegetation with canopy cover greater than 15 % but less than 65 %
Planted/Cultivated	Planted/cultivated include forest plantations, admitted farming and illegal farms

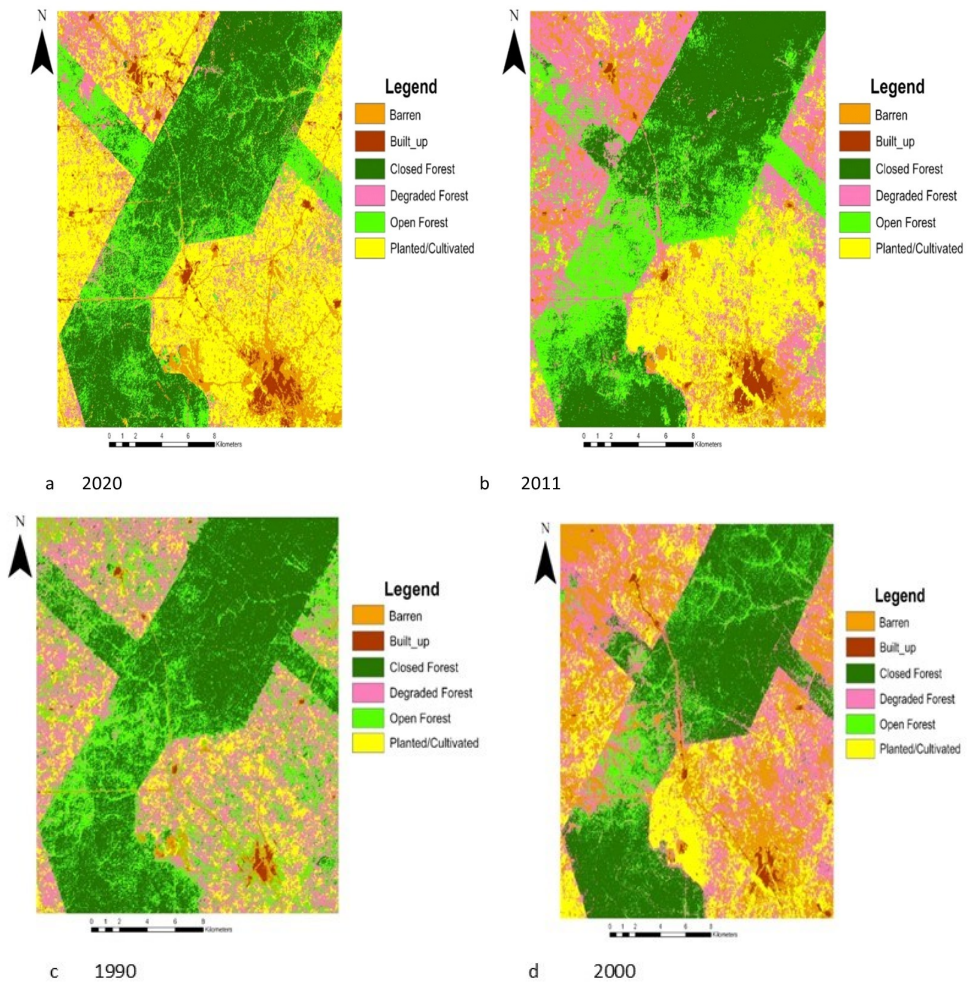


Fig. 2. Classified Land Use Land Cover Image of Bia-Tano forest reserve and surrounding areas

Tab. 2. 1990 error matrix table (in pixel)

Classified	Barren	Built-up	Closed forest	Degraded forest	Open forest	Planted/Cultivated	Classified Total
Barren	46	0	0	0	0	0	46
Built-up	0	190	0	0	0	0	190
Closed forest	0	0	747	0	24	0	771
Degraded forest	0	0	1	42	7	0	50
Open forest	6	0	43	11	100	0	160
Planted/Cultivated	3	0	0	0	0	35	38
Total	53	190	791	53	131	35	1 255

Based on the equation above, we generated the 1990 base year error matrix from Table 2, and the kappa coefficient produced the result below:

$$K = \frac{(1255*(46+190+747+42+100+35)) - ((46*55) + (190*190) + (771*791) + (50*53) + (160*131) + (38*35))}{1255^2 - ((46*55) + (190*190) + (771*791) + (50*53) + (160*131) + (38*35))}$$

$$K = 0.868$$

The overall accuracy (OA) for the base year 1990 was generated as follows:

$$OA = (46+190+747+42+100+35)/1255$$

$$OA = 0.92430$$

Given that $0.92430 > 0.868$ and nearer to 1, the classification performed for the base year 1990 was significantly accurate and reliable. Based on these calculations, we generated a kappa coefficient and overall accuracy assessment for the remaining 2000, 2011 and 2020 images of Bia-Tano forest reserve and the surrounding areas in Tab. 3 below:

Tab. 3. Summary of accuracy assessment of 1990, 2000, 2011 and 2020 classification

Accuracy Assessment	1990	2000	2011	2020
Overall Accuracy	0.924303	0.841181	0.92152	0.871272
Kappa	0.8678	0.6839	0.8334	0.8256

Tab. 4. Summary of land use cover changes of Bia-Tano forest reserve and surrounding areas

Years	Barren	Built-up	Closed forest	Degraded forest	Open forest	Planted/Cultivated
Year 1990	16.6689	2.5731	176.7537	130.8168	126.5157	46.368
Year 2000	95.2326	4.3731	151.0713	120.9177	44.7174	83.3841
Year 2011	44.6814	6.2550	126.2655	124.6869	102.6837	95.1237
Year 2020	53.8713	9.7596	149.8050	50.7546	76.5405	158.9652

