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Investigating the impact of a long-term research and conservation project on the expansion of land use and land cover in a remote area of central DRC

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ABSTRACT

Anthropogenic impact and population growth have caused a dramatic loss of biodiversity worldwide. Deforestation due to logging, mining, and burning are of particular severity in tropical rainforests with the Amazonian and Congolese basins harboring the largest reminders on our planet. While research projects particularly those with permanent presence on ground have been considered as excellent conservation measures to protect habitat and wildlife, no studies are known to assess their negative implications. Here, we assess the impact of a long-term research project on the tropical rainforest in the Democratic Republic of the Congo (DRC). We investigate the LuiKotale Bonobo project (LKBP) established for research and conservation in 2002, closely cooperating with several villages located in the buffer zone of Salonga National Park, Block South, Territoire d'Inongo, Province Mai-Ndombe, DRC. We combine the results of Land Use and Land Cover (LULC) drawn from satellite imagery with population data for four villages comparing anthropogenic impact before and after establishment of the project covering 31 years between 1987 and 2018. While deforestation decreased in Lompole, the first and main village of collaboration, it increased continuously over time in neighboring villages. Increase can be linked to population growth and cash income provided by the LKBP with habitants investing into construction material and expansion of agricultural fields for cash crops.

1. Introduction

Between 2015 and 2020, tropical rain forests globally disappeared at a rate of 10 million ha/year (FAO 2020a) and deforestation tends to be increasing in Central Africa (Réjou-Méchain et al., 2021). Main decline came from commercially driven anthropogenic land use such as mining (Sonter et al., 2017), logging (Edwards et al., 2014), and burning (Juárez-Orozco et al., 2017; Armenteras et al., 2021; van Wees et al., 2021), but also increasingly from land use connected to population growth such as shifting cultivation, urbanization and road expansion (van Vliet et al., 2012; Malhi et al., 2013; Berakhi et al., 2015; Curtis et al., 2018; Kleinschroth et al., 2019). While in Asia and South America, tropical rain forest loss is predominantly driven by interests of the agricultural industry generating cash-crops such as oil-palm plantations, fiber, soya and pasture (Barona et al., 2010; Abood et al., 2015), in sub-Saharan Africa it is mainly driven by shifting cultivation (92%) (Curtis et al., 2018; Chiaka and Zhen 2021; Jellason et al., 2021). Overall, forest loss in the tropics is mainly related to fire, with rather small scale fires in Africa compared to large scale fires in South America and Asia (van Wees et al., 2021).

In sub-Saharan Africa, population growth is considered as main reason for deforestation (Otum et al., 2017; Oyetunji et al., 2020) with two major factors being responsible: (1) subsistence farming by local people (Jellason et al., 2021); (2) commercial interests by people usually originating from afar responsible for (a) logging and (b) land conversion for agricultural use (cash-crops) (De Marinis et al., 2021). Both logging and agricultural expansion are causing biodiversity loss (Chiaka and Zhen 2021).

The largest block of tropical rainforest in Africa is the Central African Forest block, covering an estimated area of 800,000 km^2 and spanning from Cameroon, Gabon and Equatorial Guinea in the West over the Central African Republic, the Republic of the Congo and the Democratic Republic of the Congo (DRC) to Burundi and Ruanda in the East. The DRC, with 2,344,858 km^2 the continent's second largest country, holds

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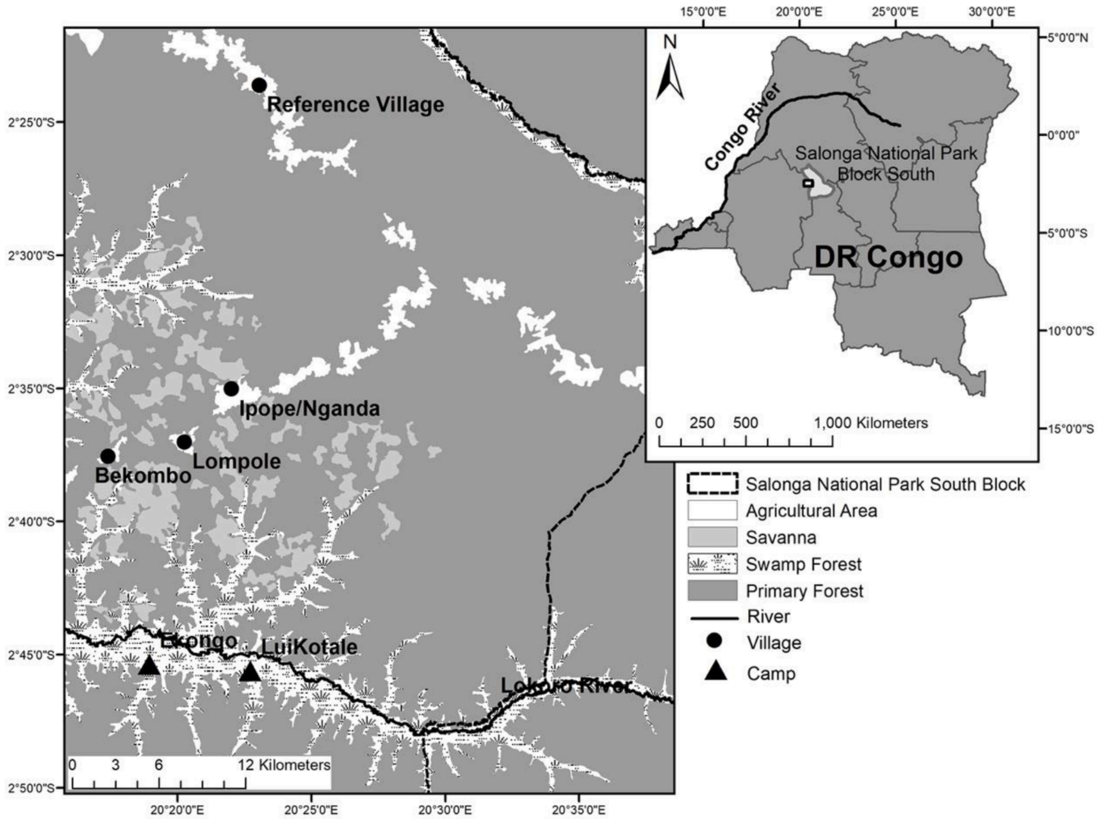

Fig. 1. Land use and land cover southwest of Salonga National Park, Block South, DRC, with locations of research camps LuiKotale and Ekongo of the LuiKotale Bonobo Project (LKBP), the villages involved (Bekombe, Lompole, Ipope/Nganda); and the reference village. White patches represent the villages' agricultural zone, grey patches naturally occurring savannahs.

with around 56 % of its total land area the majority of this forest block (FAO 2020b; World Bank Data 2021). Between 2002 and 2015 a forest loss of 12% was estimated for rural complex expansion located in areas within 5 km to mines, logging concessions and plantations (Molinario et al., 2020). Later assessments showed around 3,110 km^2 of forest per year being degraded due to uncontrolled logging and shifting cultivation (2010 – 2015) (FAO 2015).

