

Modeling the Conversion of Forest Land to Other Types of Occupation Due to Urban Growth in Five Forest Towns in the Congo Basin

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How to cite this paper: Binsangou, S.M., Ifo, S.A. and Mertens, B. (2025) Modeling the Conversion of Forest Land to Other Types of Occupation Due to Urban Growth in Five Forest Towns in the Congo Basin. *Open Journal of Ecology*, 15, 43-64. <https://doi.org/10.4236/oje.2025.151003>

Received: October 4, 2024

Accepted: January 6, 2025

Published: January 9, 2025

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Abstract

The conversion of forest land to other types of land cover is one of the major issues in the global fight against climate change. Understanding the direct and indirect factors of these conversions from local studies in the tropics is essential to project the future impact of human activities on the preservation of tropical forests in general and the forests of the Republic of Congo in particular. This study, conducted in five localities with different socioeconomic contexts in the Republic of Congo, aims to analyze the variability of drivers of deforestation and forest degradation linked to urbanization in the Congo Basin. Using a series of land cover maps from the years 1986, 2003 and 2019 for the cities of Ouessou, Pokola, Ngombe, Impfondo and Dongou, as well as field data and socio-economic information collected from local and central administrations, a unique model has been developed to understand the explanatory patterns of forest loss. Deforestation around urban centers is mainly due to urban agriculture due to population growth, as well as the spatial expansion of cities, which have a major impact on the stability and integrity of forests. Shifting agriculture is the main direct cause of deforestation and forest degradation, representing 48% of the total sample, followed by the collection of wood fuel (22%), the collection of construction wood (19%), illegal logging (6%) and urban expansion (5%). Forecasts indicate that forest loss around major cities will increase by 487, 20 ha to 5266, 73 ha by 2050 compared to the base year of 2019. This study highlights the need for a new system of land management and poverty alleviation of local populations to ensure the stability of the Congo Basin tropical forests around large and small African cities.

Keywords

Deforestation, Degradation, Modeling, Congo Basin, Land Use Change, Landsat, Strong Points

1. Introduction

Climate change represents a major challenge for the scientific community, civil society organizations, natural ecosystems and human societies, as well as for the health of the population [1] [2]. In order to combat these changes, different strategies have been put in place, including the definition and implementation of mitigation policies, the development of adaptation actions at the local level and the establishment of strong economic measures to finance the ecological transition [3] [4].

Deforestation and tropical forest degradation contribute about 17% - 25% of human-caused carbon emissions and result in the destruction of globally significant carbon sinks [5]-[7]. However, the impacts of forest degradation are understudied and poorly understood, mainly due to the focus of international emission reduction programs on deforestation, which is easier to detect and monitor.

A consistent estimate of emissions from forest degradation between 2005 and 2010 in 74 developing countries, covering 2.2 billion hectares of forest, puts annual emissions at 2.1 billion tons of carbon dioxide [8].

Several studies have addressed the direct and indirect causes of the loss of tropical forests in recent decades worldwide, as well as in specific countries [9] [10]. These studies, usually conducted in tropical countries, have identified the causes of degradation and deforestation, as well as determining the contribution of degradation to global greenhouse gas emissions [8]. The conversion of forests for agricultural purposes is the most widespread human activity on planet Earth [11]. In addition to this, there is logging, firewood harvesting, forest fires and urban expansion in forest areas [9].

However, many questions remain about the future evolution of the causes of deforestation and forest degradation in the world, as well as in specific regions. These questions are linked to global and regional demographic growth, as well as the evolution of global economic parameters. The drivers of these forest losses have both international and national origins.

Modeling deforestation and degradation helps to understand the spatio-temporal dynamics of this phenomenon and promotes a better understanding of the factors that contribute to deforestation [12]. According to this author, the model's primary function is to schematize reality, to propose a theoretical scheme that provides information on the processes and relationships that exist between the elements of a system. In the current context of sustainable development and climate change adaptation policies, it is essential to identify and assess the parameters at the origin of deforestation and forest degradation in order to understand

and control the future changes, particularly for regional issues (heritage and economic value) or planetary issues (carbon stock and emissions, biodiversity) [13].

Modeling the factors explaining deforestation and forest degradation is of great importance, as it combines verbal formalization and graphic formalization [14]. It makes it possible to measure the effects on deforestation, to better understand the complex mechanisms underlying deforestation and forest degradation [15]-[17] and to develop scenarios for the evolution of social ecosystems [18]. The literature offers several models in different fields, such as the environment or land use.

The main objective of these models is to contribute to a better understanding of the factors (environmental or cultural) explaining deforestation and forest degradation [19] [20], to propose a theoretical scheme allowing to understand the socio-economic and ecological processes as well as the existing relationships between different parameters, whether environmental or cultural [12] [19], and to predict the rate of expansion of deforestation [19].

To characterize the process of evolution of surface conditions, these models answer three questions: what environmental and cultural variables best explain deforestation as well as the ecological and socioeconomic processes that support them? How fast is this deforestation progressing? Which areas are most affected by deforestation? [19]

Several modeling studies have been carried out in Congo, Africa and the rest of the world [17] [21]-[25].

These studies have shown the close link between population growth, urban sprawl and pressure on natural resources, especially forest resources. For example, the city of Brazzaville, which was mainly forest-based in 1946 [26], has suffered the effects of urbanization and population growth on the sustainability of forests [27] [28]. Other studies have helped to understand the causes of forest loss not only globally, but also in the Congo Basin [9] [20] [29] [30]. Urbanization, which is a direct cause of deforestation, is incompatible with maintaining the sustainability of forest ecosystems [31].

According to [32], cited by [33], the high rate of population growth is associated with a high rate of deforestation in developing countries. Population increase poses a direct threat to the local environment and reduces the natural assimilative capacity of the environment [33].

This study presents the originality of simultaneously addressing the future modeling of deforestation and forest degradation based on cities with different development histories. Indeed, among the towns studied, some emerged from logging camps, while others began as simple logging fishing camps with no logging activity.

The objective of this study is to identify the past causes of deforestation and forest land degradation through a diachronic cartographic study, to propose a complex spatial and economic model that accounts for the complex interactions explaining deforestation and forest degradation in the localities studied, and to

define the rate of forest loss by predicting the future.

