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Deforestation is driven by agricultural expansion in Ghana's forest reserves

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ABSTRACT

Ghana's protected forest reserves have suffered average annual deforestation rates of 0.7%, 0.5%, 0.4%, and 0.6% for the periods 1990–2000, 2000–2005, 2005–2010 and 2010–2015, respectively. The Ashanti region has recorded the second highest deforestation rates. Despite the government's efforts to maintain and protect Ghana's forest reserves, deforestation continues. We observed deforestation patterns in the Ashanti region of Ghana from 1986 to 2015 using Landsat imagery to identify the main causes of deforestation. We obtained and processed two adjacent Landsat images from the United States Geological Survey's (USGS) National Centre for Earth Resources Observation and Science at 30 m spatial resolution for 1986, 2002, and 2015. We then supported the results with findings from 291 farm household surveys in communities fringing the forest reserves. By 2015, dense forest covered 53.3% of the land area of the forest reserves, and the remaining area had been disturbed. Expansion of annual crop farms and tree crops caused 78% of the forest loss within the 29-year period. Afforestation projects are ongoing some of which employ the participation of farmers, yet agricultural expansion exerts more pressure on the remaining dense forest. Agricultural intensification on existing farmlands may reduce farm expansion into the remaining forest areas. Strengthening and enforcing forest protection laws could minimise the extent of agricultural encroachment into forests. Mixed tree-crop systems could reduce the effects of arable farming on deforestation, limit the clearance of trees from farmlands, enhance the provision of ecosystem services, and improve the soil's fertility and moisture content. A forest transition may be underway leading to more trees in agricultural systems and better protection of residual natural forests.

Introduction

The tropical forest areas of Ghana form part of the Guinea Forest Region of West Africa, one of 34 severely threatened World Biodiversity Hotspots [9]. Human activities have degraded about 85% of Ghana's Guinea Forest Region. Meanwhile,

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more than 10% of Ghanaians live at the fringes of forest reserves and benefit from timber and non-timber forest products [4]. Forest resources contribute up to 38% to the income of Ghana's forest dwellers and about 6% annually to the Gross Domestic Product of the country [4,8]. The decline of the resource will impact on the livelihoods of those who depend directly on the forest and the economy of the country as a whole. With the current rate of deforestation, Ghana's forests could completely disappear in 25 years [11]. One means to curb deforestation in Ghana is to identify and tackle the drivers of forest loss – the physical human-induced and location-specific drivers of deforestation such as agriculture.

Global biodiversity and other ecosystem services have declined markedly over the last three decades [19,24]. Much of this loss has resulted from human-induced degradation and deforestation [41]. In North America for instance, wood removal and fire are the major causes of deforestation [25]. In the Asia Pacific region, fire, wood removal, and expansion of estate crops are dominant causes of degradation and deforestation [26,28]. Protected areas have been created in an attempt to curb deforestation and biodiversity loss [14,27]. Assessments of global trends of deforestation in protected areas have shown the extent to which protected areas could reduce forest clearing [27,32]. The extent to which forest reserves (these are just one category of protected area) curb deforestation in African countries however have not been adequately assessed [12]. Mapping the trend of deforestation within forest reserves demonstrates the effectiveness of forest reserves in reducing deforestation and the spatial factors causing deforestation in the continent.

Africa has a relatively high rate of deforestation compared with other continents [19,24]. Assessments in West and Eastern Africa demonstrate the highest rate of deforestation. West Africa has had average annual net loss of 0.13% from 1990 to 2015 while Eastern Africa has had annual net loss of 0.19% from 1990 to 2015 [19]. Pastoralism, small-scale farming, and expansion of industrial tree crop estates have contributed to forest cover loss on the continent [37]. Much of the forest in the western part of the continent, especially in countries such as Ghana and Cote D'Ivoire, are now mosaics of agricultural crops and modified natural vegetation [14,37].

During the early 1900s, Ghana's natural forest covered a third of the country's land area [43]. Over-exploitation of timber prompted the colonial government to reserve some portions of the natural forest from the 1920s to the 1940s. This was done mainly to limit timber exploitation to outside the forest reserves [29]. The country has over 256 forest and nature reserves for sustainable production and protection purposes [36]. Deforestation in Ghana, including in forest reserves, continued to increase even after the reservation of the forests. By 1989, about 80% of the forest had been converted to other land uses [35]. Ghana recorded annual deforestation rates of 0.7%, 0.5%, 0.4%, and 0.6% for the periods 1990–2000, 2000–2005, 2005–2010 and 2010–2015 respectively (annual deforestation rate = total deforestation for a period/period of deforestation * 100) [19] and various studies have demonstrated similar trends especially within Ghana's forest reserves [14,31]. The forest reserves were created to protect the remaining biological diversity for continual flow of environmental benefits, yet deforestation continues in most reserves.