In the two decades between 2000 and 2020, DRC's population has almost doubled increasing from 47,105,830 to 89,561,404 inhabitants (World Bank Data 2021). In 2020, two-thirds of the population lived in rural areas, with most of these people being dependent on slash and burn agriculture for subsistence farming (Nackoney et al., 2013). The considerable population growth (47%) lead to increased deforestation in rural areas (Tranquilli et al., 2014; Ochege et al., 2017). In addition, this population growth also contributed to depletion of other non-timber forest products for subsistence including a wide range of animals (Fa et al., 2003; Effiom et al., 2013).

Attempts to implement conservation measures to counter or decelerate the loss of fauna and flora are manifold, although their efficiency has rarely been investigated. For example, implementation, harvest and commercialization of non-timber forest products such as cash crops, fish and livestock are considered to support local households and reduce poverty as well as deforestation (Lowore et al., 2018). For the protection of wildlife, permanent presence of researchers has been considered an excellent conservation measure (Struhsaker et al., 2005; Campbell et al., 2011). However, although undoubtly conservation oriented, their overall impact on other fronts such as their influx of money and material, has not been investigated so far.

Here, we fill this gap by investigating the effect of the LuiKotale Bonobo Project (LKBP), a long-term research and conservation project, on local human demography, their villages and land-use expansion. Since 2002, LKBP, focusing on the bonobo (*Pan paniscus*), an endangered species of great apes, and the larger eco-system it is embedded in, is permanently present on ground. It is located in the buffer zone of Salonga National Park, Block South, Territoire d'Inongo, Province Mai-Ndombe, Democratic Republic of the Congo (DRC) (Hohmann et al., 2003). It is operating with a team of international researchers and assistants, including and closely collaborating with local communities.

We hypothesize that the impact of the project is visible in both demographic changes and land use patterns. Specifically, we predict that villages cooperating with the project

(1) expand their fields beyond the need of subsistence as the project obtains local crops regularly for the team's provisioning.
(2) increase their population size beyond the usual birth rate as the project providing options for income generation may incite influx from people from other villages.
(3) reduce or keep their amount of cash crops stable, as the project's monetary influx allows to cover the need for cash.

We assess land use and land cover changes across time using remote sensing in order to document both the actual and historic states of land use/land cover patterns on a local level (Mengistu et al., 2007; Potapov et al., 2012). We focus on the spatio-temporal development of Shifting Cultivation in four villages. We also estimate future land use for one selected village applying a state- and-transition simulation model (STSM) (Daniel et al., 2016). We judge the decline in pristine forest comparing satellite imagery before and after the project was established, and incorporate demographic data for the village the project started its collaboration with.

Table 1
Characteristics of satellite imagery used for assessing shifting cultivation.

Satellite / Sensor	Date	Resolution	Bands	Village
Landsat 5 TM	06.02.1987	30 × 30 m	3, 4, 5	All Villages
Landsat 5 TM	12.02.1995	30 × 30 m	3, 4, 5	All Villages
Landsat 5 TM	24.03.2001	30 × 30 m	3, 4, 5	All Villages
Landsat 8 OLI/ TIRS	21.07.2018	30 × 30 m	4, 5, 6	All Villages
WorldView-02	05.03.2011	0.5 × 0.5 m	Natural Color	Bekombo
WolrdView-01	12.07.2010	0.5 × 0.5 m	Panchromatic	Ipope/Nganda
WolrdView-01	12.07.2010	0.5 × 0.5 m	Panchromatic	Lompole
WolrdView-01	14.03.2009	0.5 × 0.5 m	Panchromatic	Reference Village

2. Materials and methods

2.1. Study area

Fig. 1 shows the field site of the LuiKotale Bonobo Project (LKBP) located approximately 13 km bee line to the western border of Salonga National Park, Block South. The study area of our investigation is located 25 km north of the field site and consists of the villages Bekombo (BK), Lompole (LP), Ipope, and Nganda (IG), where the latter two have fused into one (Fruth et al., 2014). Each of these villages averages 0.24 km^2 and harbors 332 people (Median 356; range 675 – 295 habitants) on average.

The reference village (RF) is located another 25 km beeline North of Lompole village and does not maintain a collaboration with the LKBP. Lompole has been in close collaboration with LKBP since 2002, followed by Bekombo in 2016.

The field site is only accessible by foot with bi-weekly transports granting provisioning. A large proportion of food consumed by the project's team, on average 10-15 people at a time, comes from above mentioned villages, where the local population practices slash and burn agriculture for subsistence including exchange and some cash income. Firewood comes from the surrounding forest. Main source for carbon hydrates is Manioc (*Manihot esculenta*) cultivated as staple, followed by mais (*Zea mays*), rice (*Oryza sativa*) and banana (*Musa* spp.). In addition, various vegetables, fruits, sugarcane and tobacco are grown and supplemented by forest produce harvested from the wild (Mato Kelenda 2006; Fruth 2011).

The climate is equatorial with abundant rainfall averaging 2.132 mm/year (SD +/- 546 mm; 2003 – 2009), a small dry season in February and a larger one between May and August. Mean monthly temperatures range between 18 and 29°C with a minimum of 15.7°C and a maximum of 37.3°C (2003–2009) (Fruth et al., 2014).

2.2. Data collection

2.2.1. Satellite imagery

We used Landsat satellite images from the years 1987, 1995, 2001 and 2018 allowing measurements of the extension of fields for each of the four villages before and after establishment of the LKBP research project (see Table 1 for details). Images were selected based on their availability and minimal cloud coverage over the area of interest. Cloud cover was less than 15% for all Landsat satellite images used.

High resolution WorldView satellite images were acquired for the time period 2009 – 2011 (Table 1). All villages were captured by WorldView-1 as panchromatic images except for Bekombo, which was captured by WorldView-2 as a natural color image.