2. Materials and Methods

2.1. Location of the Study Area

Study Areas

This study was carried out in five localities of the Republic of Congo, which confirmed the initial hypothesis according to which these localities were initially covered with forest. The localities concerned are Impfondo and Dongou, located in the department of Likouala, as well as Ouesso, Pokola and Ngombé, located in the department of Sangha (see **Figure 1**).

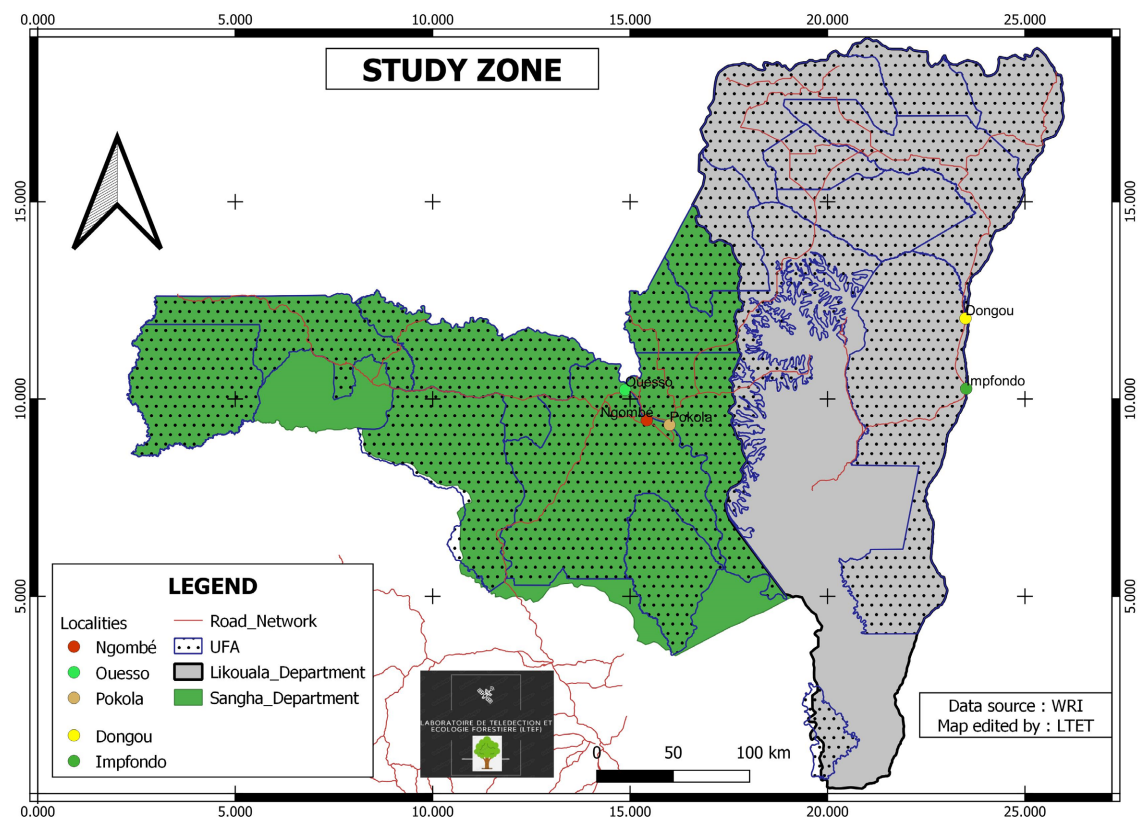


Figure 1. Map of the study area.

2.2. Methodology

2.2.1. Study of the Causes of Deforestation and Forest Degradation

The causes of deforestation and forest degradation in the urban and local areas of this study were examined in three stages: 1) analysis of past land cover maps, 2) collection of data on the field through surveys, and 3) building a model to project future deforestation.

2.2.2. Image Acquisition and Processing

For this study, Landsat Operational Land Imager (OLI) images covering the different study areas and different years were downloaded from the USGS website

(Earth Explorer, <https://earthexplorer.usgs.gov/>). These images had a spatial resolution of 30 meters. Prior to classification, a series of pre-processing operations were performed on the selected images of the study area. Then, a post-classification was performed on these images to produce the final maps. All these steps were carried out using the free software QGIS version 2.18.

It was possible to highlight the different types of land use and produce the corresponding map. The first land cover map was produced based solely on training areas determined visually from Landsat pixels. Five land cover classes were selected: urban area, dense forest, degraded area (agriculture, fallow land), savannah and water. The second land cover map for the same area was created by combining both data from “Google Earth” and ecological data collected during field visits. This made it possible to map the agriculture class and the secondary forest class.

2.2.3. Collecting Socio-Economic Data in the Field through Surveys

A questionnaire was developed with the aim of collecting relevant information on the history of land use in the different localities for the years 1986, 2003 and 2019. This survey was conducted randomly with five hundred people from different localities in the study area, as well as with forest services and local administrations.

The questionnaire also aimed to identify the direct or indirect causes of deforestation and forest degradation, as well as to collect socio-economic data. These data should make it possible to understand all the factors of anthropogenic pressure on local forests, in order to propose a spatial and economic model that can explain the complex future interactions explaining deforestation and forest degradation in connection with population growth.

The demographic data of the various localities studied were collected from the National Institute of Statistics and from the archives of the reports of the administrations responsible for human demography in the Republic of Congo. Missing demographic data between two periods were obtained by simulation from existing data using Equations (1) and (2) (growth rate r and basic population data).

Other data, such as income-generating activities (IGA), monthly income of populations, statistics on civil war refugees from neighboring countries, and the impact of the policy of building modern infrastructure in localities forests, were collected in the field from the local authorities of the different localities studied.

2.2.4. Population Estimate

To estimate the population size for the years when we were unable to obtain population size data, we used the following equations:

$$PE(t+1) = \left(Tac \times \frac{P(t)}{100} \right) + P(t) \quad (1)$$

$$PE(t) = \left(P(t+1) / \left(\frac{Tac}{100} + 1 \right) \right) \quad (2)$$

where:

- $PE(t + 1)$ = estimated population of year $t + 1$ knowing the size of the

population of year t ;

- $PE(t)$ = estimated population of year t knowing the size of the population of year $t + 1$;
- Tac = Annual growth rate;
- $P(t)$ = population at time t ;
- $P(t + 1)$ = population at time $t + 1$.