Deforestation in Ghana is attributed to overexploitation of natural resources through illegal and unsustainable logging and mining, and agricultural expansion, coupled with land tenure insecurity [8,40,42]. Most of these causes have been identified in studies utilising interviews with forestry officials and residents of forest fringe communities [8,15,16]. However, these findings do not have spatial attributes and they reveal subjective opinions of respondents. The extent of deforestation over a period cannot be known without spatially analysing land cover changes within the reserves. Land cover change studies are available mostly for the western and eastern regions of Ghana, [14,31,42]. Almost 23% of the country's forest reserves (3785 km^2) are located in the Ashanti region, making the region the second largest host of forest reserves in Ghana [36]. The forest reserves in the region also have the most fringe communities in the country some of whom depend on the forests for their livelihoods [36]. Mapping the extent and trend of forest cover loss in forest reserves in the Ashanti region will provide insight into what management strategies could apply to which reserves in order to reduce deforestation and sustain the remaining forests while not depriving the dwellers of their livelihoods. We define deforestation, the focus of this study, as the replacement of forest cover with other land cover such as agriculture.

Materials and methods

We mapped land cover changes in forest reserves in the Ashanti region of Ghana from 1986 to 2015 to determine the extent and trend of change in dense canopies and other land covers using satellite imagery. We then cross-referenced the change patterns of forest cover with household data on farming systems, farm size, and location of farms to assess the influence of agricultural practices on the transition from dense forest to croplands.

Study area

The Ashanti region of Ghana (Fig. 1) occupies a total land area of 24,389 km^2, and is centrally located in the middle belt of Ghana between longitudes 0.15 °W and 2.25 °W, and latitudes 5.54 °N and 7.46 °N [23]. The region falls within three ecological zones. The moist and dry semi-deciduous zones cover more than half of the region while the savannah zone covers some portions of the north due to extensive agricultural and other human induced activities. The region has mean annual rainfall of 1270 mm and two rainy seasons: April–August and September–November. The region covers about 10% of the land area of Ghana and contains 58 of the 256 forest reserves in the country (Fig. 1). We chose this region for the study because of its increasing deforestation gradually transitioning the northern part of the region from forest vegetation to savannah woodlands [36].

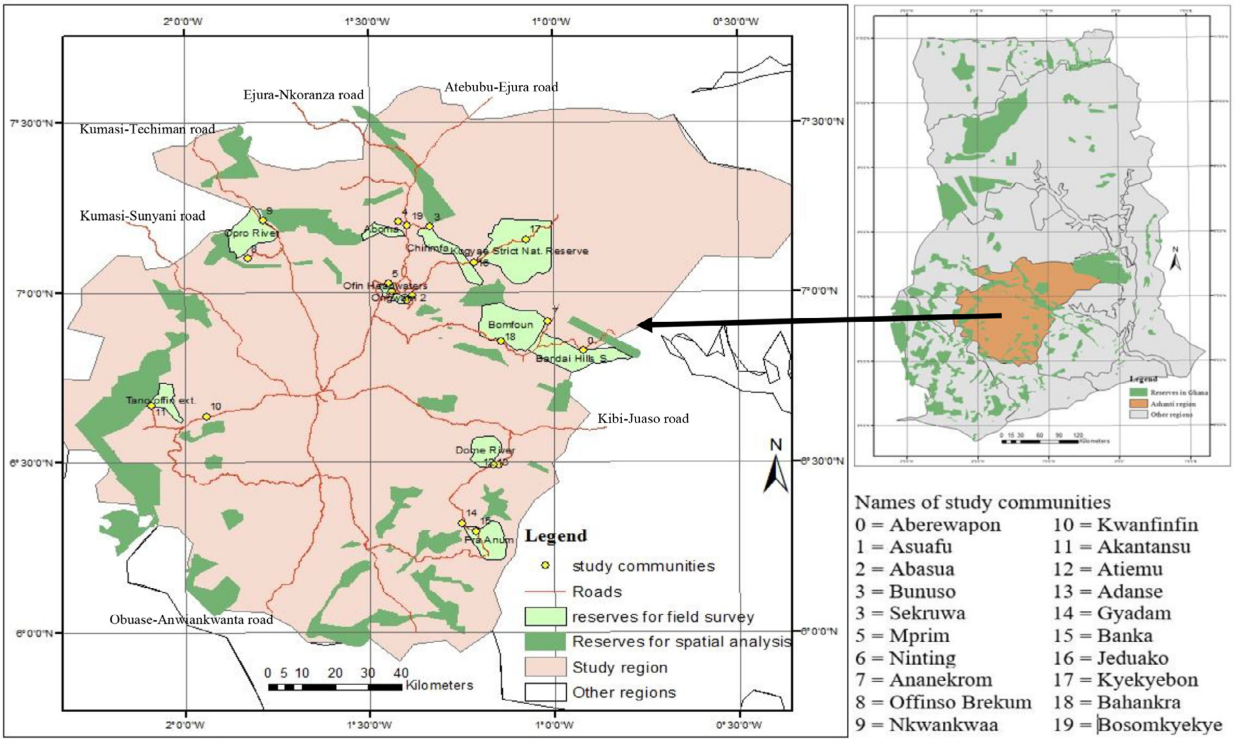

Fig. 1. The Ashanti Region of Ghana and its forest reserves.
Source: RMSC, 2016.