2.2.2. Houses and demography

We used the number and quality of houses owned by each household as a proxy for the cash income of a given family. Each house was georeferenced using a handheld GARMIN GPS 62 (or 64). Details such as size, construction material of walls (clay bricks, palm leaves), roof (corrugated iron, palm leaves), and condition (well maintained, worn down) were recorded. Clay bricks were sun dried, palm leaves (*Elaeis guineensis; Raphia* spp.*; Sclerosperma mannii*) were used as such or converted into shingles. Houses were distinguished according to function such as residence, kitchen, school or assembly place. Households owning multiple houses, large house(s) or houses covered by corrugated iron have higher income compared to those built of palm leaves. In addition, we recorded number and size (residents of all age- and sex-classes) of each household for Lompole (2002, 2013 and 2018) and Bekombo (2018) providing the data for the villages' demographic change.

2.2.3. Analysis

The software ArcMap provided by the Environmental Systems Research Institutewas used for the satellite image processing (ESRI, 2020). The bands Short-Wave Infrared (SWIR) 1, Near Infrared (NIR) and Red of the Landsat satellite imagery were merged into one layer using the tool "layer stacking" and applying the "Maximum Likelihood Classification" to extract all pixels representing the class <Field>.

To achieve a better horizontal accuracy of the high-resolution WorldView-1 and WorldView-2 imagery, we applied the orthorectification tool to depict objects and features closer to their actual location. In addition, we applied an image enhancement tool for improved visualization by increasing the contrast between the features and applying a sharpening filter or radiometric stretch to the pixel values. To distinguish the boundary between cultivated areas and tropical rain forest, a semi-automated classification was applied to all satellite imagery. In addition, based on the high-resolution imagery, the village area including details of trails and houses was assessed. By that, we obtained maps depicting village details, and the boundaries between village and fields, and fields and forest.

For the calculation of the area of shifting cultivation, we considered Landsat imagery of the year 1987 as baseline, and established four subsequent intervals I – IV corresponding to the satellite imagery acquisition dates 1987 – 1995 (= I), 1995 – 2001 (= II), 2001 – 2009/ 2010/2011 (= III) and 2009/2010/2011 – 2018 (= IV). We calculated the change of area and change of percentage of shifting cultivation for each interval.

In order to assess the annual speed (fast / slow) of change in shifting cultivation (relative loss of forest), we used the 2.3 % of DRC's annual forest loss published for the year 2000 (Potapov et al., 2012) as threshold for comparison. We applied the shifting cultivation change rate analysis (Nackoney et al., 2013) to each village.

2.2.4. Validation

To achieve an accurate classification of Landsat and WorldView imagery, a groundcover survey was conducted walking one line transect of 1 km length in the villages Lompole and Bekombo, recording field limits, their crops and ripeness stages to both sides of the transect. Ground truth data were obtained using a handheld GPS 62 or 64.

2.2.5. Simulation

In order to predict transitions from forest to cultivated areas for Lompole village extrapolating to the next 50 years, we used the open-source Tool ST-Sim version 3.2.28 of the free-source software SyncroSim version 2.2.27 (APEX 2020). SyncroSim is based on a stochastic state and transition simulation model which allows to calculate land use and land cover change under different annual rates of shifting cultivation over time. We set the initial start time to the year 2018, and the end time to the year 2068. We used a non-spatial model with the state classes of forest and fields. We used three scenarios which differed in their shifting cultivation rate to simulate the transition from forest to fields with population increase as the driving factor. For Scenario 1 (S1), we chose a shifting cultivation rate of 0.05 km^2 which was the average annual increase of fields between 1987 and 2018 in Lompole. For Scenario 2 (S2), we chose a shifting cultivation rate of 0.1 km^2 and for Scenario 3 (S3) a shifting cultivation rate of 0.18 km^2, being the highest

Table 2
Shifting Cultivation increase and percentage change of total village area derived from satellite imagery between 1987 and 2018.

Village	1987 – 1995		1995 - 2001		2001 - 2009/2010/2011		2009/2010/2011 – 2018		1987 - 2018	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Bekombo	0.123	11.4	0.051	6.8	0.200	8.8	1.248	33.6	1.622	20.7
Ipope/Nganda	0.371	34.3	0.186	24.7	0.860	37.8	1.609	43.3	3.026	38.7
Lompole	0.375	34.7	0.220	29.3	0.424	18.7	0.368	9.9	1.388	17.7
Reference Village	0.212	19.6	0.295	39.2	0.789	34.7	0.490	13.2	1.787	22.8
Total	1.082	100	0.752	100	2.273	100	3.716	100	7.823	100

measured annual shifting cultivation increase measured in Bekombo, the neighboring village of Lompole.

3. Results

3.1. Changes in agricultural land use 1987 – 2018

The total area of shifting cultivation for the 5 villages investigated increased from 6.317 km^2 in 1987 to 14.053 km^2 in 2018. Across these 31 years, the shifting cultivation area increased by 7.823 km^2, with the smallest increase of 0.752 km^2 (10%) between 1995 and 2001, and the largest one of 3.716 km^2 (48%) between 2009/2010/2011 and 2018 (Table 2).

The average expansion per year was 3%. Comparing expansion of fields across villages, Lompole fields did not increase significantly compared to the neighbouring villages Bekombo and Ipope/Nganda ($X^2 = 0.85$, $p = 0.36$).

Fig. 2 shows the general expansion of fields for all villages from 1987 onwards. The 1987 extension represents village squares and fields since the villages' establishment in the 1920s.

Table 2 shows the increase of fields in km^2 and the annual shifting cultivation change rate in % for each village and time interval, as well as the overall time period (1987-2018).

Ipope/Nganda. The cumulative area used for agriculture was 0.557 km^2 in 14 years (1987 – 2001) and 0.86 km^2 in the subsequent 9 years (2001 – 2010). It almost doubled to 1.609 km^2 in the next 8 years (2010 – 2018). With 4% and 12% / year respectively, the villages' relative loss of forest to shifting cultivation was slower in the first three intervals, and highest between 2010 and 2018.

Bekombo. The cumulative area used for agriculture was 0.374 km^2 in 24 years (1987 – 2011). It increased in the subsequent 7 years (2011 – 2018) by 1.248 km^2. This increase in shifting cultivation was significant ($X^2 = 0.57$, $p = 0.1$). In 2018, the area cleared for fields totaled 1.622 km^2, exceeding that of Lompole (1.388 km^2) by 0.234 km^2.

