Land Cover Changes Within and Around Protected Areas in Côte d'Ivoire From 1986 to 2017: A Case Study of the Mabi-Yaya-Songan-Tamin Reserved Forests

Olena Boiko

South Dakota State University

Follow this and additional works at: https://openprairie.sdstate.edu/etd

Part of the Environmental Sciences Commons, Physical and Environmental Geography Commons, and the Remote Sensing Commons

Recommended Citation
https://openprairie.sdstate.edu/etd/3253

This Thesis - Open Access is brought to you for free and open access by Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange. For more information, please contact michael.biondo@sdstate.edu.
LAND COVER CHANGES WITHIN AND AROUND PROTECTED AREAS IN CÔTE D’IVOIRE FROM 1986 TO 2017: A CASE STUDY OF THE MABI-YAYA-SONGAN-TAMIN RESERVED FORESTS

BY
OLENA BOIKO

A thesis submitted in partial fulfillment of the requirements for the
Master of Science
Major in Geography
South Dakota State University
2019
LAND COVER CHANGES WITHIN AND AROUND PROTECTED AREAS IN CÔTE D'IVOIRE FROM 1986 TO 2017: A CASE STUDY OF THE MABI-YAYA-SONGAN- TAMIN RESERVED FORESTS

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree in Geography and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Darrell Napton, Ph.D.
Thesis Advisor

Dr. Robert Watrel, Ph.D.
Head, Department of Geography

Dean, Graduate School
ACKNOWLEDGEMENTS

I would like to thank my adviser, Dr. Darrell Napton, who helped me to move in the right direction when selecting my thesis topic and constantly supported me during this project. He encouraged me to continuously grow professionally, acquire new skills, and share my ideas with others. His interest in my professional success and his guidance helped me to not only develop my research and writing skills, but also to advance my ability to think critically and to take ownership in my work.

I am thankful to all professors from the Geography Department who provided their comments that helped make this research more comprehensive and my findings more valuable. I would like to thank Dr. Bruce Millet and Gray Tappan from EROS (Earth Resources Observation and Science Center) for being on the committee for my thesis. I would like to acknowledge Gray Tappan for providing me with the guideline on how to use Rapid Land Cover Mapper add-in and with the background knowledge of the landscape in the study area and its physical and human geography contexts. Thank you, Gray, for volunteering your time and sharing your knowledge and ideas.

I wish to acknowledge the Joseph F. Nelson Graduate Scholarship Committee for providing me with financial support for my thesis research. This will give me an opportunity to present my research to a broader audience and hopefully to conduct a field trip to the study site in the future to help communities navigate their decisions in the context of rapidly changing global environment.
Finally, I would like to thank my mother and my sister who supported me during my studies abroad and provided the best role models for my personal and professional growth.
# CONTENTS

ABBREVIATIONS.................................................................................................................. viii
LIST OF FIGURES................................................................................................................... ix
LIST OF TABLES....................................................................................................................... xii
ABSTRACT............................................................................................................................... xiii

## CHAPTER 1. INTRODUCTION .................................................................................................. 1

1.1. Description of the problem............................................................................................... 1
1.2. Research objectives .......................................................................................................... 3

## CHAPTER 2. LITERATURE REVIEW ....................................................................................... 5

2.1. Global tropical forest decline .......................................................................................... 5
  2.1.1. Land cover changes and land degradation ................................................................. 5
  2.1.2. Drivers of global tropical forest decline ..................................................................... 6
  2.1.3. Consequences of global tropical forest decline ......................................................... 8
  2.1.4. Role of protected areas for resources conservation ................................................... 8
  2.1.5. Intensification of human activity around protected areas ........................................ 9

2.2. Tropical forest in Côte d’Ivoire ....................................................................................... 10
  2.2.1. Degradation of Upper Guinean Forest ......................................................................... 10
  2.2.2. Background to the study area .................................................................................... 11
  2.2.3. Socioeconomic context of deforestation in the study area ......................................... 13
  2.2.4. Consequences of deforestation in Côte d’Ivoire ......................................................... 13
  2.2.5. Forest restoration efforts in Côte d’Ivoire ................................................................. 15

2.3. Study area profile ........................................................................................................... 16
  2.3.1. The location of the study area ..................................................................................... 16
  2.3.2. The ecoregion of the study area ................................................................................. 18
  2.3.3. Physical geography of the study area ......................................................................... 18
  2.3.4. Protection status of the study area ............................................................................ 20

## CHAPTER 3. METHODS ........................................................................................................ 25