Satellite image processing and analyses techniques

The Ashanti region's 58 forest reserves have a total land area of 3785 km^2. It is impossible to carry out field inventory to examine the land cover changes within these reserves from 1986 to 2015. There is inadequate historical data for the 29-year period for such a spatial analysis, although there are some land cover change studies that covered portions of the region for some periods [3,13]. We therefore used Landsat satellite images from 1986 (Landsat TM 5), 2002 (Landsat ETM 7), and 2015 (Lnadsat 8 OLI/TIRS) for the land cover change assessment (see Appendix A for the properties of the images). We obtained the satellite images from the United States Geological Survey's (USGS) National Centre for Earth Resources Observation and Science (http://glovis.usgs.gov) at 30 m spatial resolution. Two adjacent images (path 194 rows 55 and 56) were analysed for 1986, 2002, and 2015 separately thus covering a 29-year period. All six images of this time series were acquired between November and January based on availability and level of cloud cover and to ensure possible comparability of vegetation signatures over the time series. We performed radiometric calibration of spectral reflectance values in the images to correct for systematic differences arising from varied illumination conditions and the use of different satellite platforms and Landsat sensors.

The images were geometrically corrected and geo-referenced by the USGS with reference system WGS 1984 UTM zone 30 N but had different acquisition dates. We therefore resampled the 1986 and 2002 images to the 2015 image such that all the three satellite images have the same geographical position. We used linear mapping function and bilinear resampling type to resample the images. We employed an unsupervised classification technique (hard classifier called "cluster" with broad generalization level) in IDRISI TerrSet version 18.30 to categorise each image into suitable land cover classes with the aid of forest cover maps from the Forestry Commission of Ghana [36] and Google Earth maps. The land cover classes were dense forest, logged forest, regrowth/tree crops, annual crop farms, and settlements/bare soil/dry grass. Dense forest is the land area covered with closed canopy of intact forest. Logged forest is the land cover where the closed canopy has been significantly disturbed through the cutting of timber. Regrowth/ tree crops refers to land cover with young trees from plantations or forest regeneration. Annual crop farms refer to agricultural lands covered with food crops. Settlements/ bare soil/ dry grass refers to land areas with no trees or crops but either bare ground, covered with grass, or buildings.

We created 365 random sample points for each of the three land cover images (1986, 2002, 2015) using stratified sampling technique. We used these points to assess the accuracy of the classification through ground truth data from Google Earth and forest reserves map from the Forestry Commission of Ghana [36]. See appendix B for the accuracy assessment results for the various land cover classes. We assessed the land cover change during the two shorter periods 1986–2002 and 2002–2015 and the single, longer period 1986–2015 using Land Change Modeller in IDRISI. This was done to assess whether the extent of land cover changes in the two shorter periods reflect the trends in the single longer period. We then computed the area of land cover transition between the periods to examine the extent of transition from forest to agriculture and other land cover types in the study area. The extent of transition from forest to agriculture and other land cover types was used to calculate the annual rate of deforestation over the 29-year period (annual deforestation rate = total km^2 of deforestation for 29 years/29 years * 100). Fig. 2 shows the trend and direction of forest cover change in the study reserves as at 1986, 2002, and 2015. The land cover classifications for 1986, 2002 and 2015 were highly accurate when compared with the minimum acceptable accuracy level of 85% [7].

Household and institutional data acquisition and analyses techniques

We collected farm household data on farming systems and practices, years of farming, and farm sizes and locations to complement the results from the classified images. The farmers are in communities both within and at the fringes of most of the forest reserves. The forest reserves are scattered across the region and most of the reserves have numerous fringe communities. The classified image for 2015 showed that the reserves in the northern part of the region have undergone more significant changes than the south. We therefore divided the region into two such that there is a northern section and a southern section. We randomly selected six and four reserves from the north and south of the region respectively for farm household data collection. We selected six reserves from the north because, proportionately, the northern section of the region has experienced more deforestation than the southern section. Although the standard distance used by the Forestry Commission of Ghana is 5 km [20] we chose to use 3 km to capture the communities that were closest to the reserves. The closer a community is to the reserve, the more influence it has on the reserve, all other things being equal. This criterion resulted in 192 communities. Two communities were randomly selected for each reserve and used for the survey. See appendix C for the reserves and associated communities used for the survey.

Farmers dominate almost all forest fringe communities in Ghana, including the study area. More than 70% of the rural households in the study area are farmers [23]. Based on this, we used a mean of 70% as the farm households in each community. Therefore, the total households for the 20 communities was 4202 out of which 2942 were farmers at the time of the survey [23]. We sampled 291 farm households using a simple random sample formula with 95% confidence level and 5% error margin for survey (see appendix D for the sample size computation [30]). The sampled farm households were proportionally distributed amongst the communities based on the total farm households in each community. We ensured that farmers selected for survey in each community were distributed across the entire community. This was done through randomly selecting houses from end to end of each community. Only one farmer was surveyed in each house since some communities had compound houses with more than one farm household. This helped to obtain a variety of information from different households. We finally contacted one forestry officer from the Forest Services Division of the Ashanti region for information about deforestation in the region. The data collected from the farmers were then analysed descriptively and related to the results from the forest-cover change analysis as well as the information from the forestry officer to examine the effects of agriculture on deforestation.