The growth rate applied to estimate the size of the population between two years varied from one locality to another according to certain criteria defined by the National Institute of Statistics. Population growth results from birth rate, death rate and migration rate. For example, for the city of Impfondo, the growth rate was 3.1 from 1984 to 2007, and 3.68 between 2008 and 2019. The value of $r = 5.1$ was applied for the city of Dongou in Likouala. For the localities of Ouessou and Pokola, an increase rate of 2.8 was used. The population explosion in the town of Impfondo is associated with the arrival of refugees from the Democratic Republic of Congo, the Central African Republic and Rwanda.

2.2.5. Construction of the Deforestation Forecasting Model

Based on the data collected in the field and the analysis of the cartographic products, interactions between the direct and indirect causes as well as between the direct causes have been identified in order to develop an explanatory framework of the anthropogenic pressure on the forests of the different study areas. In order to establish future projections, an annual growth rate has been applied to follow the evolution of the various parameters until 2030 and 2050.

2.2.6. Population Projection

The future population numbers in the different cities were obtained through modeling using the Excel 2019 forecasting tool. For this modeling or projection, two parameters were taken into account: the reference year of the study, the final year of the study and the year for which we wish to estimate the population, as well as the known population counts of the reference year and the last year available.

2.2.7. Deforestation Projection

These forecasts were obtained using two main parameters: the year for which we wish to estimate the area, the reference year and the final year of the study, as well as the existing area at these different periods. For this, we entered all these data in the Excel spreadsheet using the forecast formula available in this tool.

3. Results

3.1. Study of the Causes of Deforestation and Forest Degradation

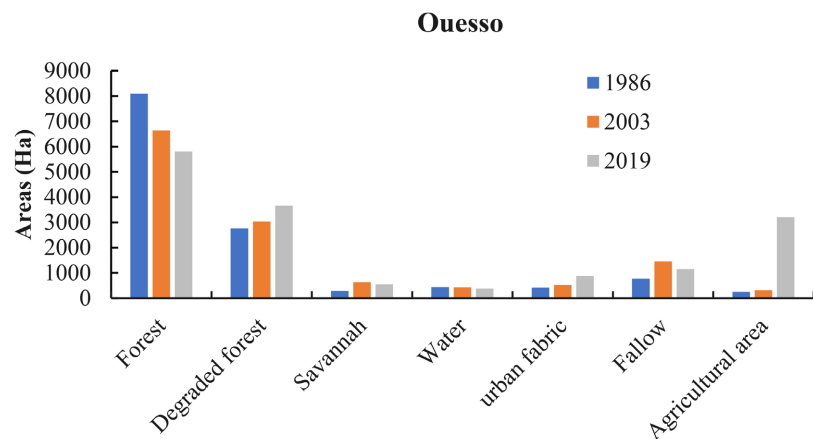
3.1.1. Analysis of Land Cover Map Results

The analysis of land cover made on the basis of land cover maps developed revealed a conversion of forest land to other types of land cover such as urban area class, degraded area class (agricultural zone and fallow land) in the five localities of the study area (Impfondo, Dongou, Ouessou, Pokola and Ngombé). These land cover maps made it possible to obtain the results of the areas indicated in **Figure**

2. This figure reveals an increase in the area of the different types of land cover regardless of the type of land conversion. Agricultural area (SA), urban area (SA) and fallow area have been steadily increasing from 1986 to 2019. The cumulative sum of these three types of land use: from the forest class to the urban fabric, agricultural zone, fallow classes from 1986 to 2019 for the five localities increased from 2690 ha to 3484.51 ha in 2003 to 6576.48 ha in 2019.

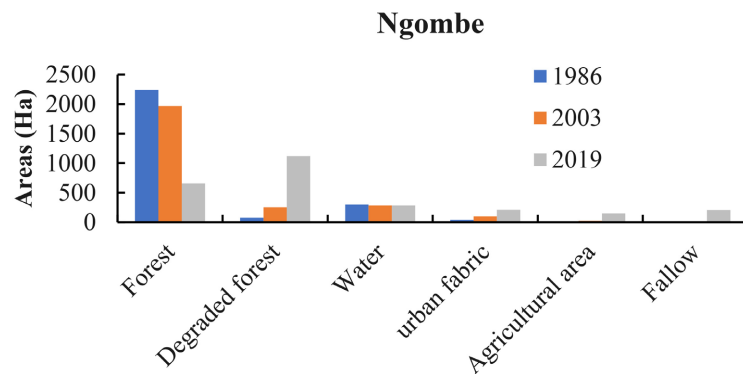
3.1.2. Area of the Different Types of Land Cover

However, one certainty emanates from the modeling results: the population of the various localities will increase significantly until 2050, assuming that the current population growth rate is maintained. The urban growth observed in 1986 is still present in 2019, in greater proportions, which attests to the importance of this factor in tropical deforestation. This increase is also correlated with the increase in areas of fallow land and agricultural land in almost all the localities studied. **Figures 2(A)-(E)** highlights the land cover classes directly associated with human activities, and therefore with the gradual replacement of forests by non-forest areas, which will then become urbanized areas with the growth of the human population in the different localities.



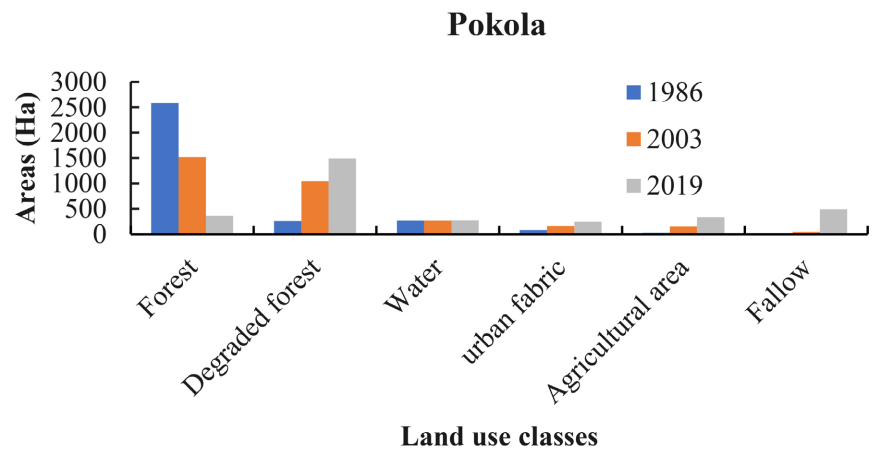
Land use classes

(A)