It shows that barren land has increased over the last 30 years from 16.67 sq.km in 1990 to 95.23 sq. km in 2000, 44.68 sq.km in 2011 and 53.87 sq.km in 2020. Similarly, the built-up area also increased over the 30 years from 2.57 sq. km in 1990 to 9.76 sq. km in 2020. However, closed forest declined from 176.75 sq. km in 1990 to 151.07 sq. km in 2000, reduced further by 126.26 sq. km in 2011, but it recovered to 149.81 sq. km in 2020. The reserve's degraded parts were reduced over the period under study from 130.82 sq. km in 1990 to 50.75 sq. km in 2020. Relatedly, open forests reduced from 126.52 sq. km in 1990 to 44.72 in 2000, increased again to 102.68 sq. km in 2011 and declined by 76.54 sq. km in 2020. Notwithstanding, planted/cultivated lands have been increasing consistently over the 30 years. In 1990 planted/cultivated areas of the Bia-Tano forest and the surrounding areas covered 46.368 sq. km, which increased to 83.38 sq. km in 2000, 95.12 sq. km in 2011 and further increased to 158.97 sq. km in 2020. The dominant crops in the

planted/cultivated class include cocoa and other food and cash crops, including plantain, yam, cocoyam, cassava and maize. The increasing trend in planted/cultivated areas in the Bia-Tano forest reserve implies that the reserve is under pressure from imminent encroachment.

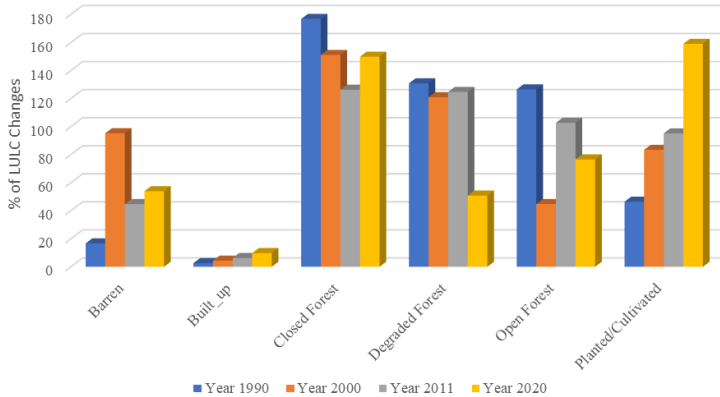


Fig. 3. Land use land cover change graph of Bia-Tano forest reserve and surrounding areas

The detection over ten years sought to ascertain changes that occurred over the years regarding the Bia-Tano forest reserve conditions and its surroundings from 1990 to 2000. Change detection illustrated in Tab. 5 indicated that closed forests declined by 14.53% from the initial state of 73.67%; it lost 15.75% and 8.51% to open forests and degraded forests. The degraded forest lost 7.57% from its initial state of 39.45%, with the greater part of the lost 31.61% going into planted/cultivated lands and 28% into barren lands. The open forest was reduced by 64.66%, with 34.83% converted into degraded forest, 16.16% into the closed forest and 14.21% lost went into planted/cultivated lands and 28.00% lost to barren lands. The Planted/cultivated gained 79.83% from its initial state of 38.98%, where the gains were accumulated from barren land at 41.60% and degraded forest at 19.07%. However, barren lands and built-up lands increased by 471.32% and 69.96%, respectively.

Tab. 5. Change detection statistics summary between 1990 and 2000

		INITIAL STATE (%) 1990					
		Barren	Built-up	Closed forest	Degraded forest	Open forest	Planted / cultivated
2000 FINAL STATE (%)	Barren	51.201	18.503	1.527	28.002	21.819	41.595
	Built-up	8.455	76.950	0.009	0.268	0.366	0.334
	Closed forest	0.988	0.105	73.669	0.191	16.155	0.004
	Degraded forest	8.013	1.084	8.512	39.450	34.827	19.066
	Open forest	1.663	0.000	15.753	0.479	12.619	0.012
	Planted/cultivated	29.680	3.358	0.531	31.610	14.213	38.989
	Class total	100.000	100.000	100.000	100.000	100.000	100.000
	Class changes	48.799	23.331	26.331	60.550	87.381	61.011
	Image difference	471.319	69.955	-14.530	-7.567	-64.655	79.831

Tab. 6. Change detection statistics summary between 1990 and 2011

		INITIAL STATE (%) 1990					Planted / cultivated
		Barren	Built-up	Closed forest	Degraded forest	Open forest	
2011 FINAL STATE (%)	Barren	38.060	17.349	0.278	12.349	9.749	19.082
	Built-up	11.517	79.538	0.001	0.496	0.859	1.188
	Closed forest	2.608	0.105	63.504	0.089	10.642	0.004
	Degraded forest	20.949	0735	5.111	44.769	30.144	33.302
	Open forest	2.435	0.175	29.907	8.012	29.040	4.724
	Planted/ cultivated	24.432	2.099	1.200	34.237	19.566	41.700
	Class total	100.000	100.000	100.000	100.000	100.000	100.00
	Class changes	61.940	20.462	36.496	55.231	70.960	58.300
	Image difference	168.052	143.092	-28.564	-4.686	-18.837	105.149

The table above shows the change detection statistics from 1990 to 2011. It shows that closed forests declined by 28.56% from the initial state of 63.50%, where 29.91% went into open forests, 5.11 % into degraded forest, with only 1.20% lost to planted/cultivated lands. On the other hand, degraded forests lost 4.69% from the initial state of 44.77%, with 34.23% losing to planted/cultivated lands and 8.01% to the open forest, with 12.34% to barren. It further reveals that open forests reduced by 18.84% from the initial state of 29.04%, where the lost went into planted/cultivated lands 19.57%, and 30.14% to degraded forest, 10.64% into closed forest, whereas 9.74% went into barren lands. On the other hand, planted/cultivated lands gained 105.14% from their initial state of 41.70%, with the gains coming from 33.30% degraded forest, 19.08% from barren lands, while 4.72% and 1.19% open forest built-up, respectively. During the period, the built-up area increased by 143.09% from the initial state of 79.54%, where the gains 17.35% came from barren and 2.09% from planted/cultivated and built-up while barren lands gained 168.05% against the initial state of 38.06%. Moreover, the greater gains emanated from planted/cultivated 24.43%, degraded forests 20.94% and 11.52%, while barren lands gained open forest land 2.44% and closed forest 2.61%.