Results

Brief background of the farmers

Out of the 291 farmers surveyed, 27.8%, 28.2% and 21% have had 1–10, 11–20, and 21–30 years of farming experience respectively. The rest of the farmers have had between 31 and 61 years of farming experience. More than half (58.4%) of the farmers inherited their farmlands from their parents and grandparents. While 23.7% farmed leased lands given by other farmers, 10.3% of the farmers farmed on reserve land given by the Forest Services Division within their areas on condition that the farmers plant trees alongside their crops (Appendix E). The rest of the farmers acquired their farmlands through outright purchase or by means of gift. Almost a quarter (22%) of the farmers have their farms within the forest reserves while another 51.9% are within 5 km distance from the reserves. Farms of the remaining farmers are more than 5 km away from the reserve. Two-thirds (66.7%) and 25.4% of the farmers practice mixed cropping and mono cropping respectively while 2.1% and 5.8% of the farmers practice crop rotation and a combination of mixed and mono cropping, respectively. Cereals are the main food crop (40.9%) followed by tree crops (26.5%), tubers (24.1%), and vegetables (8.6%). These farming characteristics (see Appendix E) partly shaped the land-cover changes that occurred within the reserves.

Status of land cover within forest reserves in the Ashanti region

Forest reserves in the Ashanti region have passed through various trajectories of forest cover change for the 29 years (Fig. 2). By 1986, the forest reserves had already undergone some deforestation. About 80% of the land cover remained intact dense forest while the 20% had been disturbed (Fig. 3). Out of the disturbed portion, logging caused 57% of the disturbance. Tree crops/regrowth within the forest reserves accounted for 29% of the disturbance while annual crop farms and settlements/ bare soil/ dry grass contributed 11% and 3% respectively to the disturbance within the forest reserves.

Between 1986 and 2002, the extent of remaining dense forest within the reserves declined further by 35.5%. While dense and logged forest areas declined within the 16-year period, regrowth/tree crops, annual crop farms, and settlements/

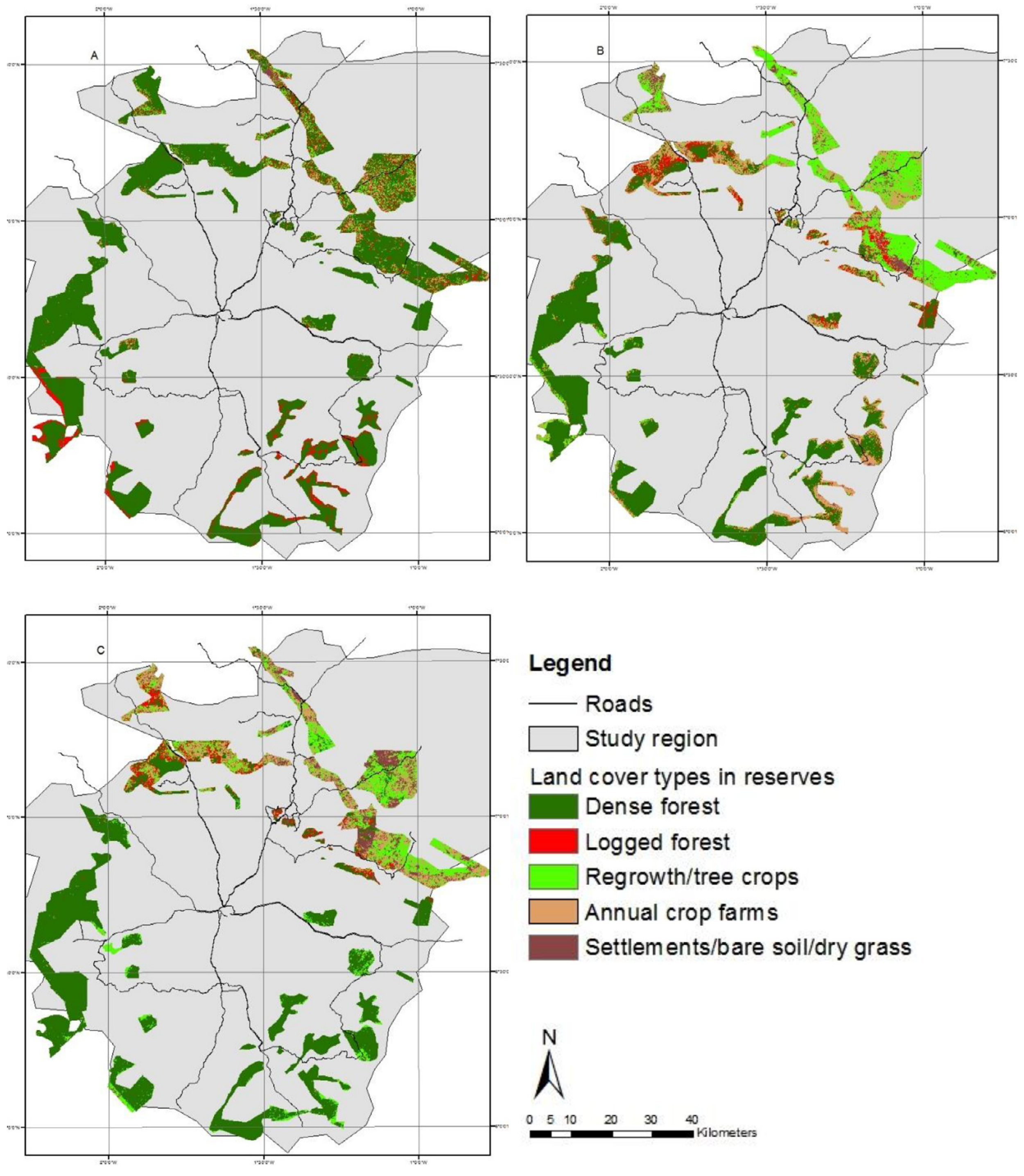

Fig. 2. Status of land cover change in forest reserves for 1986, 2002, and 2015. The upper left figure (A) represents the initial state of the forest reserves as at 1986, the upper right figure (B) shows the change that occurred by the end of the year 2002, and the lower right figure (C) shows the state of the reserves as at 2015.
Source: Authors' results from satellite image processing, 2018.