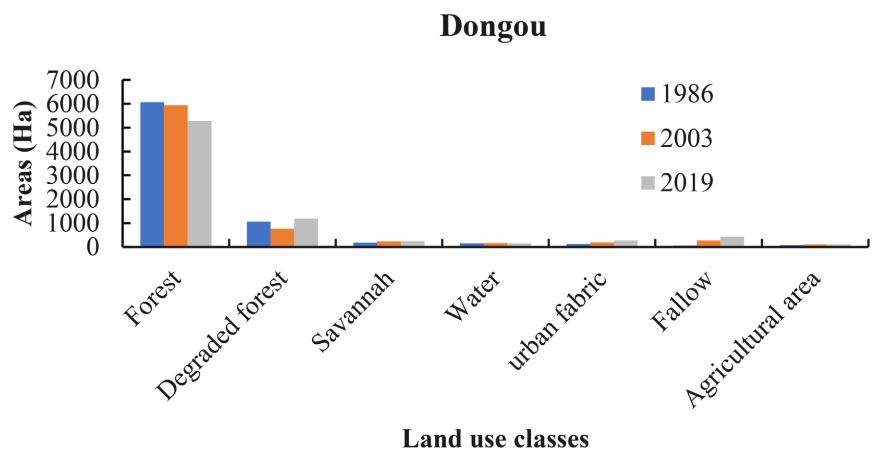


Land use classes

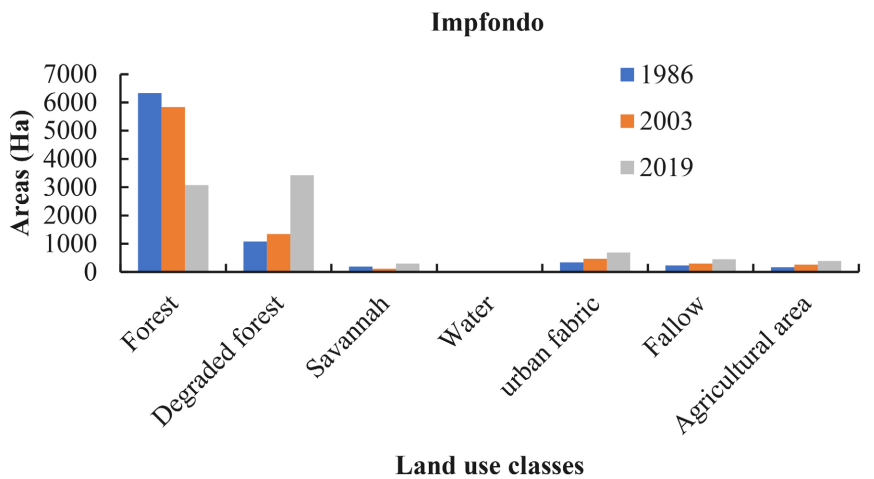
(B)



(C)



(D)



(E)

Figure 2. Evolution of the areas of the different types of land use between 1986 and 2019 in the different localities.

Figures 2(A)-(E) illustrates an increase in the areas of the different land cover classes at the expense of the forest class in all localities of the study area, between

1986 and 2019.

The growth of the urban fabric, which corresponds to the zone where constructions develop (Figure 3), and agricultural activities are in fact the main causes of deforestation in these study localities.

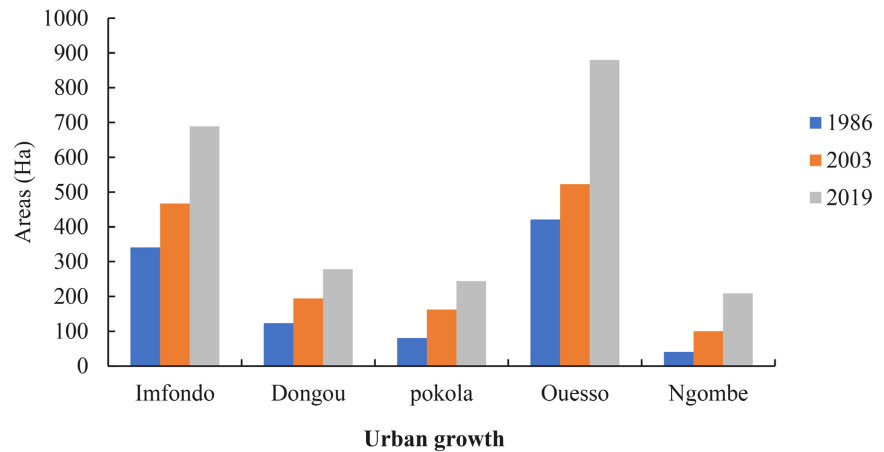


Figure 3. Urban growth in the different cities studied.

Demographic data collected at the National Institute of Statistics in Brazzaville and in the various local administrations, as well as estimates based on the growth rate, made it possible to construct the population growth curve (Figure 4).

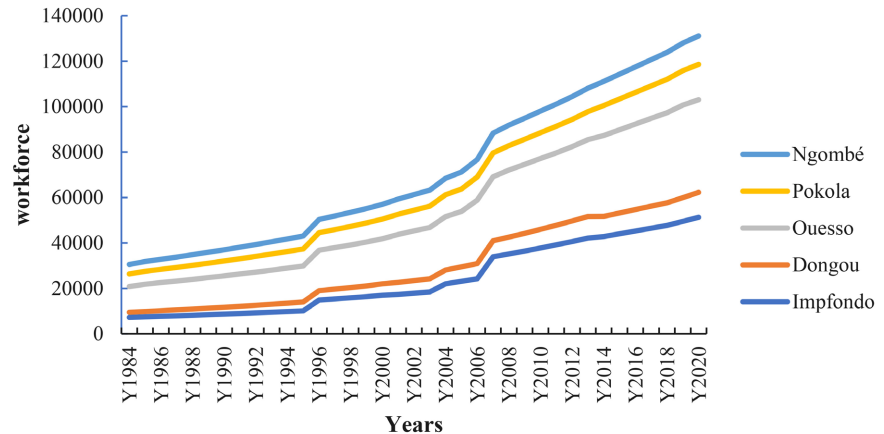


Figure 4. Populations in the different cities studied.

Data on population counts collected in the field in the different localities for the different dates were used to estimate the population counts for the intermediate years where data were missing between 1986 and 2019.