Lompole. The cumulative area used for agriculture was 1.388 km^2 in 31 years (1987 – 2018). The increase in area used for fields almost doubled from 0.22 km^2 to 0.424 km^2 between the second and third interval, and retained nearly the same level (0.368 km^2) between 2010 and 2018.

Reference Village. The cumulative area used for agriculture was 0.212 km^2 (1987 – 1995). With 0.295 km^2 in the subsequent 6 years (1995 – 2001), it remained stable.

Overall, prediction 1 was not met as expected as villages cooperating with the project reflected land use across time since start of the project differently with some (Ipope/Nganda), expanding their fields for cultivating cash crops, and some not (Lompole and Bekombo).

3.2. Shifting cultivation change rate analysis

Investigating all villages jointly, the loss of forest to shifting cultivation was with 1.99% for the first time interval (1987 – 1995) and 1.62% for the second one (1995 – 2001), relatively slow. Thereafter, the annual rate of forest loss to shifting cultivation increased above the 2.3% threshold, with 2.49% for the third (2001 – 2009/2010/2011) and 3.39% for the fourth interval (2009/2010/2011 – 2018).

Looking into each village separately, the villages Bekombo, Ipope/Nganda and Reference Village experienced with 1.6%, 1.3%, and 1.5% respectively a slow rate of annual forest loss to shifting cultivation for the first two intervals (1987-2001). For these three villages the fast increase began with 2.3% in the third time interval (2001 – 2018) coinciding with the time after the initiation of the LKBP. For Bekombo and Ipope/Naganda the annual shifting cultivation change rate remained above the 2.3% threshold uniform line, whereas the Reference Village stayed with 1.31% below. Lompole experienced with 6.09% the highest annual shifting cultivation change rate (1987 – 1995), decreasing by time interval. Nonetheless, the value of the annual change rate remained above the 2.3% threshold until 2018.

3.3. Agricultural land use prediction

Starting from the total area of Lompole fields in 2018 (6.395 km^2), the increase in fields and according deforestation has been simulated over the upcoming 50 years (2018 – 2068) for the three different scenarios (S1-S3): Fig. 5a shows the expected increase of fields, while Fig. 5b depicts the decrease of forest based on the average annual shifting cultivation rate. Fig. 5c shows the trend and variation of the average projected shifting cultivation per year for each scenario. For the upcoming 50 years, for S1 (shifting cultivation rate of 0.05 km^2), the total increase in area of fields is estimated to 9.122 km^2 (SD = 2.556 km^2); for S2 (shifting cultivation rate of 0.1 km^2) to 11.445 km^2 (SD = 3.353 km^2); and for S3 (shifting cultivation rate of 0.18 km^2) to 15.484 km^2 (SD = 1.678 km^2).

3.4. Population growth and agricultural zones in Lompole 2002 – 2018

Lompole population tripled from 83 habitants in 2002 to 261 habitants in 2013 (average 16.2/year) and increased by another 95 habitants from 2013 to 2018 (average 19.0/year) resulting in a total population of 356. In Lompole, the average annual population growth was 9.5% between 2002 and 2013 and is threefold higher than the annual growth rate of DRC in the same time period.

On average, nine people per year migrated into Lompole village. This number is consistent since initiation of the LKBP. Births per year increased from 6.9 (2002 – 2013) to 9.8 (2013 – 2018) on average, while the village lost on average 0.4 (2002 - 2013) and 3.0 (2013 – 2018) habitants due to mortality. The total number of households had increased from 19 in 2002 to 53 in 2018. The number of houses had doubled from 19 in 2002 to 44 in 2013. By that, prediction 2 prognosing increased population size due to influx from people from other villages was only met for the first 11 years since the initiation of the LKBP. Between 2013 and 2018 in Lompole population growth was slightly more due to births than to immigration.

In 2002, when the LKBP project started, the total area of Lompole fields was 124 ha, representing 1.50 ha per habitant. Since, it decreased to 0.67 ha / person in 2013, and to 0.55 ha / person in 2018. Considering grown-ups only (12 age onwards), the per capita surface was 1.22 ha in