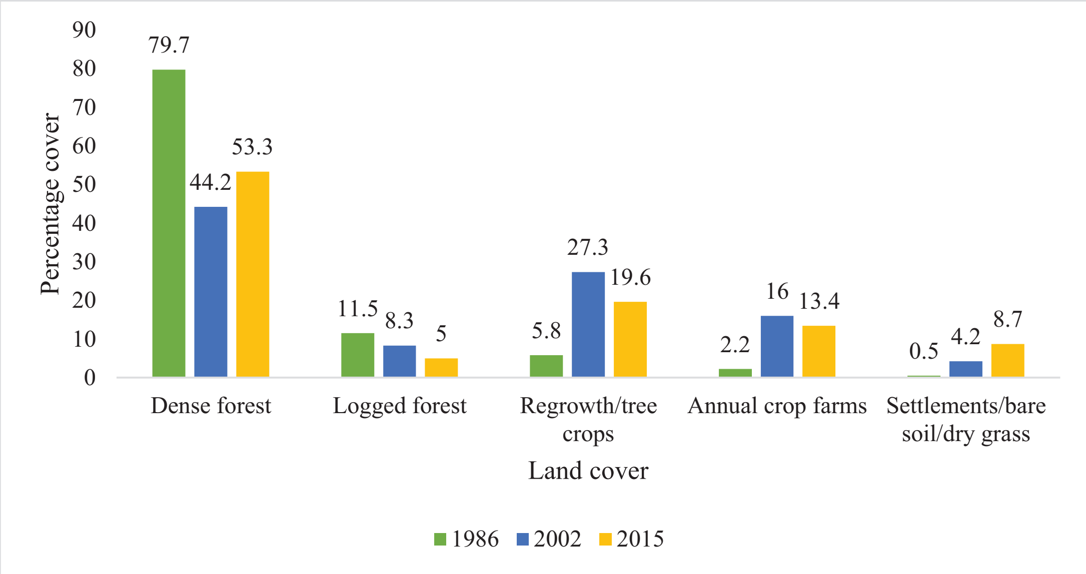

Fig. 3. State of land cover within reserves, 1986–2015.
Source: Authors' results from satellite image processing, 2018.

Table 1
Contributors to land cover change for 1986–2002 and 2002–2015.

1986–2002 contributors	Dense forest		Logged forest		Regrowth/tree crops		Annual crop farms		Settlements/ bare soil/dry grass	
	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%
Dense forest	–	–	205.49	169.9	637.69	78.3	409.66	80.4	91.44	64.6
Logged forest	−205.49	15.3	–	–	185.05	22.7	114.95	22.5	26.46	18.7
Regrowth/tree crops	−637.69	47.4	−185.05	−153.0	–	–	−3.32	−0.6	12.01	8.5
Annual crop farms	−409.66	30.5	−114.95	−95.0	3.32	0.4	–	–	11.53	8.2
Settlements/bare soil/dry grass	−91.44	6.8	−26.46	−21.9	−12.01	−1.4	−11.53	−2.3	–	–
Total net change	−1344.28	100.0	−120.98	100.0	814.05	100.0	509.77	100.0	141.44	100.0
2002–2015 contributors										
Dense forest	–	–	−120.15	−96.2	−67.81	−23.4	−152.39	−158.1	−0.93	−0.5
Logged forest	120.15	35.2	–	–	10.11	3.5	−18.87	−19.6	13.51	8.0
Regrowth/tree crops	67.81	19.9	−10.11	−8.1	–	–	94.85	98.4	136.84	80.8
Annual crop farms	152.39	44.6	18.87	15.1	−94.85	−32.8	–	–	19.94	11.7
Settlements/bare soil/dry grass	0.93	0.3	−13.51	−10.8	−136.84	−47.3	−19.94	−20.7	–	–
Total net change	341.28	100.0	−124.90	100.0	−289.39	100.0	96.34	100.0	169.37	100.0

Source: Authors' results from satellite image processing, 2018.
Note: The upper half of the matrix (first six rows) represents the contributors to land cover change from 1986 to 2002. The lower half (last six rows) represents the contributors to land cover change from 2002 to 2015. The columns represent the changes that have occurred in a land cover. The rows represent which land cover contributed to the changes in the columns. The percentages are calculated as change/total net change of the particular period.

bare soil/ dry grass each expanded more than three times (Fig. 3). A significant feature was the substantial increase in settlements/ bare soil/ dry grass in the study area within the 16-year period. Settlements expanded from 0.5% to 4.2% of the land area, more than 700% increment, followed by annual crop farms. Between 2002 and 2015, the downward trend in dense forest reversed while logged forest area continued to decrease. The land area occupied by regrowth/tree crops and annual crop farms decreased due to the increase in dense forest (Fig. 3). Settlements/bare soil/dry grass continued to increase despite the decline in cultivation within the reserves. Overall (from 1986 to 2015), the extent of dense and logged forests had decreased while regrowth/tree crops, annual crop farms, and settlements/bare soil/dry grass had increased over the 29-year period (Table 1). The succeeding section presents the reasons for the land-cover change dynamics within the reserves.