Different growth rates were applied to obtain the curves (Figure 4), thus making it possible to make future projections on the evolution of the urban area by modeling. This curve shows an increase in population in all localities during the study period. The city of Impfondo experienced the strongest population acceleration between 2007 and 2019. On the other hand, the city of Dongou, although

having a regular increase in its population, remains the locality with the lowest number among the five studied.

This difference can be explained by the high concentration of refugees from neighboring countries. These refugee populations, deprived of financial resources, had as their only source of subsistence the dense forests located around the towns of Impfondo and Dongou.

3.1.3. Analysis of the Survey on the Causes of Deforestation and Degradation Carried out in the Five Study Localities

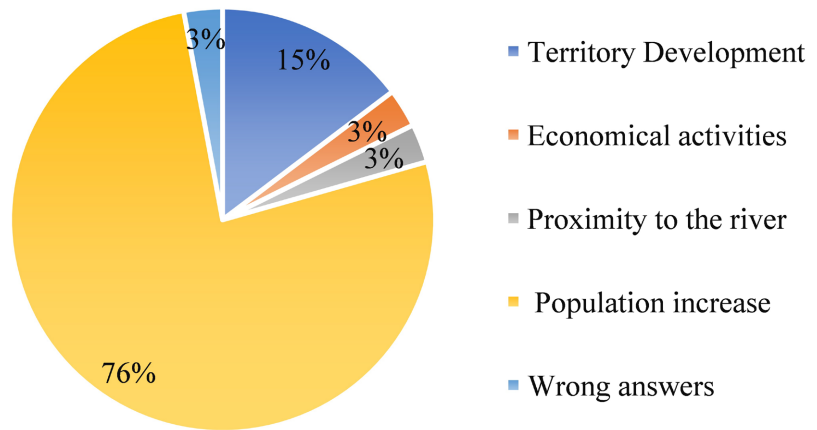
The counting and analysis of collection sheets made it possible to obtain results on the main income-generating activities in the study localities, the causes of the rural exodus towards the different study localities, the causes of urban growth, as well as the causes of deforestation and forest degradation. Analysis of **Figure 4** reveals that among the respondents, 38% mentioned traditional agriculture as the most common activity, followed by fishing at 27%, trading at 15%, animal husbandry at 10% and hunting at 6%. Activities such as crafts and masonry are the least mentioned, representing only 2% of the sample of the population questioned. Among these activities mentioned, only agriculture has an impact on forests.

A study of the causes of forest loss, city by city, indicates that the causes differ from one locality to another. For example, in the localities of Ngombe and Pokola, forest degradation is mainly due to logging and the construction of living bases for forest industry workers and their families. In the town of Dongou, which was originally a fishing camp, development took place slowly in the 1970s and 1980s. Agriculture around the town is the main income-generating activity, associated with the fishing in the Oubangui River. The survey of local populations on the causes of urban growth revealed that population growth was the most frequently cited cause (76% of the sample), followed by land use planning (15%). Economic activities and proximity to the river are the least cited causes with 3% (**Figure 5**).

The results of the survey revealed that several reasons were mentioned by the subjects questioned to explain the displacement of local populations from villages to large urban centers, which are our different study localities (**Figure 5**): the reasons given include more favorable living conditions in these urban centers compared to rural areas, proximity to major rivers (Sangha and Oubangui) and access to education for children. Each of these reasons was cited by 16% of respondents, out of a total of 100%. Reasons related to health and the need to live in these urban centers were mentioned by 13% of the subjects, while the status of a shopping center and professional reasons were mentioned by 6% of the individuals. Religious reasons and ease of disposal of products account for 3% of responses, and 9% of individuals did not answer this question.

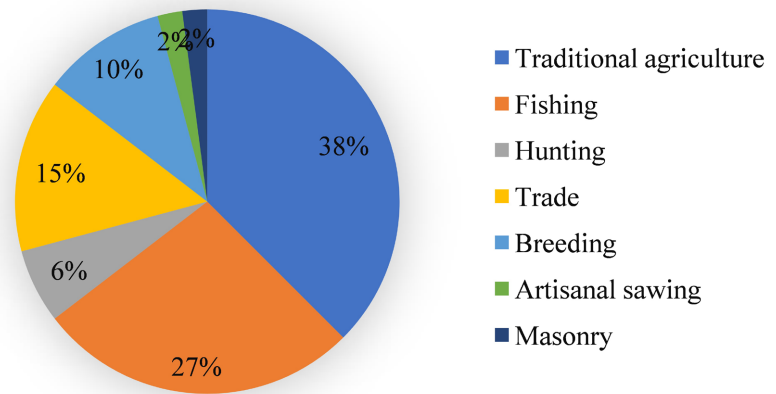
Regarding the direct causes of deforestation and forest degradation, if we consider the number of respondents who answered this question, shifting cultivation is identified as the main cause, cited by 41% of the total sample. Then, the collection of wood fuel is mentioned by 22%, the collection of construction wood by 19%, the illegal exploitation of wood by 6% and the extension of cities by 5%.

Causes of urban growth



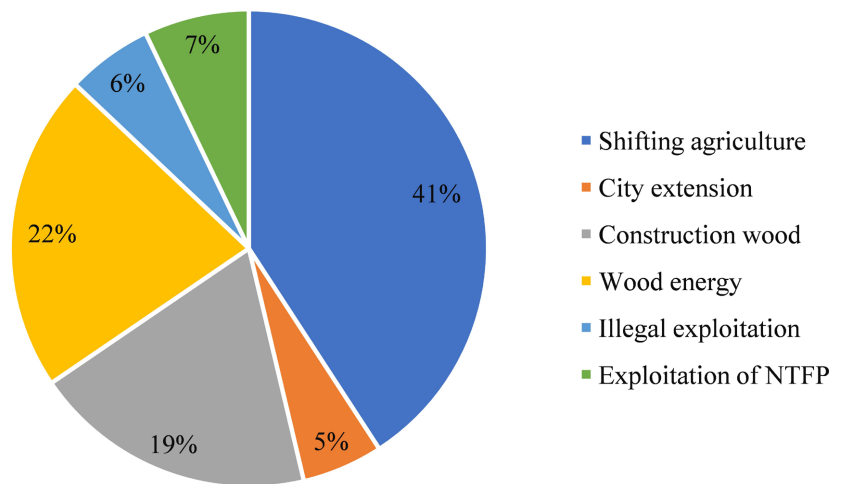
(A)