Tab. 7. Change detection statistics summary between 1990 and 2020

		INITIAL STATE (%) 1990					Planted / cultivated
		Barren	Built-up	Closed forest	Degraded forest	Open forest	
2020 FINAL STATE (%)	Barren	48.000	18.783	1.080	14.030	12.168	20.982
	Built-up	13.671	78.699	0.006	1.602	1.556	2.977
	Closed forest	2.246	0.070	70.294	0.661	19.193	0.977
	Degraded forest	7.802	0.420	2.627	18.240	11.832	12.877
	Open forest	2.246	0.035	23.006	4.074	23.420	1.167
	Planted/ cultivated	26.035	1.994	2.986	61.393	31.831	61.924
	Class total	100.000	100.000	100.000	100.000	100.000	100.000
	Class changes	52.000	21.301	29.706	81.760	76.580	38.076
	Image difference	223.184	279.293	-15.246	-61.202	-39.501	242.834

Change detection results from 1990 to 2020 (Tab. 7) indicate that closed forests lost 15.24% from the initial state of 70.29%, where 23.01% was lost to open forests, with 2.63% and 2.97% loss to the degraded forest and planted/cultivated lands, respectively. Degraded forest declined by 61.20% against its initial state of 18.24%. Degraded forest lost 61.39% to planted/cultivated lands, 4.07% to open forest, 14.03% to barren lands and 1.60% to built-up areas. Similarly, open forest declined by 39.50% compared to its initial state figure of 23.42%. The loss of open forest was due to 31.83% going to planted/cultivated lands, while 11.83%, 19.19%, and 12.17% were converted into degraded forests, closed forests and barren lands. On the contrary, planted/cultivated increased by 242.83% as against its initial state of 61.92%, where the gains were as a result of accumulated 20.98% barren land, 2.98% built-up areas, 12.88% degraded forest, 1.17% from open forest and less than 1% from closed forest. However, over the 30 years, barren lands increased by 223.18%, with gains coming from 13.67% built-up lands, 2.23% closed forest, 7.80% degraded forest, 2.23% open forest and 26.04% planted/cultivated lands.

Tab. 8. Change detection statistics summary between 2011 and 2020

		INITIAL STATE (%) 2011					Planted / cultivated
		Barren	Built-up	Closed forest	Degraded forest	Open forest	
2020 FINAL STATE (%)	Barren	47.625	22.576	1.200	10.917	0.845	15.962
	Built-up	8.841	76.921	0.000	0.392	0.010	0.525
	Closed forest	0.352	0.000	80.665	3.150	42.562	0.177
	Degraded forest	9.499	0.000	1.092	21.093	7.149	12.079
	Open forest	0.449	0.000	16.229	11.161	39.204	1.763
	Planted/ cultivated	33.233	0.504	0.814	53.287	10.230	69.498
	Class total	100.000	100.000	100.000	100.000	100.000	100.000
	Class changes	52.375	23.079	19.335	78.907	60.796	30.502
	Image difference	20.029	18.643	18.643	-59.294	-25.460	67.114

Change detection statistics from 2011 to 2020, as illustrated in Tab. 8, showed a gain in closed forest by 18.64% from its initial state of 80.67%. The gains emanated from open forest by 16.23%, with a little over 1% gain from barren lands, degraded forest, and less than 1% of planted/cultivated lands. Degraded forest reduced by 59.29% from its initial state of 21.09%. The loss to planted/cultivated land was 53.29%, 11.16% open forest and 10.92% barren land, while 3.15% was lost to closed forest. Open forest declined by 25.46%, against its initial 39.20% state, where the open forest lands were lost to planted/cultivated lands by 10.23%, 42.56% of open forest lands grew into closed forest, 7.15% into degraded forest. On the other hand, planted/cultivated lands increased by 67.11%, from its initial state of 69.49%. Much of the planted/cultivated land gain came from 15.96% barren land, 12.08% degraded forest and 1.76% open forest. Barren land and built-up areas increased by 20.03% and 18.64% within the nine years, respectively.

In the Bia-Tano forest reserve itself, an analysis of classified land use and land cover types for 1990, 2000, 2011 and 2020 covers land classes of barren, closed forest, degraded forest, open forest and planted/cultivated. The summary statistics are presented in a table and a chart (Fig. 4).