Contributory factors to land-cover change dynamics within forest reserves

The main factors causing deforestation within the reserves were the expansion of annual crop farms and tree crop plantations followed by logging. Out of the 1344 km^2 of deforestation that occurred between 1986 and 2002, expansion of

Table 2
Land cover change within forest reserves, 1986–2015.

Land cover	1986–2002 (%)			2002–2015 (%)			1986–2015 (%)		
	Gain	Loss	Net	Gain	Loss	Net	Gain	Loss	Net
Dense forest	2.8	47.3	−44.5	31.6	11.2	20.4	7.3	40.5	−33.2
Logged forest	66.8	94.7	−27.8	47.8	87.6	−39.8	40.5	97.1	−56.6
Regrowth/tree crops	410.8	39.2	371.6	37.3	65.3	−28.0	304.1	64.6	239.5
Annual crop farms	620.9	84.1	536.8	66.1	82.0	−15.9	507.9	72.5	435.4
Settlements/bare soil/dry grass	845.3	55.6	789.7	190.7	84.4	106.3	1813.9	78.5	1735.4

Authors' results from satellite image processing, 2018.

tree crop plantations (and some regrowth) and annual crop farms accounted for 78% (Table 1). Cross reference with the household data indicated that more than one-fifth (22%) of the farmers surveyed had their farms within the forest reserves and 42% of these farmers inherited their farmlands from their parents and grandparents. The inherited farmlands totaled 1.19 km^2 and were inherited between 1958 and 2015. These farms belonged to people living within the forest before the Forestry Commission of Ghana demarcated the areas as reserves. The Commission delineated the boundaries of the farms and gave them to their rightful owners. Most of these farms have however been expanded into the forest reserves.

Cocoa and oil palm were the major tree crops these farmers had planted amidst their food crops. According to the farmers, when the tree crops formed a closed canopy such that food crop cultivation was no longer possible, they extended their farms to areas with no tree cover to grow their food crops. This strategy had resulted in a gradual expansion of farms into the remaining forest reserves. According to the farmers, they extend their farms to areas of the reserves that have already been logged or where the tree canopy is not yet closed. The Landsat data showed that unsustainable logging (transition of dense forest to logged forest) and expansion of settlements (transition from dense forest to settlements/bare soil/dry grass) caused 15.3% and 6.8% of the deforestation that occurred between 1986 and 2002, respectively (Table 1). According to the household survey, these communities existed within the forest before the reservation took place from the 1920s to the 1940s. Since then, the communities have been expanding due to population growth and activities of humans within the communities such as extensive farming and illegal and unsustainable logging have partly contributed to the deforestation.

Land-cover change dynamics in the reserves demonstrates deforestation; however, there were also some forest gains. Dense forest recorded a net gain of 341 km^2 from 2002 to 2015 (Table 1). This gain was derived from previously logged forest that was not taken over by farmers and has naturally regenerated over the 13 years (35.2%), annual crop farms that were mixed with tree crops in 2002 and had fully grown to form dense canopy (44.6%), and 20% from regrowth/tree crop plantations (Table 1). The reason for the migration of annual crop farms into dense forest was, first, due to the growing of tree crops by the farmers who inherited their farmlands. The maturity of tree crops such as cashew, cocoa, mangoes, oranges, etc. to form dense canopy should be regarded as "deforestation in disguise" since these tree crops are seen as causes of deforestation in Ghana's forest reserves by the Forestry Commission of Ghana. The second reason was a planned reforestation strategy undertaken by the Forestry Commission of Ghana. According to the respondent from the Forest Services Division of the Forestry Commission, since the year 2001, the Commission has embarked on series of National Plantation Projects some of which involved the participation of farmers in forest fringe communities.

A cross reference with the household data indicated that out of the 64 farmers who farmed in the forest reserves, 47% had obtained their farmlands from the Forest Services Division in their respective areas. These lands belonging to the 47% (or 30 farmers) totaled 0.46 km^2 and were acquired between 1998 and 2018. The farmers explained that the Forestry Officers required them to take care of the young trees planted (mainly teak) while they tilled the land. According to the farmers, after three to four years of cultivating the land and nurturing the planted trees, they had to move to new lands since the trees begin to form a canopy. This strategy coupled with the regeneration of logged forest, and the maturity of tree crops (deforestation in disguise) to form dense canopy altogether contributed to the increase in dense forest cover over the 13-year period. Nevertheless, the extent of deforestation over the previous 16-year period had resulted in a 33.2% net loss of intact dense forest over the 29-year period (Table 2).