Activities carried out in the study areas cited by respondents



(B)

Direct causes of deforestation and forest degradation



(C)

Indirect causes of deforestation and forest degradation

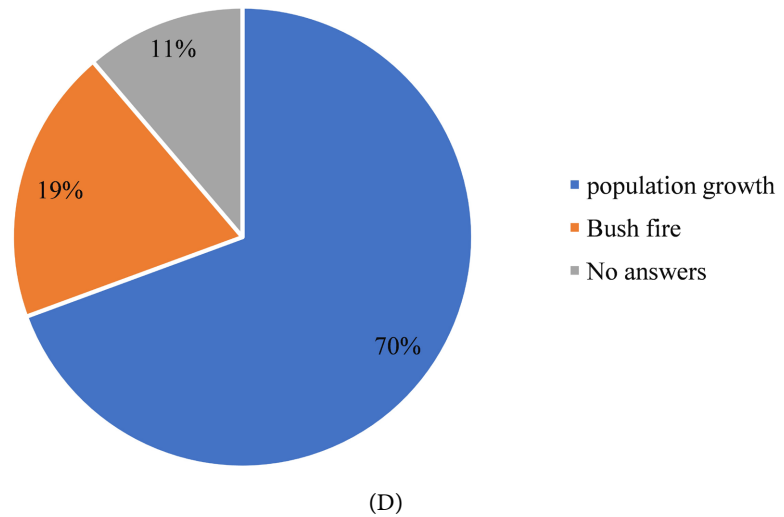


Figure 5. Survey results.

By analyzing the survey data on the indirect causes of deforestation and degradation, population growth turns out to be the main cause with 70% of the total surveyed, followed by bush fires with 19%. About 11% of participants did not answer this question.

3.2. Projected Population and Area Deforested by 2050

By projecting these population counts to 2050, we found that all curves follow an exponential trend for each locality (Figure 6), indicating a gradual increase in population in all cities. Forecasts show that the population of Dongou town, which was the lowest among the five localities between 1986 and 2019, will eventually surpass the populations of Pokola and Ngombe in 2050. Ouesso, which initially had the largest population, is surpassed by Impfondo, which becomes the city with the highest population until the end of the study period.

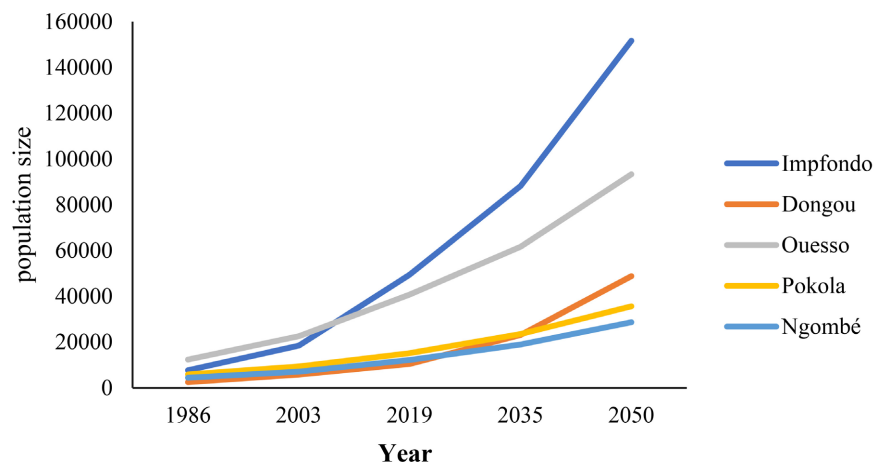
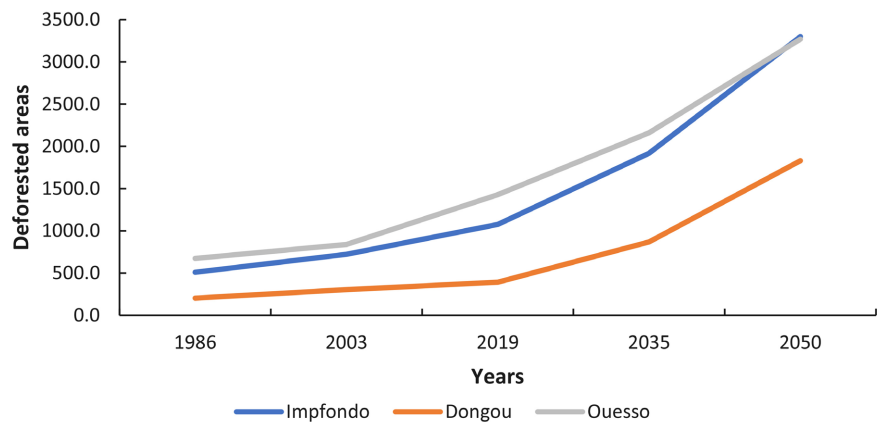


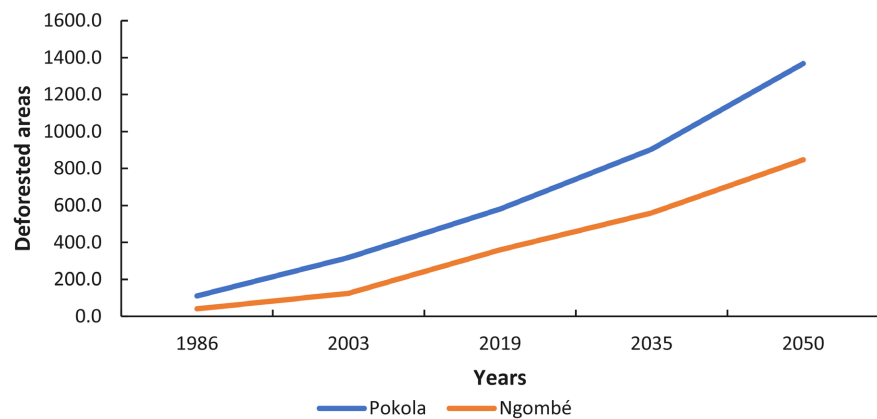
Figure 6. Simulation of the population growth of the main cities.

If the population continues to grow according to the observed and simulated trend, the locality of Impfondo will reach a population of 151,681 inhabitants, Dongou will have 48,804 inhabitants, Ouesso will have a population of 93,339 inhabitants, Pokola will have 35,634 inhabitants and Ngombe will reach 28,679 inhabitants by 2050 (Figure 6). It is important to note that the populations of Impfondo and Dongou will double their current numbers by 2050.