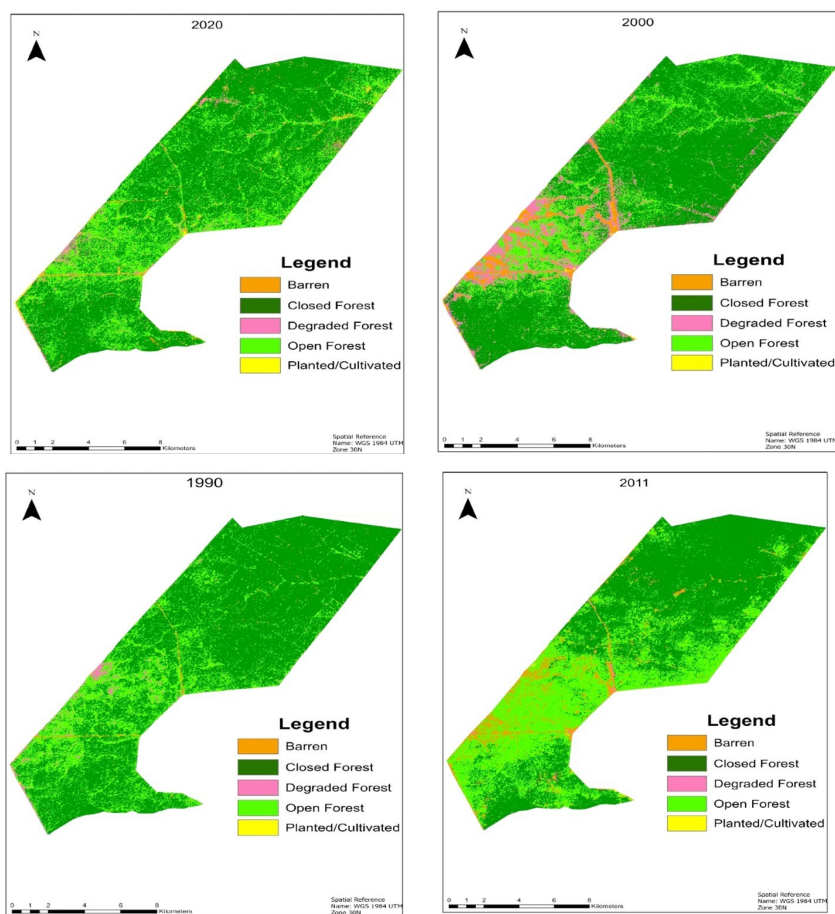


Fig. 4. Classified Land cover types and images of Bia-Tano forest reserve

Analysis of classified land use and land cover types for 1990, 2000, 2011 and 2020 are shown in Fig. 4 and the corresponding LULCC histogram (Fig. 5). The LULC change analysis for barren land stood at 1.22 sq. km in 1990, increased to 6.03 sq. km in 2000, decreased to 0.49 sq. km in 2011 and increased again to 2.13 sq. km in 2020. The closed forest stood at 139.31 sq. km in 1990, reduced to 125.23 sq. km in 2000, further declined to 104.51 sq. km in 2011, and recovered again by 130.98 sq. km in 2020. Degraded forest during 1990 stood at 3.25 sq. km, but dramatically degraded further to 18.75 sq. km in 2000. However, the degraded areas reduced to 12.46 sq. km in 2011 and further declined to 5.15 sq. km in 2020. Open forest covered 45.10 sq. km in 1990, declined to 38.32 sq. km in 2000, while it increased drastically to 71.27 sq. km in 2011 and declined again to 48.19 sq. km in 2020. Planted/cultivated lands have increased since 1990 from less than 0.11 sq. km to 0.64 sq. km in 2000, 0.26 sq. km in 2011 and 2.54 sq. km in 2020. The planted/cultivated lands (convalescence areas) in the Bia-Tano forest reserve consist of forestry crops such as (Ofram and Cedrella) while the agricultural crops include plantain and cocoyam.

Tab. 9. Summary of Land use land cover changes of Bia-Tano forest reserve

	Barren	Closed forest	Degraded forest	Open forest	Planted/cultivated
Year 1990	1.2240	139.3083	3.2454	45.1035	0.1134
Year 2000	6.0345	125.2485	18.7524	38.3157	0.6435
Year 2011	0.4932	104.5062	12.4623	71.2719	0.2610
Year 2020	2.1267	130.9824	5.1498	48.1968	2.5389

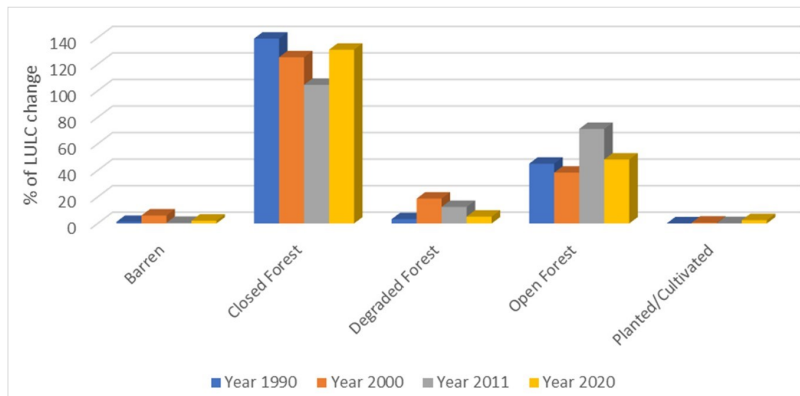


Fig. 5. Land use land cover changes graph of Bia-Tano forest reserve

Tab. 10. Change detection statistics summary between 1990 and 2000

		INITIAL STATE (%) 1990				
		Barren	Closed forest	Degraded forest	Open forest	Planted / cultivated
2000 FINAL STATE (%)	Barren	49.412	0.580	22.851	8.550	21.429
	Closed forest	11.912	78.142	3.688	35.750	0.794
	Degraded forest	15.368	4.092	54.576	24.532	24.603
	Open forest	21.176	17.156	11.925	30.350	0.000
	Planted/cultivated	2.132	0.031	6.961	0.639	53.175
	Class total	100.000	100.000	100.000	100.000	100.000
	Class changes	50.588	21.424	45.424	69.470	46.825
	Image difference	393.015	-10.093	477.815	-15.049	467.460

The Bia-Tano forest reserve change statistics presented in Table 10 from 1990 to 2000 indicate that closed forests declined by 10.09%. It maintained 78.14% of its initial state while losing 17.17% to open forest, 4.09% to degraded forest, with 0.61% losing to the barren land and planted/cultivated combined. Over the ten years, degraded forest increased by 477%, compared to its initial state of 54.58%. The gains emanated from barren portions 22.85%, 3.69% from the closed forest, 11.93% from open forest, and 6.96% of planted/cultivated portions of the reserve. On the contrary, open forests were reduced by 15.05% of their initial state of 30.35% while losing 24.53% to the degraded forest, 35.75% to closed, 8.55% to

barren portions and less than 1% to planted/cultivated. However, barren portions increased by 393.02%, where the gains emanated from closed forests at 11.91%, degraded forests at 15.37%, open forests at 21.18% and 2.13% planted / cultivated. The planted/cultivated increased massively from its initial stage of 53.2% to 467.5%.