Results from Table 2 showed that within each land cover type there were both losses and gains over the study period. Dense forest cover for instance gained 2.8% extra land from other land covers but lost 47.3% of its cover to other land cover types within the same period of 1986 to 2002 resulting in 44.5% net loss for the 16-year period. However, between 2002 and 2015, dense forest recorded more gains than losses hence, registering 20.4% increase in land cover. The net gain of dense forest over the 29-year period was lower than the net loss and this resulted in net deforestation. Logged forest recorded more losses than gains through a mix of maturity to dense forest and conversion to tree crops, annual crop farms, and settlements/ bare soil/ dry grass (Table 1) throughout the 29-year period contrary to regrowth/tree crops, annual crop farms, and settlements/ bare soil/ dry grass (Table 2).

By 2015, the forest reserves had recorded annual deforestation rates of 1.1% for dense forest and 2% for logged forest. Regrowth/tree crops and annual crop farms had recorded annual increases of 8.3% and 15% respectively over the same period within the forest reserves. Settlements/ bare soil/ dry grass that occupied only 0.5% of the land area of the forest reserves increased by 60% annually from 1986 to 2015 (Table 2).

Discussion

Forest resources support the livelihoods of rural dwellers and provide environmental and ecological services. A change in forest cover has impacts on the provision of forest goods and services. Deforestation threatens ecosystem services such as climate regulation, biodiversity conservation, water catchment protection and livelihood support to forest dwellers [38]. Sustaining the remaining forest in the tropics is paramount to continued provision of ecosystem services.

Land cover change within forest reserves, 1986–2015

Ghana's forest cover has been declining since before 1986 [29,35] and the protected forest reserves in the Ashanti region are an example (Fig. 3 and Table 1). The decline in dense forest over the 29-year period was similar to what was recorded for the entire country between 1980 and 1985 [35]. The extensive deforestation that took place within the 5-year period (1980–1985) partly resulted in the state of the dense forest cover as at 1986 (Fig. 3). Since 1990, the annual deforestation rate for Ghana has been estimated at 0.6% [19]. The Ashanti region is the second largest host of forest reserves in the country and has recorded annual deforestation rate of 0.5% higher than the country's overall estimate [21]. Although the estimates may differ due to different assessment methods used, evidence shows that deforestation in Ghana occurs more in the most forested areas and the Ashanti region is one of them [14,31]. The continuous clearing of the forests in the study area will lead to loss of biodiversity and other ecosystem services and threaten the livelihoods of forest dependant communities.

More than a tenth of Ghana's population live within and at the fringes of forest reserves [31]. These dwellers collect non-timber forest products (NTFPs) for their livelihoods while some of them legally and illegally farm within the reserves for survival [6]. Others engage in plantation programs through which they get access to forestlands for their food crops production [1]. Aside from access to farmlands, forest resources contribute 38% to the income of Ghana's forest dwellers [8]. The contribution of forest resources to the income portfolio of the people is also evident in other tropical countries. Marketing of wild foods from forests contributes between 15% and 40% to rural household income in Nigeria, Ethiopia, Sudan, Togo, and South Africa [33,44]. Forest resources could serve as safety nets for forest dependant communities in off-farming seasons. Nonetheless, this safety-net role of forests will eventually end if the current trend of deforestation continues.

Human activities mainly agriculture, and illegal and unselective logging have degraded 85% of Ghana's Guinea Forest Region, a severely threatened World Biodiversity Hotspot [9]. In addition, unsustainable logging and agricultural activities that occurred between 1993 and 2010 had led to a 50% decline in forest understory birds [9]. The maintenance of forest biodiversity in Ghana is contingent upon the regulation of human activities within the forests. Strict enforcement of environmental laws is key to effective regulation of human activities such as illegal logging and farming that trigger deforestation and subsequent biodiversity loss.

Contributory factors to deforestation within forest reserves

Population growth coupled with increasing rural poverty, resulting in agricultural expansion, has dominated the global discussion on the causes of deforestation in the tropics [38]. Between 1986 and 2015, a third of the intact dense forest within the study reserves was converted to mainly tree crop plantations and annual crop farms. Agricultural expansion has caused 78% of the deforestation in the study reserves while expansion of settlements and other human activities has caused 6% of the deforestation. The reason for the existence of farms and settlements in the forest reserves is that, before the demarcation of the areas as forest reserves, these settlements and farms already existed within the forests. According to a respondent from the Forest Services Division, The Forestry Commission of Ghana allowed the settlers (known as "admitted settlers") and their farms (known as "admitted farms") to remain in the forest reserves. The Commission delineated the boundaries of the settlements and the farms so that encroachment of the forest reserves would not occur.

However, population growth and weak enforcement of forest protection laws have led to gradual expansion of the admitted settlements and farms into the remaining forest reserves over the 29-year period. The majority of the settlers have their inherited farms within the forest reserves and tree crops such as cocoa, cashew, oil palm, avocado, mango, and citrus are the main cash crops they grow. These admitted settlers interplant their food crops with the cash crops and depend on natural soil fertility to increase output. According to the farmers surveyed, when the tree crops form a canopy, they encroach the adjoining forest for fertile land to cultivate their food crops for consumption. The forested areas fringing farms serve as land banks for fertile soil for most farmers in the hinterlands owing to their inability to buy farm inputs to enrich the existing soil [1,2]. Since the tree crops are the main source of income for the farmers, in about two years of producing food crops on the newly cleared land, the farmers would start inter-planting the food crops with tree crops. After about five years of continuous cultivation on the new land, the need for more fertile land for food crops cultivation would emerge. This process of forest clearing for agriculture coupled with unsustainable logging has been the major cause of deforestation in the Ashanti region and Ghana as a whole [8].