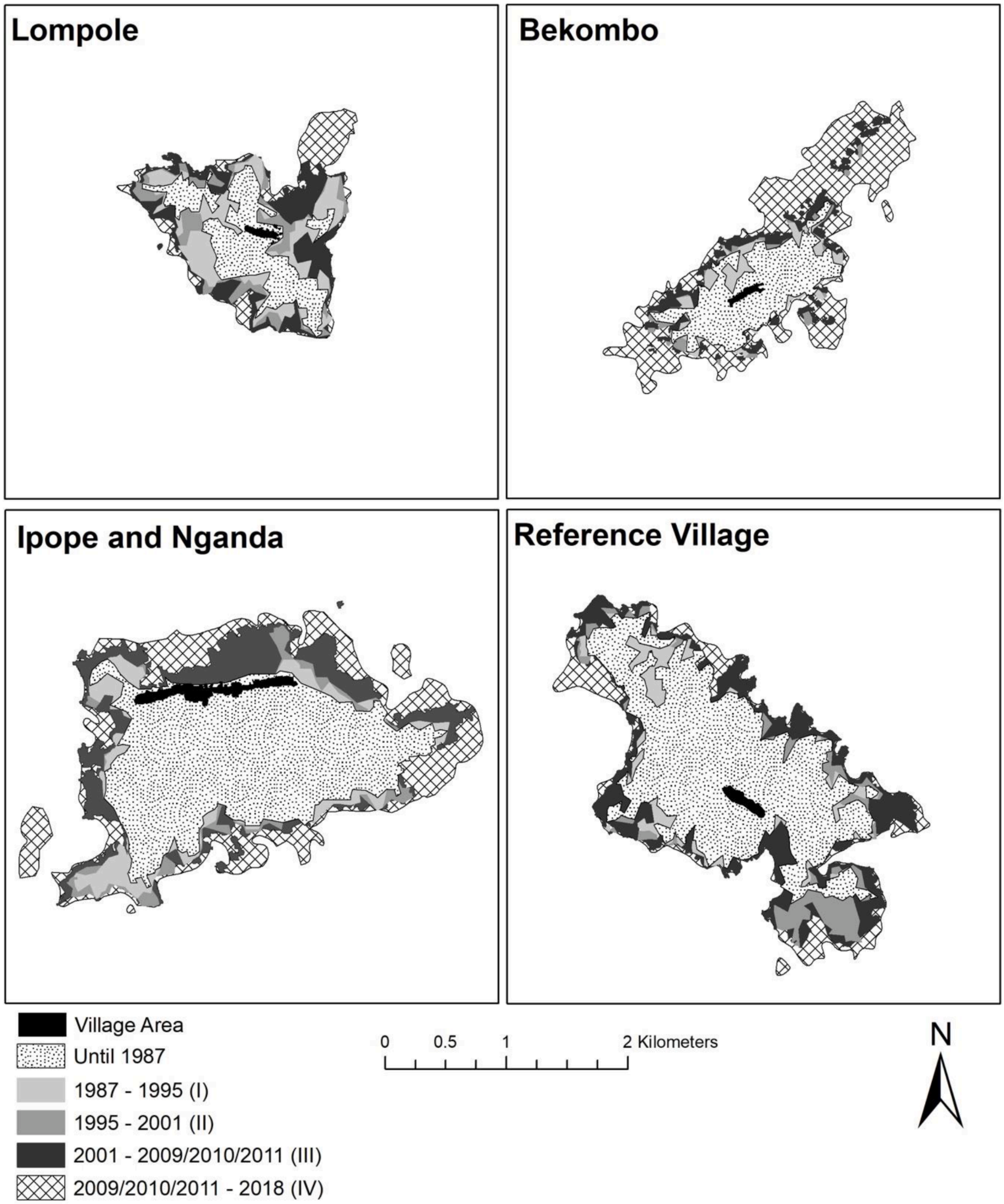

Fig. 2. Agricultural zones derived from Landsat and WorldView satellite imagery for intervals I – IV. I+II = all villages; III: 2001 – 2009 = Reference Village, 2001 – 2010 = Ipope/Nganda and Lompole, 2001 – 2011 = Bekombo; IV: 2009 – 2018 = Reference Village, 2010 – 2018 = Ipope/Nganda and Lompole, 2011 – 2018 = Bekombo.

2013 and 0.96 ha in 2018.

In Lompole the average field size was 0.233 ha in 2020. In the 1st decade, the total area of fields increased by 30%, from 124 ha in 2002 to 176 ha in 2013. In the following 5 years, the total area of fields increased additionally by 11%, to 197 ha in 2018. While Manioc was cultivated on 97% of all fields in 2013, corn was cultivated on 62% of all fields in 2018.

The total amount of households cultivating corn increased from 19 in 2013 to 28 in 2018. In the same period of time, the number of households had increased by nine. This is more than expected by chance ($X^2 = 0.36$, $p = 0.5$). By that, prediction 3 was not met.

3.5. *Socio-economic development in Lompole and Bekombo*

Lompole: Between 2010 and 2018, 12 additional houses were built in Lompole, resulting in a total of 64 houses (Fig. 6). In regard to roofing, all houses were covered with palm leaf material in 2010. From 2013 on, 3 houses had a roof cover of corrugated iron. Most of the 27 houses

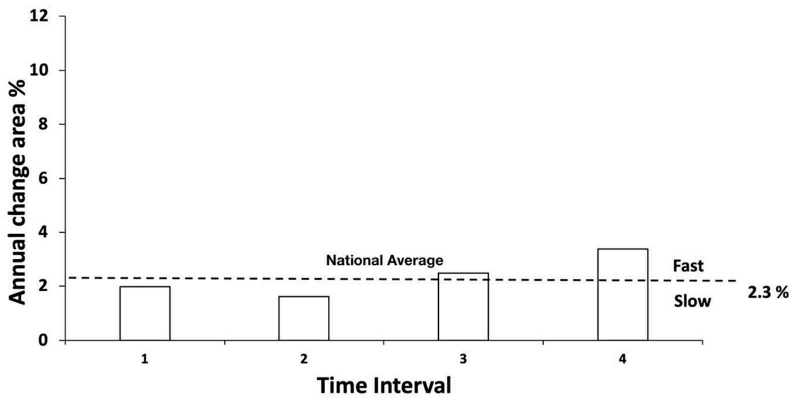

Fig. 3. Annual shifting cultivation change rate (%) for all villages across four periods 1987-1995 (I), 1995-2011 (II), 2001-2009/2010/2011 (III) and 2009/2010/2011-2018 (IV). Dashed line represents the threshold of 2.3 % (Potapov et al., 2012), setting apart fast (above line) and slow (below line) deforestation. I+II = all villages; III: 2001 – 2009 = Reference Village, 2001 – 2010 = Ipope/Nagnda and Lompole, 2001 – 2011 = Bekombo; IV: 2009 – 2018 = Reference Village, 2010 – 2018 = Ipope/Nganda and Lompole, 2011 – 2018 = Bekombo.