Tab. 11. Change detection statistics summary between 1990 and 2011

		INITIAL STATE (%) 1990				
		Barren	Closed forest	Degraded forest	Open forest	Planted / cultivated
2011 FINAL STATE (%)	Barren	11.544	0.110	0.887	0.365	4.762
	Closed forest	32.794	67.362	1.082	22.678	0.794
	Degraded forest	38.162	2.228	44.287	16.370	61.905
	Open forest	17.206	30.275	51.525	60.265	27.778
	Planted/cultivated	0.294	0.025	2.219	0.321	4.762
	Class total	100.000	100.000	100.000	100.000	100.000
	Class changes	88.456	32.638	55.713	39.735	95.238
	Image difference	-59.706	-24.982	283.999	58.019	130.159

The change detection statistics from 1990 to 2011 are presented in (Tab. 11). During the twenty-first year, closed forests declined by 24.98%, losing 30.28% to open forests and 2.23% to degraded portions in the reserve. However, degraded forests increased by 283.99% from their initial state figure of 44.29%, with the gains coming from open forests 51.53%, 1.08% from closed forests, and 2.23% from planted/cultivated. Open forests gained 58.09% overall, while 22.68% and 16.37% of the gains came from closed and degraded forests, respectively. Planted/cultivated lands increased by 130.16%, where the greatest gains came from 61.91% and 27.78% of degraded forest and open forest, respectively. However, barren portions of the reserve declined by 59.71%; the loss went into closed forests by 32.79%, degraded forests by 38.16% and 17.21 to open forests.

Tab. 12. Change detection statistics summary between 1990 and 2020

		INITIAL STATE (%) 1990				
		Barren	Closed forest	Degraded forest	Open forest	Planted / cultivated
2020 FINAL STATE (%)	Barren	34.118	0.757	2.357	1.277	0.381
	Closed forest	26.397	78.138	16.057	47.193	0.000
	Degraded forest	7.647	1.266	18.414	5.902	28.571
	Open forest	20.221	19.174	52.191	43.318	5.556
	Planted/cultivated	11.618	0.665	10.982	2.309	63.492
	Class total	100.000	100.000	100.000	1000.000	100.000
	Class changes	65.882	21.862	56.682	56.682	36.508
	Image difference	73.750	-5.977	58.680	6.858	2138.889

Table 12 depicts the change detection statistics from 1990 to 2020. Over the thirty years, all the reserves' classes registered a gain except closed forest, which

lost 5.98%, 19.17% converted into open forest and 1.27% degraded forest. Overall, the degraded forest increased by 58.68%, gaining 52.19% from open forest, 10.98% from planted/cultivated portions, 16.06% from closed forest and barren land contributing 2.36% to the degraded forest. Similarly, open forests increased by 6.86%, with gains emanating from closed forests by 47.19%, degraded forests by 5.90%, 2.31% planted/cultivated and 1.23% barren. Planted/cultivated lands increased by 2138.89%, with the gains being 28.57% from degraded forest and 5.56% from open forests. Barren portions of the reserve also increased by 73.75%, with much of the gains coming from closed forests 26.39%, open forests 20.22%, 11.62% planted/cultivated and 7.65% degraded forests.

Tab. 13. Change detection statistics summary between 2011 and 2020

		INITIAL STATE (%) 2011				
		Barren	Closed forest	Degraded forest	Open forest	Planted / cultivated
2020 FINAL STATE (%)	Barren	36.861	1.015	0.622	0.418	3.793
	Closed forest	18.861	83.047	22.987	57.796	17.241
	Degraded Forest	7.664	1.043	12.320	3.427	16.897
	Open forest	20.803	14.137	52.120	37.476	43.793
	Planted/cultivated	16.058	0.758	7.951	0.883	18.276
	Class total	100.000	100.000	100.000	100.000	100.000
	Class changes	63.139	16.953	87.680	62.524	81.724
	Image difference	331.204	25.335	-58.677	-32376	872.759

This nine-year period shows the recent happenings regarding the changes that had occurred within the forest reserve. During this period, closed forests saw an increase of 25.34%, with much of the open forest gains by 14.14%. However, both degraded and open forests declined by 58.68% and 32376%, respectively. Degraded forest lost to closed forest by 22.99%, 52.12% to open forest and 7.95% to planted/cultivated lands, while open forest lost 57.80% to closed forest and 3.43% to degraded forest. However, planted/cultivated portions within the reserve increased by 872.76%, where 43.79% of open forest, 16.89% of degraded forest, 17.24% and 3.79% were affected. Similarly, barren portions of the reserve increased by 331.20%, whereas the gains resulted from the losses from closed forests were by 18.86%, open forests by 20.80%, planted / cultivated by 16.06% and degraded forests by 7.66%.

RESPONDENTS' VIEWS ON KEY DRIVERS OF THE RESERVES COVER DEPLETION

During the survey, household heads indicated whether the products they obtain from the reserve have decreased, increased, remained the same, or they do not know over the past ten years. Respondents' responses indicate a decrease in almost all the forest products over the past ten years with no significant increase or remained the same over the years. In particular, pestles, mushrooms, fuelwood, bushmeat, leaves, and medicinal plants decreased considerably over the past ten years.