The deforestation forecasts in the vicinity of different cities are presented in Figure 7. It reveals that by the year 2050, the areas of deforested land are increasing. In 2019, for example, the deforested area was 391.4 hectares; it will increase to an estimated area of 1829.6 hectares in 2050 for the city of Dongou, representing a loss of 1438.1 hectares during this period. This increase in the deforested area is also significant for the cities of Impfondo, Ouesso, Pokola, and Ngombe, with respective values of 3298.1 hectares, 3268.5 hectares, 1368.0 hectares, and 847.0 hectares. This corresponds to estimated forest losses of 2222.5 hectares, 1829.6 hectares, 786.8 hectares, and 487.2 hectares between 2019 and 2050. These projections highlight the need to pay particular attention to the cities of Ouesso, Dongou and Impfondo, whose total projected areas will be significant if no sustainable land management measures are put in place.



(A)



(B)

Figure 7. Simulation of increased deforestation around major cities.

4. Discussion

4.1. Model of Deforestation and Forest Degradation

The model of deforestation and forest degradation proposed in this study (**Figure 8**) was constructed from the direct and indirect factors of deforestation and forest degradation (**Table 1**) identified through the analysis of survey data collected on the field during the various missions. Among these direct and indirect causes are: Urban growth, timber extraction, shifting agriculture, population growth, proximity to waterways, etc. Indeed, the main direct cause of land conversion is urban growth. According to [34], the processes of degradation and deforestation evolve from specific areas corresponding to towns or villages. This observation is confirmed by our studies in the localities concerned. Data collected from local governments, indigenous populations and colonial document archives indicate that the five localities studied were initially fishing camps, which have now become developed towns. This urban growth is induced by the increase in population, which in turn positively influences land use planning, land occupation and the issue of poverty of this population and economic activities. These factors interact with traditional agriculture, illegal logging and the use of wood as a source of energy. Generally, at the level of territorial governance, the central government develops projects aimed at improving the habitat. However, this development can exceed the limits and lead to deforestation. For example, in the city of Ouesso, one of the main cities studied, urban growth at the expense of forests is explained by the occupation of land for cadastral purposes. The increase in population is manifested by anarchic occupation of land and a growing demand for housing, which pushes the State to develop the territory to promote the development of different localities. The development model of cities, characterized by rapid population growth and anthropogenic pressure, leads to logging and therefore to deforestation.

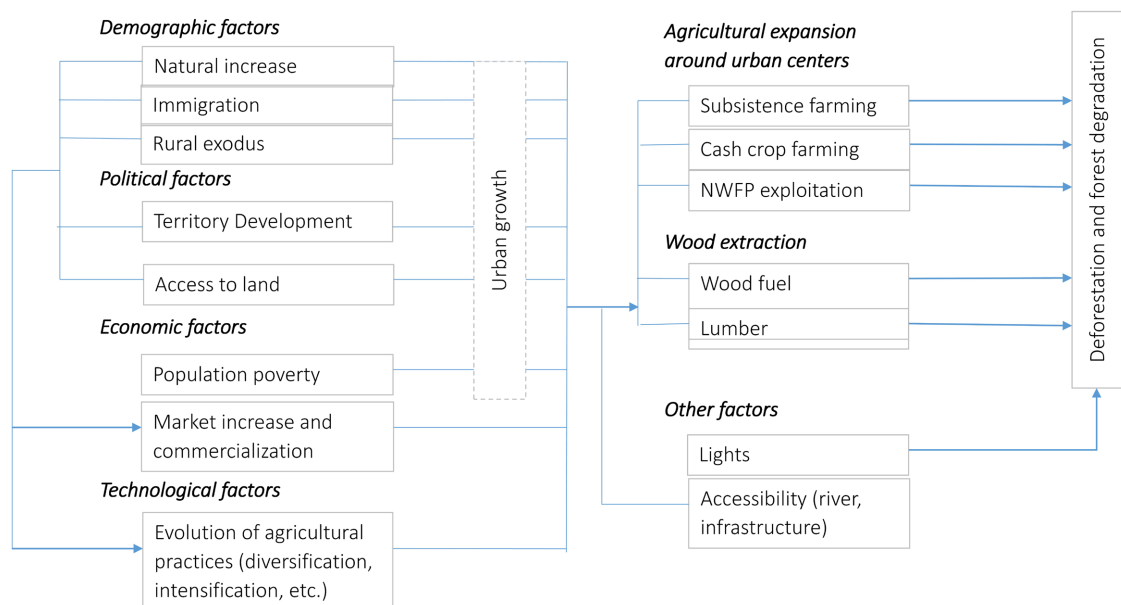


Figure 8. Model of deforestation and forest degradation of deforestation.

Table 1. Causes according to the different study areas.

	IMPFONDO	DONGOU	OUESSO	POKOLA	NGOMBE
<i>Agricultural extension</i>					
Subsistence farming	X	X	X	X	X
Cash crop farming	X		X		
NWFP exploitation/collection	X	X	X	X	X
<i>Wood extraction</i>					
wood fuel	X	X	X	X	X
Lumber				X	X
<i>Other factors</i>					
Accessibility (river, infrastructure)	X	X	X	X	X

4.2. Influence of Population on Forests and Urban Growth

The results of the study showed a rapid increase in the human population in all the forest localities studied. Indeed, the Republic of Congo is one of the most urbanized countries in the world [35] [36]. The large forest towns of the Republic of Congo have experienced a high concentration of population in recent decades [35] [37]-[39]. According to the latest estimates, 61.8% of the population lives in urban areas, with a higher concentration in the two main metropolises [36]. The reasons vary from North to South of the Republic of Congo depending on the centers of economic interest such as the establishment of forestry companies, administrations, health and education structures (middle and high schools), etc. This observation was also confirmed by [40] and [27], who both claim that the city offers opportunities for education, access to health and social services, as well as paid employment to its inhabitants. [34] stated that cities are centers of diverse activity. Also, this population increase is not only due to an increase in births within local populations, but rather also, to the arrival of external populations (refugees from the civil war) due to armed conflicts in the Democratic Republic of the Congo, Rwanda and the Central African Republic. Their installation has contributed significantly to the expansion of cities by building sites on the outskirts for their accommodation [41]. For example, the town of Impfondo received a total of 30,600 refugees from the DRC in November 2000, according to an NGO, African doctors [35]. The GAF project has shown that, from 2000 to 2010, significant areas of forest were lost around the localities of Bétou, Dongou and Impfondo, leading to the expansion of these towns.