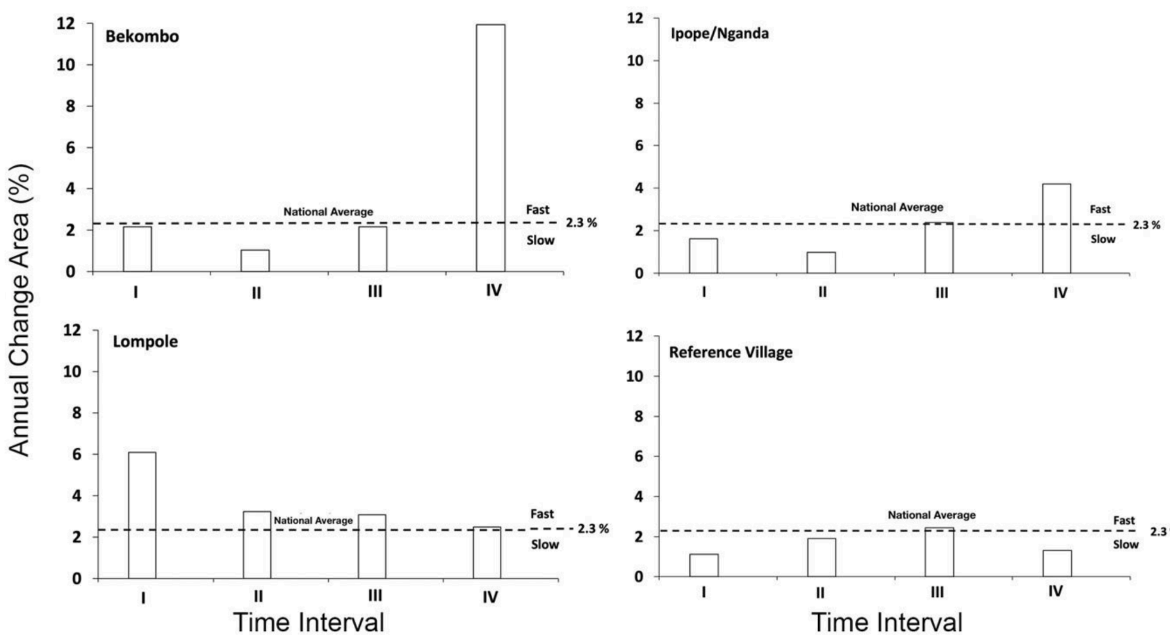

Fig. 4. Rate of annual forest loss to shifting cultivation for the villages, and time intervals 1987-1995 (I), 1995-2011 (II), 2001-2009/2010/2011 (III) and 2009/2010/2011-2018 (IV). I+II = all villages; III: 2001 – 2009 = Reference Village, 2001 – 2010 = Ipope/Nagnda and Lompole, 2001 – 2011 = Bekombo; IV: 2009 – 2018 = Reference Village, 2010 – 2018 = Ipope/Nganda and Lompole, 2011 – 2018 = Bekombo.

recorded in 2013 and 2018 were built of clay bricks. During this time, houses built of palm leaf walls decreased from 5 to 1. Prior to the start of the LKBP, each Lompole household owned one single house. The 2013 census revealed three households owning a total of two or three houses. In 2018, an additional four households owned multiple houses.

Bekombo. Between 2011 and 2018, five new houses were built, resulting in 57 houses (Fig. 6). During this time, roofing changed from palm leaf to corrugated iron in one house only.

In both villages additional houses were built, twice as many houses were built in Lompole compared to Bekombo.

4. Discussion

We investigated 31 years (1987 - 2018) of land use and landcover changes across 5 remote villages embedded in the evergreen lowland rainforest of the Democratic Republic of the Congo. We assessed the effect of the LuiKotale Bonobo Project (LKBP) implemented in 2002, by comparing development before and after its initiation. We measured deforestation due to shifting cultivation under consideration of population growth for the village of Lompole cooperating with the LKBP since its start, their neighboring villages Bekombo (since 2016) and Ipope/Nganda, using an independent reference village as control. We estimated the future land use for Lompole projecting current trends over the next 50 years.

We found that the rate of Shifting Cultivation decreased in Lompole since start of the LKBP compared to the neighboring villages Bekombo and Ipope/Nganda where it increased continuously across all time intervals. Lompole village is in charge of provisioning the LuiKotale research camp since 2002. While the majority of households of Lompole had access to income generation provided by LKBP, households of neighboring villages had not. Traditionally, slashing of trees and burning fields in preparation for planting livelihoods is men's work, while the subsequent care of planting and caring for crops, harvesting and processing is women's business. The rate of shifting cultivation of Lompole village may have decreased with start of the LKBP as households may have used the available income to acquire their and the project's food supplies from the neighboring villages. Additionally, the cooperation contract between Lompole village and the LKBP providing income generation to habitants may have bound human resources originally free for clearing and maintaining fields. Given close family ties across villages, livelihoods purchased from neighboring villages

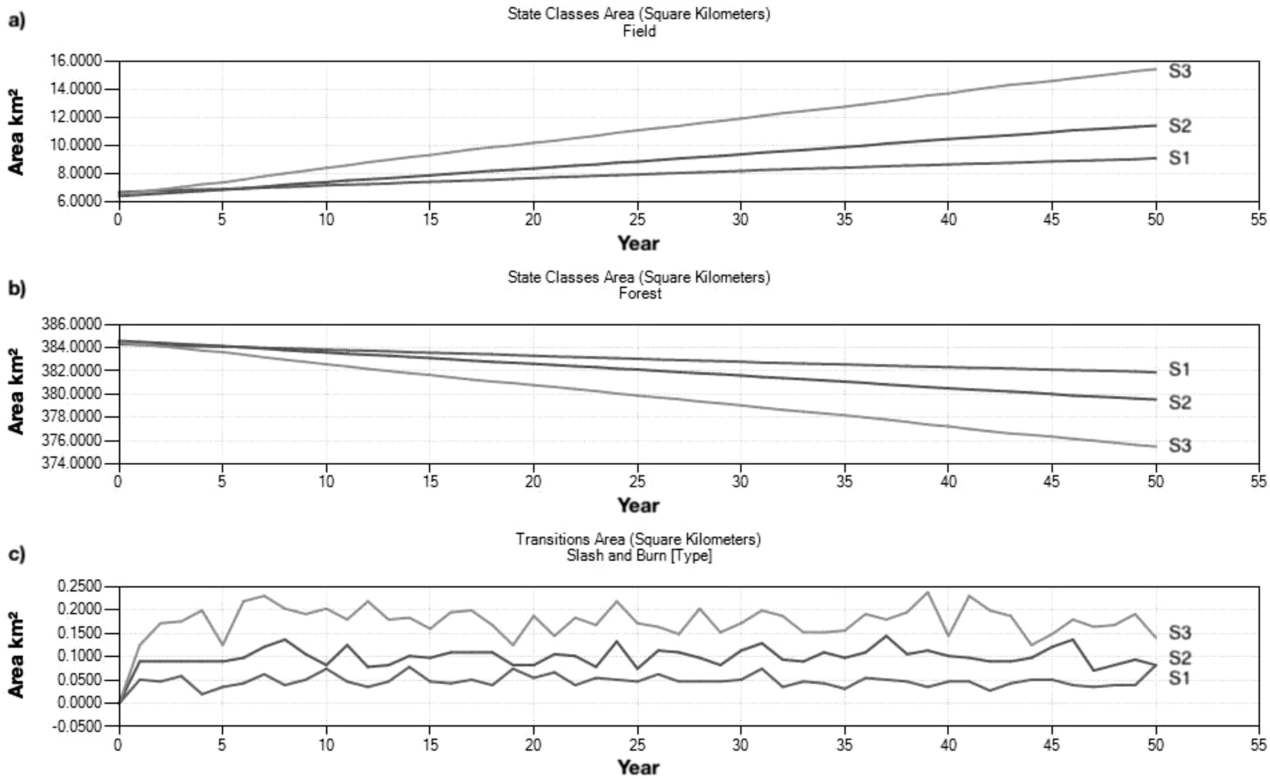

Fig. 5. Agricultural land use prediction 2018-2068 for (a) Fields; (b) Forest, and (c) annual area change in Lompole

allows cash to down-trickle with neighboring villages investing their time to create additional fields to meet the increasing demands from Lompole village, and to generate income.