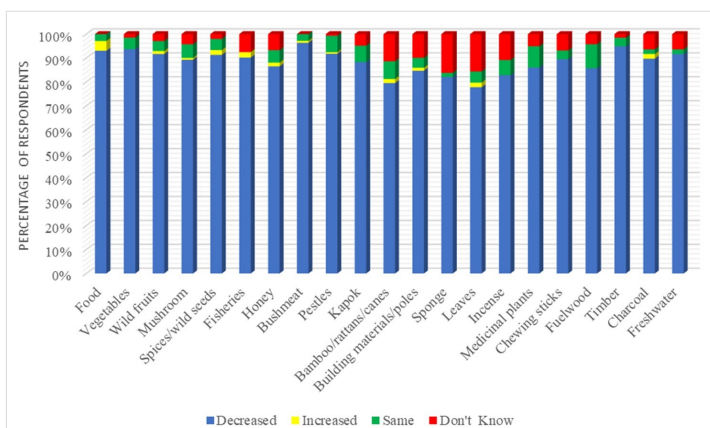


Fig. 6. Changes in availability of forest reserve products

During the survey, household heads were to indicate the direct and indirect factors that constitute the key drivers of forest cover change and degradation. The result is presented in (Fig. 7), where 216 household heads stated illegal logging/chainsaw operation as an “extremely” important driver of forest cover degradation and change of the reserve, followed by legal timber harvesting, illegal farming and overexploitation of forests products/goods. The reserve’s encroachment, excessive poaching/hunting, and forest/bush fires are extremely important drivers of forest cover changes and degradation. Illegal mining was not important because, within the reserve, no traces of illegal mining were reported. However, the reserve has reduced quality and quantity over the past years. The major causes responsible for the degradation and depletion of the reserve were legal and illegal timber felling. Accordingly, while the big timber companies cut the giant trees, illegal loggers and charcoal burners cut the small trees expected to grow to replace the bigger ones cut by the two big companies operating within the forest reserve.

The reserve is now dry, and some places look like a park; in the next 30 years, the forest will be gone if nothing is done to save it (FGD participant December 10th 2020).

The timber contractors were doing selective logging and leaving the smaller trees to grow, but now every tree is being cut (FGD Female participant, December 10th 2020).

The challenge is that forest guards connive with illegal chainsaw operators to engage in illegal logging in the reserve. Although the military is on patrol in the reserve to arrest the illegal loggers, the practice has not stopped.

The FC and government-mandated agencies charged with protecting the forest must work and stop the corrupt acts that degrade the reserve (FGD participant December 10th 2020). Nevertheless, unfortunately, the FC does not live with us all the time; we are the ones who enter the reserve and engage in illegal chainsaw operations (FGD participant, December 10th 2020).

The results show household heads’ opinions on the reserve’s governance and highlight whether they involve the reserve fringe communities in the governance

process. The result depicts 182 household heads (60.7%), indicating the reserve is governed well, while 118 (39.3%) thought otherwise.

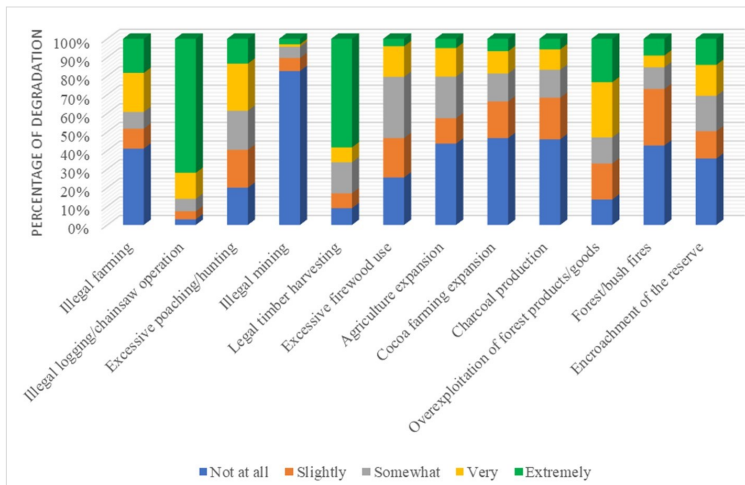


Fig. 7. Key drivers of reserve’s cover change and degradation identified by household heads

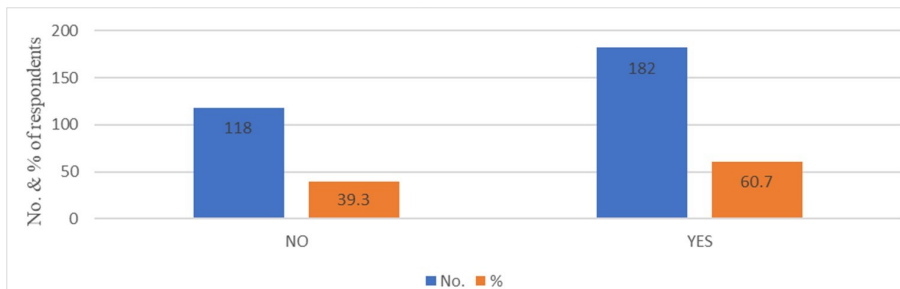


Fig. 8. Respondents’ opinions on whether the Bia-Tano forest reserve is governed well

DISCUSSION

The unregulated land use activities call for proper and immediate actions to protect the reserve from further deterioration. The study’s findings determined the classified LULC maps for the Bia-Tano forest reserve and surrounding lands covering nine reserve-fringe communities obtained for 1990, 2000, 2011 and 2020. Table 1 presents LULCC statistics of barren, built-up, closed forest, degraded forest, open forest and planted/cultivated lands classes. The decline in the closed forest over 30 years was alarming, requiring an immediate integrated governance and management intervention. This decline is not peculiar to the Bia-Tano forest reserve and its surroundings, as it remains the biggest challenge in many forest areas in Ghana. For instance, the conversion of forests into cocoa plantations constituted 54.6% and 77.8% of closed and open forests, respectively (Benefoh et al. 2018). In addition, the F.G.F.R. (2015) observed that Ghana’s closed forest cover of