The economic benefits from tree crops drive their expansion but not their intensification thereby causing more forest clearing especially in areas with weak enforcement of forest protection laws [1]. A major challenge for conservationists and agriculturalists in the forest frontiers of Ghana has been how to balance the economically driven agricultural expansion with conservation priorities to maintain ecosystem integrity and species viability [10]. The Forestry Commission of Ghana has implemented afforestation programs more than two decades ago to reverse deforestation in the country [21]. Part of these programs allowed farmers to be given degraded forestlands to interplant their food crops with specific trees [1] and this was evident in the study area. Yet, agricultural expansion has continuously exerted pressure on the remaining forest cover since 1986. Agricultural intensification is needed to improve yield and increase output without necessarily increasing farm size to cause deforestation. According to the farmers surveyed, those whose farms were in the reserves have not been using any modern technology to improve yield and increase output. Just as farmers at fringes of off-reserve forests in Ghana use the forests as land banks to increase agricultural production [34], farmers within the forest reserves have relied solely on the reserves for fertile soil. Intensifying agriculture with fertilisers and other soil-enriching techniques would help improve yield, increase output, and consequently spare the remaining forest.

Lands with agricultural potential are available in many developing nations including Ghana, but they mainly consist of forests whose conversion would mean loss of biodiversity and ecosystem services [22]. For farmers who farm in forest reserves, the only option to produce more without causing deforestation is to apply modern farm techniques. The use of improved seeds, fertilizers and soil enrichment techniques have proven to double yield on the same piece of land [5]. However, farmers would require education and training on the use of modern farm methods for high yielding results. Producing more on the same piece of land would be one way of contributing to food supply without causing forest loss but this would require strict enforcement of forest protection laws.

Africa's population is expected to quadruple in the 21st century [18]. This will create demand for increased agricultural land to meet food demand. It has been suggested that agricultural production would have to increase by 70–110%, implying that about 1 billion hectares of land would have to be converted to agriculture [17]. Agricultural expansion means loss of forest cover, a phenomenon well demonstrated in the study area over the 29-year period. An alternative to increasing yield without expanding farms would be to intensify farming [39]. Farm intensification involves using high-yielding varieties of seeds and spacing for planting, acceptable methods of controlling pests and diseases, and the right quantity of organic and inorganic fertilizers to boost the yield of crops. Farmers are willing to adopt farm intensification techniques to increase yield but the cost involved and the lack of farmer education and training programs make them continue to practice traditional farming methods. Agricultural intensification could double or even triple smallholder farmers' output [5]. The remaining forest in Ghana could be conserved and the food requirements of the populace could be met if farmers intensify their farming. The surplus yield resulting from the intensification could be marketed and contribute to the farmers' household income.

Conclusion

We examined the patterns of deforestation in the Ashanti region of Ghana to identify the main factors causing forest loss in the region. Through the images' change detection process, we showed that agriculture is expanding to dominate land cover in the Ashanti study area and this has been and remains a major threat to the remaining dense forests. Forest extent has been declining annually and tree crops and planted forests are replacing the original dense forests. Each of the study periods recorded a loss and a gain, but the amount of the annual losses has reflected the decline in dense forest cover over the 29-year period. Agricultural expansion into forests, the main cause of deforestation in the study area, will not provide a sustainable long-term solution to food security and poverty reduction. Agricultural intensification through the adoption of sustainable agricultural practices is the only viable long-term solution for achieving food security while minimising effects on the environment.

Agricultural intensification could offer a wide range of benefits. First, it could save the forest and its biodiversity since farmers would no longer depend on forest as a source of fertile land for agricultural production. Second, the food needs of smallholder farmers would be met and the surpluses could be marketed to increase the income portfolio of farm households. Third, agricultural intensification could allow smallholder subsistence farmers to transition to become commercial farmers without expanding their land holdings. Promoting agricultural intensification, employing technology to decrease post-harvest losses and wastes, and ensuring efficiency in the food chain system could be a significant pathway out of poverty, ensure sustained food supply to manage the increasing population, and minimize pressure on the remaining forests to provide biodiversity conservation benefits.

To sum up, this research has demonstrated that increased agricultural production is the main factor behind forest encroachment in Ghana, just as has been found in other developing countries [8,34]. Addressing deforestation in developing countries therefore requires collaborative action between foresters and agriculturalists. While foresters continue to protect and sustain the remaining forests, further research is required to investigate how farmers, especially in forest fringe communities in developing countries, adopt progressive but sustainable agricultural practices as a way to enhance yields but also restore the fertility of farmlands and subsequently lessen the pressure on forest for fertile land.

Declaration of Competing Interest

None.

CRediT authorship contribution statement

Emmanuel Opoku Acheampong: Formal analysis, Writing - review & editing, Validation, Conceptualization, Data curation. **Colin J. Macgregor:** Formal analysis, Writing - review & editing, Validation. **Sean Sloan:** Formal analysis, Writing - review & editing, Validation, Conceptualization, Data curation. **Jeffrey Sayer:** Formal analysis, Writing - review & editing, Validation.

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Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2019.e00146.

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