When the project expanded its cooperation to the village of Bekombo in 2016, the higher rate of Shifting Cultivation measured since 2011 may be due to starting provisioning of the Ekongo in addition to the LuiKotale research station.

Another considerable factor for the increasing rate of Shifting Cultivation certainly is population growth. Although at different scale, this is in line with observations from Tanzania (Kilawe et al., 2018), where population pressure due to migration caused a transformation from shifting cultivation to intense cultivation. With about 19 people / year for Lompole village it is considerable. This rate is due to two factors, the immigration of new habitants (9.2 persons/year) from other villages consistent across the investigation period; and the birth rate increasing from 6.9 births/year between 2002 and 2013, to 9.8 births/year between 2013 and 2018. Countrywide, the birth rate continuously decreased from 6.7 (2002) to 6.4 (2013) and to 5.9 (2018) in DRC. The same trend applies to sub-Saharan Africa with births per woman having decreased from 5.7 to 4.7 between 2002 and 2018 (World Bank Data, 2021).

While population growth triggers house construction, the observed increase of houses can't be explained by this alone. The over proportional construction of houses may be explained by increased wealth, where construction work can be delegated. With regard to the increase of the total number of houses, between 2010/2011 and 2018, houses in Lompole village increased twice as much as in Bekombo.

Increased wealth likely due to cash income provided by the LKBP also started to become visible in construction material. Habitants of Lompole and Bekombo started to afford purchasing construction material such as corrugated iron, although this change to persistent construction material so far only changed in a few houses.

People not directly benefitting from LKBP cash, may have done so indirectly by expanding their crops to meet local demands such as self-distilled alcohol, skimming the cash availability. We found Lompole fields growing corn to have increased by 15% across five years between 2013 and 2018. This increase can be explained by corn having turned from a subsistence into a cash-crop, providing additional income for households, particularly for women in charge of the plowing, where corn is turned into Lotoko, a highly concentrated alcohol consumed locally.

In contrast to other regions such as Madagascar, the increase of cash crops and intensifying agriculture is related to balance cash crop price fluctuations. Here, the cash crop cultivation increased when the price for crops increased. In contrast, the cultivation for cash crops stayed stable or was reduced when the price for crops decreased (Llopis et al., 2019).

Our results indicate that the continuous increase of shifting cultivation in the neighboring villages of Lompole not only compensated the demand of food supplies for the LKBP, but also of the villages themselves, reflecting increased demands due to population growth, as well as a new allocation of time and money.

Lompole population tripled from 83 habitants in 2002 to 261 habitants in 2013 (average 16.2/year) and increased by another 95 habitants from 2013 to 2018 (average 19.0/year) resulting in a total population of 356. In Lompole, the average annual population growth was 9.5% between 2002 and 2013 and was threefold higher than the annual growth rate of DRC in the same time period. On average, nine people per year migrated into Lompole village. This number was consistent since initiation of the LKBP. Observed population growth in Lompole clearly exceeded the steady increase of population in DRC since the end of the second war in 2003. Prior to the war, annual population growth had its peak in 1992 with 3.9% and decreased to 2.3% during the war. After the war, annual population growth in DRC increased to an average of 3.1% (World Bank Data, 2021). This can be explained by displacements and unsuitable living conditions of the population during the war. After the war, displaced people relocated back into their villages and were able to reestablish subsistence agriculture. We cannot exclude that countrywide demographic statistics were not reliable during times of war and shortly