3,108,508 ha in 1990 had declined to 1,204,372 ha in 2020. The consistent decline in closed forest calls for proper governance and management interventions to save the reserve closed forest from further deterioration. The increase in planted/cultivated areas indicates illegal farming activities in the forest reserve. The practice of illegal farming in the forest reserve implies a relaxation of rules and regulations meant to protect and conserve the forest from illegal encroachment. Largely, agricultural expansion has resulted in Ghana's massive degradation of several forest reserves (Acheampong et al. 2019). Similarly, the increased built-up and barren land areas call for more appropriate interventions to increase the reserves' vegetation cover. Built-up expansion leading to forest cover degradation in the protected forest areas is a major problem in Ghana. The significant increase in barren and built-up areas in the reserves and their surroundings agrees with a study by Lossou, Owusu-Prempeh and Agyemang (2019), which finds a major upsurge in the bare land/built-up using 1990 as a base year. The increased built-up and barren land areas are attributed to several factors (see Fig. 7); however, illegal logging and chain saw operations, legal logging, overexploitation of NTFPs and illegal farming constitute the major causes. In particular, illegal logging occurred as the reserve field inspection found traces of routes used by illegal loggers to engage in illegal chain-saw operations (Lossou et al. 2019). This means the monitoring and patrolling operations by the forest guards are not adequate to deal with illegal activities in the forest reserve. The settlement expansion in forest areas poses a key forest degradation challenge in Ghana (Awotwi et al. 2018). For instance, the massive degradation in the Kakum Conservation areas is attributable to the expansion of built-up settlements (Doe et al. 2018). Also, the growing urbanization and unregulated peri-urbanization for settlements in many parts of Ghana are responsible for forest cover conversion (Appiah et al. 2017, Acheampong et al. 2019, Antwi-Agyei et al. 2019 and Tsai et al. 2019). Land use planning coupled with sustainable forest governance and management interventions are necessary in order to protect Ghana's forest reserves from further degradation and deterioration. Although most respondents believed that the reserve was governed and managed well, the illegal activities that deforest and degrade the forest vegetation cover occur unabated. Forest governance is not only about the fringe communities' involvement and participation in the reserve's governance processes.

Most respondents who indicated the forest reserve is governed well might not fully understand what constitutes proper governance. Because if the reserve is governed well, there will not be a continuous decline in its NTFPs. The reserve suffers from numerous human activities (Fig 7) that significantly degrade and deplete its products and resources. It is about making strenuous efforts to ensure that the forest cover and resources are fully protected and conserved in a sustainable manner to continue its service delivery and provision, such as carbon mitigation and NTFPs to fringe communities. Proper land use planning requires efficient use of resources to meet the people's needs and safeguard the resources for future use. The proper land use of the Bia-Tano forest reserve will ensure sustained provisioning services to benefit the lives and livelihoods of the dependent forest fringe communities. They will enjoy the sustainable collection and harvesting of NTFPS for consumption and sale to earn income to support their livelihoods. The Fig. 4 provide the detailed land cover information on LULC changes for the actual Bia-Tano forest reserve from its surrounding areas. This is intended to show that the forest cover and vegetation have decreased over the past 30 years. Forest degradation constitutes a major

challenge in Ghana's forest reserves (Lossou et al. 2019) as, in many cases, encroachments are pervasive (Mensah and Amoah 2013 and Benefoh et al. 2018). The nearness of the forest fringe communities to the forest reserve implies that they will have easy access to enter the reserve and carry out illegal activities if monitoring and patrolling systems are not heightened. The Forestry Division in Goaso Forest Districts (the reserve caretaker) must beef up its watchdog operations by increasing monitoring and patrolling activities to safeguard the reserve, and its resources in order to continue services provision and delivery. The degraded areas of the forest reserve were also attributed to the wildfires that engulfed a significant part of the reserve in 2013 (Lossou et al. 2019). However, the continuous decline in forest cover and increased reserve degradation have implications on the sustainable provision of the reserve's benefits to satisfy the wellbeing of fringe communities and biodiversity conservation to enhance the reserve's carbon storage and sequestration potentials. Thus, the decline in the provision of goods and products resulted from the decrease in the reserve's cover changes. Therefore, the need for assessing the direct and underlying drivers, pressures, state and impact responses of deforestation and forest degradation is urgently required to save Ghana's forests and reserves from persistent deterioration and loss (Kyere-Boateng and Marek 2021).

CONCLUSIONS

The classified LULC images and summary of change detection analysis using the years 1990, 2000, 2011 and 2020 indicate a decline in closed forests, increased open forests, planted / cultivated areas, barren areas and built-up areas. However, over the same period, degraded areas were reduced. The consistent decline in the closed forest has implications for the reserve's future biodiversity and ecosystem services. Thus, if the decline in closed forests continues, it will significantly impact the quality and quantity of the provision of service of the reserve, thus ultimately affecting the provision of NTFPs, carbon sequestration and carbon storage. The summary change detection statistics of land use cover images of the actual Bia-Tano forest reserve, excluding the resources areas and communities, indicating an increase in barren areas, closed forests, open forests and planted/cultivated areas. Degraded forest portions of the reserve were negligible in 1990; however, they increased tremendously in 2000 and 2011 before dropping in 2020. Therefore, effective landscape planning and governance strategies should be adopted to reverse the downward trend in the closed forest of the actual Bia-Tano forest reserve. This research has provided evidence-based accounts through land use cover changes statistics, which show a continuous decline in close forest cover and increased planted/cultivated, barren and built-up areas and surrounding areas.