4.3. Impact of Population Increase

Assuming the population continues to grow at the same rate, this indicates a considerable increase in the local population. This increase in population will lead to an expansion of residential, agricultural and fallow areas by 2050 in each locality studied.

Thus, population growth puts pressure on the land by using large areas for

housing construction and for agriculture (cultivation of cassava, corn, etc.) around the study areas. After a maximum of three harvests in cultivated areas, these populations seek new land due to soil depletion. They then turn to forests, which are rich in organic matter and therefore very fertile in nutrients to improve the agricultural yield of their crops.

Moreover, as the population increases, the percentage of poor population becomes more important, which translates into a scarcity of income-generating activities in all forest localities. Existing activities are not able to provide income that can be redistributed to the entire local population, which would contribute to limiting the exploitation of forest resources.

Another impact of population growth in a city, in addition to the need for energy, is the search for food and access to non-timber forest products (NTFPs). Population growth leads to growing demand for goods, services and livelihoods, which degrades the environment and puts pressure on natural resources [42]. The pressure increases with the population density per hectare. For example, the town of Impfondo, which is the administrative capital of the department of Likouala and is home to the only major high school in the department, has a large young population. Unfortunately, this youth, deprived of financial means, turns to forest resources, such as the collection of NTFPs such as honey, edible fruits, caterpillars, asparagus, etc., to meet their needs. These practices are generally accompanied by the killing of certain species. If socioeconomic parameters do not change, it is expected that the extraction of natural resources to meet nutritional needs will increase in the context of this study.

4.4. Impact of Economic Growth on Deforestation

According to [24], when population increase is not accompanied by economic growth, it has adverse consequences on the population situation and threatens the sustainability of natural resources (aggravates the consequences of deforestation). In dense forest areas, local people are very poor and highly dependent on forest resources for their livelihoods [43] [44]. In the Republic of Congo, the percentage of the population living below the national poverty line fell from 50.7% in 2005 to 40.9% in 2011 [36]. This rate is 64.4% in the department of Sangha and 66.7% in the department of Likouala [45], the two departments involved in this study. These statistics underline the total dependence of local populations on forest resources.

Field investigations revealed traces of human activities in the forests up to about 15 km around the towns of Impfondo and Dongou. For example, Dongou had only 8 state officials at the time of the survey, which also reflects the low circulation of money from the central government. In these two study localities (Impfondo and Dongou), the prevailing model is the impoverishment model developed by [15]. In this model, the poor population exerts pressure on the forest (clearing for agriculture, felling of trees for firewood, etc.) to meet their primary needs. According to the model called “environmental Kuznets curve”, economic growth

worsens the consequences of deforestation when per capita income is low [46].

In these localities, slash-and-burn agriculture is the main livelihood activity and source of income in these localities [47]-[49]. [46] points out that a significant annual loss of forest area and a significant annual gain of agricultural area have been observed in low-income countries. Although some studies have noted that an increase in population does not necessarily lead to an expansion of agricultural land [27], other studies have found that as the population increases, the demand for agricultural products is also increasing, leading to an increase in urban areas [48]. [50] asserts that the increase in urban population translates into a growing need for food, thus encouraging commercial farmers to increase their production.

[47] points out in his study that African cities, with their characteristics such as demographic explosion, uncontrolled urbanization and the importance of the informal sector, promote the development of urban and peri-urban agriculture. In this context, the poor population, which does not have sufficient means, illegally exploits the wood both for the construction of houses, the manufacture of canoes, furniture and also for food (wood fuel).

5. Conclusions

The study of land conversion is a complex process involving many actors and complex interactions between direct and indirect drivers of deforestation and forest degradation in peri-urban areas. These activities, which initially lead to forest degradation, eventually lead to deforestation due to the lack of forest recovery due to urban growth. Population growth, land use planning, land occupation, population poverty and economic activities are the main factors that contribute to deforestation and forest degradation in the localities studied. In other words, it should be said that there are three main things that would explain the destruction of forests around large cities: the satisfaction of food needs, energy needs, and housing. As the population grows, so does the demand for space, building materials, wood fuel and food. Consequently, this leads to an expansion of urban areas and an increase in pressure on the surrounding forests.

If this increase in population continues at the same rate, it will lead to a considerable increase in the local population. It is therefore necessary to put in place measures for the conservation and sustainable management of forest resources to prevent the continued loss of forests and preserve the environment. We have outlined several suggestions to promote the conservation and sustainable management of forest resources, including:

- ✚ Implement land use plans that integrate protected areas around cities to limit uncontrolled urban expansion. Encourage sustainable urban development models that optimize the use of available spaces to reduce encroachment on surrounding forests.
- ✚ Promote access to renewable energy sources, such as cooking gas and solar electricity, to reduce reliance on wood fuel. Encourage the use of improved stoves and energy-efficient technologies to significantly decrease wood fuel

consumption.

- ✚ Support the establishment of plantations dedicated to fast-growing tree species to meet the demand for construction materials and wood fuel. Additionally, promote the use of alternative or recycled materials in construction to ease pressure on natural forest resources.
- ✚ Incorporate trees into agricultural systems through agroforestry to maintain forest cover while addressing food needs. Invest in intensified agricultural practices to limit the expansion of agricultural land and reduce deforestation.
- ✚ Propose alternative economic activities, such as ecotourism or local crafts, to reduce pressure on forest resources. Simultaneously, train populations in diversified professions unrelated to forest exploitation, contributing to their economic empowerment.
- ✚ Strictly enforce laws against illegal deforestation and strengthen measures to control land use. Educate local populations on the importance of forest conservation and the harmful impacts of deforestation through education and communication campaigns.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Supplementary Instruction

- Urban growth in the forest areas of the Republic of Congo is directly responsible for tropical deforestation, with population growth as the underlying driver.
- The areas of fallow land and agricultural areas around cities have increased considerably over the past forty years.
- The interactions between the direct and indirect causes of forest loss are complex but important for understanding the reasons for these forest losses.
- Satisfying the primary needs of populations, such as food, access to land and energy, leads to the depletion of forest resources.