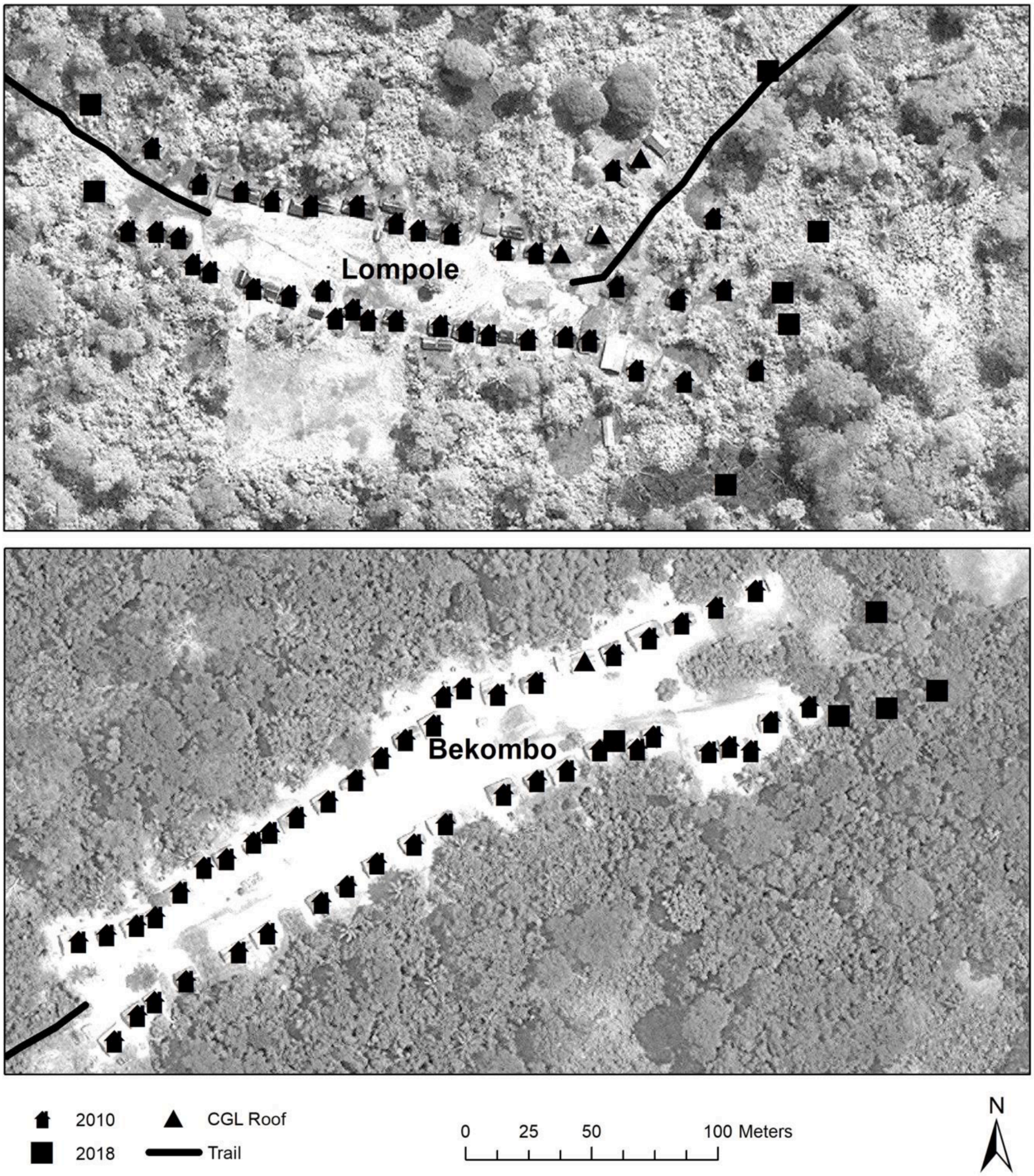

Fig. 6. Lompole and Bekombo villages. Houses depicted by symbol (1) house existed in 2010 (Lompole), and 2011 (Bekombo); (2) square was built till 2018; (3) triangle: roof with corrugated iron (CGL; built between 2010/2012 and 2018).

Table 3
Population growth in Lompole between 2002 and 2018.

Year	Total population	Total No. of families	No. of families owning multiple houses		Total population increase	Births	Deaths	Increase due to migration	No. of families increased
2002	83	19	0						
2013	261	44	3	2002 - 2013	178	76	4	102	25
2018	356	53	7	2013 - 2018	95	49	15	46	9

after, when the country was still in civil disorder.

In DRC the migration contributed to the population growth after 2007 because the net migration was dominated by emigration between 2002 and 2007 (World Bank Data, 2021). Births per year increased from 6.9 (2002 – 2013) to 9.8 (2013 – 2018) on average in Lompole, while the village lost on average 0.4 (2002 - 2013) and 3.0 (2013 – 2018) habitants due to mortality. Conversely, births per woman and mortality decreased in DRC. The average births per women decreased from 6.6 between 2002 and 2013 to 6.2 between 2013 and 2018 (Word Bank Data, 2021). Furthermore, the mortality decreased from average 13 deaths per 1000 people (2002 – 2013) to average of 10 deaths per 1000 people in the time of 2013 – 2018 in DRC (World Bank Data, 2021). Thus, the population growth is caused by the increase of births as well as by the migration between 2002 and 2018 in Lompole. In comparison to DRC, the population growth is determined by immigration starting in 2007 while births rate and mortality even decreased between 2002 and 2018.

Overall, small-holder agriculture is the dominant factor for deforestation in Africa (61.1%). This is similar to Asia (35.0%), although here, tree crops (27.9%) follow as second important factor of deforestation. In contrast, in South America the conversion from forest to pasture is the dominant factor (72.2%) (De Sy et al., 2019). In Southeast Asia, forest loss is caused predominantly due to population pressure increasing crop agriculture. This is especially true for lowland forests located in a flat topography prone for conversion in land use from forest to agricultural land. However, in a few countries of Southeast Asia (Philippines, Thailand, and Vietnam), and inverse effect became visible with deforestation transitioned into forest regeneration caused by socioeconomic improvement (Imai et al., 2018). Nonetheless, the expansion of agricultural cropland is the main driver for forest loss across the pantropic regions.

The highest population increase is expected in Africa and Asia, while in Africa the population is almost quadrupling (Laurance et al., 2013). Our simulation assessing the trend of deforestation over the upcoming 50 years predicts a considerable increase in cultivated land along with a considerable decrease in forest, and a successive approximation between the villages ́agricultural zones. This finds support in studies conducted in Eastern Africa (Berakhi et al., 2015) and Nigeria (Ochege et al., 2017) where deforestation is increasing due to continuous population growth. Our findings confirm studies relating population increase with deforestation peaking in the traumatizing fact complete clearing of DRC's forest by 2100 modelled based on the UN predicted population growth from currently 89 million to 379 million people until 2100 (Tyukavina et al., 2018). Some studies suggest driving factors on a smaller scale like access and length to roads and waterways, effects of climate change and poverty causing deforestation (Jaffé et al., 2021; Laurance et al., 2014; Lawrence et al., 2015; Miyamoto 2020). Therefore, in our study area the implementation of alternative land use policies may allow to regulate the local cultivation of cash crops to avoid further agricultural expansion. For a sustainable application, land use policy should be developed in agreement with the concerned villages associated to the LKBP. Ideally, conservation of the pristine primary evergreen lowland rainforest shall be an integral part of all future land use policy, particularly in the context of the protection of the Salonga National Park, the largest protected area of lowland evergreen rainforest, and a World Heritage Site. Here, alternatives to current cash crops, and particularly plans concerning the use of the Park's buffer zone (WWF, 2021), should be developed jointly with the local population for the advantages of both the people and their natural habitats (Figs. 3, 4, Table. 3).

This study provides a baseline looking into the development of shifting cultivation in relation to population growth under the consideration of the start of a long-term project in place. In future, this study can be improved considerably by conducting a population census in regular intervals, and by further delineation of cash crop fields at village level. More detailed delineation of cash versus subsistence crops, ideally in connection to owners, will allow to measure a household's needs. To measure LULC changes and dynamics, remote sensing analysis should continue. It should focus on the spatial transition of LULC classes and be applied to proactive-decision processes in local land use policies for villages in collaboration with LKBP.

Overall, the project has implemented strategies to protect bonobos (*Pan paniscus*), a flag-ship species of a vast and healthy interconnected animal community, with great success. This includes sensitization of the local population, environmental education, and other measures allowing direct participation of the local population in conservation measures. Villages have been integrated stepwise providing income generation enlarging the protected area under focus in return. However, it becomes visible that these mentioned measures are not the sole solution, and any increase in cash induces additional demands for cash, igniting the growth spiral as we can observe it in almost any other place of our planet with mostly detrimental consequences for nature. The difference is the value of what is sacrificed, with pristine evergreen rainforest habitats and a high biodiversity on the one hand, and the largely human made /controlled landscape on the other. Despite the evidence of this imbalance, and the need to protect what is left from the second largest rainforest block of our planet, convincing alternative strategies to traditional conservation and development projects have yet to be implemented into the policies of large conservation organizations. Here, we try to strive for a participatory approach protecting the traditional forests acknowledging *Homo sapiens* as part of the ecosystem.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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