In contrast, the reserve itself has experienced increased barren, planted/cultivated areas over the past 30 years with a decline in the close forest, although it has regained a little over the 2000 and 2011 losses. The increased planted/cultivated areas indicate illegal farming activities in the actual forest reserve areas, as some forest reserve fringes exhibit encroachment traces. The closeness of the fringe communities to the reserve makes access to resources very prevalent, whether legally or illegally. The lack of proper harmonization of policies and institutions of the reserve has affected the reserves' service provision in terms of quality and quantity, and the situation will deteriorate if urgent governance and management interventions are not in place.

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HODNOTENIE ZMIEN EKOSYSTÉMOVÝCH SLUŽIEB POSKYTOVANÝCH ĽESNOU REZERVÁCIOU BIA-TANO V ZÁUJME UDRŽATEĽNEJ MITIGÁCIE UHLÍKA A POSKYTOVANIA NEDREVNÝCH PRODUKTOV ĽESA

Miléniové hodnotenie ekosystémov z roku 2005 definuje ekosystémové služby ako „prínosy, ktoré ľudia získavajú z ekosystémov“. Sú to okrem iného drevo, zdroje potravy, rastliny, živočíchy či mikroorganizmy poskytujúce základné produkčné i (auto)regulačné služby. Sem patrí napr. opelenie rastlín, prevencia proti vodnej erózii, samočistenie vody, ako aj celý rad kultúrnych služieb vrátane rekreácie či uspokojovania duchovných potrieb. Lesné ekosystémy však poskytujú aj množstvo ďalších služieb a prínosov, z ktorých profituje kvalita ľudského života. Sú tiež dôležité z hľadiska zachytávania a viazania (sekvestrácie) uhlíka a ďalších tzv. skleníkových plynov. V mnohých rozvojových krajinách lesné ekosystémy predstavujú zdroj potravy, poskytujú pracovné príležitosti a zmierňujú následky chudoby. Z toho je zrejmé, že z ekosystémových služieb profitujú dotknutí obyvatelia nielen priamo, ale aj nepriamo – vrátane takých pozitívnych prínosov, ktoré ľudia ani nemusia bezprostredne vnímať. Mimoriadny je pritom význam tropických lesov, ktoré predstavujú najproduktívnejšie suchozemské ekosystémy vyznačujúce sa extrémne veľkou biodiverzitou.

Prvoradým cieľom štúdie je vyhodnotiť zmeny ekosystémových služieb v jednom z takýchto ekosystémov, konkrétne v lesnej rezervácii Bia-Tano v Ghane (v období rokov 1990 – 2020) s využitím GIS a satelitných snímok. Ide o hľadanie odpovede na otázku, ako ľudské aktivity a deštruktívne zásahy prispievajú k znižovaniu úrovne ekosystémových služieb poskytovaných lesnými ekosystémami na území skúmanej rezervácie. Gnozeologické východisko predstavuje štúdium prác zameraných na problematiku ekosystémových služieb vo všeobecnosti, ako aj analýza výsledkov výskumov orientovaných na ekosystémové služby poskytované lesnými ekosystémami v rôznych častiach sveta s dôrazom na tropické oblasti. Tieto výsledky dokumentujú, že hlavnou priamou príčinou degradácie až straty

ekosystémových služieb v lesných oblastiach je deforestácia a nahrádzanie pôvodných prírodných lesov umelo vysadenými.

Týka sa to aj lesnej rezervácie Bia-Tano. Analýza zmien a porovnanie situácie v časových horizontoch rokov 1990, 2000, 2011 a 2020 dokumentuje pokles výmery pôvodných porastov a pribúdanie umelo vysadených, kultivovaných a zastavaných plôch. Na druhej strane, výmera degradovaných území sa v poslednej dekáde znížila.

Hlavné otázky, na ktoré sa štúdia snaží odpovedať v súvislosti s lesnou rezerváciou Bia-Tano, sú: Ako sa tu zmenil charakter lesného krytu v priebehu uplynulých 30 rokov? Čo spôsobilo tieto zmeny? Ako tieto zmeny ovplyvnili služby, produkty a celkovo prínosy plynúce z rezervácie? Ako hodnotia spôsob hospodárenia, resp. manažmentu v týchto lesoch predstavitelia miestnej Lesníckej komisie zodpovednej za správu rezervácie Bia-Tano na jednej strane a miestni obyvatelia na strane druhej?

V štúdiu sa použili ako kvantitatívne metódy výskumu (GIS a satelitné snímky), tak aj kvalitatívne metódy (dotazníky a riadené rozhovory). Až 80 % respondentov z oslovených domácností nachádzajúcich sa v okolí rezervácie Bia-Tano konštatovalo pokles pri 21 vybraných službách a produktoch poskytovaných miestnymi lesnými ekosystémami. Pokiaľ ide o ťažbu dreva v rezervácii, podľa prevažujúceho názoru respondentov rozsah ilegálnej prevyšuje legálnu. Ak sa tento trend nezmení, môžu lesy v rezervácii Bia-Tano čoskoro stratiť svoj sekvestračný potenciál.

Záver štúdie majú odporúčací charakter a sú adresované najmä decízorom a manažmentu rezervácie s cieľom zlepšiť starostlivosť o ekosystémy a prijať vhodné opatrenia na zabezpečenie udržateľnosti a odolnosti lesných ekosystémov v rezervácii voči nepriaznivým antropogénnym vplyvom. Zároveň užívatelia ekosystémových služieb poskytovaných miestnymi lesnými ekosystémami sa z výsledkov štúdie môžu dozvedieť o vplyve ich aktív na prírodu, ktorá je zdrojom uspokojovania väčšiny ich materiálnych i duchovných potrieb.



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