3.1. Geographic Theory .......................................................................................................... 25
  3.1.1. Framing human-induced environmental changes geographically .............................. 25
  3.1.2. Semantic problems of defining ‘forest’ and ‘degraded forest’ ....................................... 25
  3.1.3. Integrating temporal and spatial analyses for land cover change detection ................ 27
  3.1.4. Event ecology approach ............................................................................................. 28
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.5. Theories of land-use change</td>
<td>28</td>
</tr>
<tr>
<td>3.2. Land cover analysis in the study area</td>
<td>30</td>
</tr>
<tr>
<td>3.2.1. Data Collection</td>
<td>30</td>
</tr>
<tr>
<td>3.2.2. Land cover classes</td>
<td>31</td>
</tr>
<tr>
<td>3.2.3. Land classification approach</td>
<td>35</td>
</tr>
<tr>
<td>3.2.4. The tool for land cover classification</td>
<td>37</td>
</tr>
<tr>
<td>3.2.5. Quantification of land cover change</td>
<td>39</td>
</tr>
<tr>
<td>3.3. Assessment of driving forces of land cover changes in Côte d’Ivoire</td>
<td>39</td>
</tr>
<tr>
<td>3.3.1. Methodological pluralism in land cover change studies</td>
<td>39</td>
</tr>
<tr>
<td>3.3.2. Proximate and underlying forces of land cover change</td>
<td>40</td>
</tr>
<tr>
<td>3.3.3. Framework on the causes of land cover change in the study area</td>
<td>40</td>
</tr>
<tr>
<td>CHAPTER 4. RESULTS</td>
<td>42</td>
</tr>
<tr>
<td>4.1. Land cover change analysis in the study area</td>
<td>42</td>
</tr>
<tr>
<td>4.1.1. Land cover description and land cover change over time</td>
<td>42</td>
</tr>
<tr>
<td>4.1.2. Quantification of land cover conversions over time</td>
<td>50</td>
</tr>
<tr>
<td>4.1.3. Size distribution of land cover classes over time</td>
<td>51</td>
</tr>
<tr>
<td>4.2. Land cover change analysis in different zones of the study area</td>
<td>54</td>
</tr>
<tr>
<td>4.2.1. Land cover change analysis in the Songan-Tamin reserved forest</td>
<td>54</td>
</tr>
<tr>
<td>4.2.2. Land cover change analysis in the Mabi-Yaya reserved forest</td>
<td>57</td>
</tr>
<tr>
<td>4.2.3. Land cover change analysis in the unprotected area</td>
<td>60</td>
</tr>
<tr>
<td>4.3. Summary of the results</td>
<td>63</td>
</tr>
<tr>
<td>CHAPTER 5. Driving forces of forest decline in Côte d’Ivoire</td>
<td>68</td>
</tr>
<tr>
<td>5.1. The role of forest reservation in Côte d’Ivoire</td>
<td>68</td>
</tr>
<tr>
<td>5.1.1. Background to forest reservation</td>
<td>68</td>
</tr>
<tr>
<td>5.1.2. The current state of forest reserves</td>
<td>71</td>
</tr>
<tr>
<td>5.2. Proximate causes of forest decline in reserved forests of Côte d’Ivoire</td>
<td>74</td>
</tr>
<tr>
<td>5.2.1. Agricultural expansion</td>
<td>74</td>
</tr>
<tr>
<td>5.2.2. Wood exploitation</td>
<td>79</td>
</tr>
<tr>
<td>5.2.3. Infrastructure extension</td>
<td>82</td>
</tr>
<tr>
<td>5.3. Underlying causes of forest decline in reserved forests of Côte d’Ivoire</td>
<td>84</td>
</tr>
<tr>
<td>5.3.1. Demographic factors</td>
<td>84</td>
</tr>
<tr>
<td>5.3.2. Economic and technological factors</td>
<td>96</td>
</tr>
</tbody>
</table>
5.3.3. Policy and Institutional factors ................................................................. 102
5.3.4. Cultural factors ......................................................................................... 107
5.4. Other Factors ............................................................................................... 108
  5.4.1. Pre-disposing environmental factors ....................................................... 108
  5.4.3. Social trigger events ............................................................................... 111
5.5. Summary ....................................................................................................... 112
  5.5.1. Interactions between driving forces......................................................... 112
  5.5.2. Why do buffer zones matter? ................................................................. 116
CHAPTER 6. CONCLUSIONS ........................................................................... 118
  6.1. The importance of the research ................................................................. 118
  6.2. Research objectives and summary of the main findings ......................... 120
    6.2.1. Summary of land cover changes interpretation .................................... 120
    6.2.2. Summary of driving forces assessment ............................................... 121
  6.3. Importance and Implications of the results .............................................. 124
  6.4. Contribution of this research .................................................................. 126
  6.5. Suggestions for further research .............................................................. 127
LITERATURE CITED ....................................................................................... 129
## ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIJ</td>
<td>Earth Island Journal</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization</td>
</tr>
<tr>
<td>FAOSTAT</td>
<td>Food and Agriculture Organization Database</td>
</tr>
<tr>
<td>HRW</td>
<td>Human Rights Watch</td>
</tr>
<tr>
<td>IDH</td>
<td>The Sustainable Trade Initiative</td>
</tr>
<tr>
<td>IUCN</td>
<td>International Union for Conservation of Nature</td>
</tr>
<tr>
<td>REDD+</td>
<td>Reducing Emissions from Deforestation and Forest Degradation</td>
</tr>
<tr>
<td>RLNM</td>
<td>Rapid Land Cover Mapper ArcMap add-in</td>
</tr>
<tr>
<td>ROAM</td>
<td>Restoration Opportunities Assessment Methodology</td>
</tr>
<tr>
<td>SEP REDD+</td>
<td>Secrétariat Exécutif Permanent REDD+, or REDD+ Programme Executive Board</td>
</tr>
<tr>
<td>SODEFOR</td>
<td>Société de développement des forêts, or Forest Development Society</td>
</tr>
<tr>
<td>STEWARD</td>
<td>Sustainable and Thriving Environment for West African Regional Development</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environmental Programme</td>
</tr>
<tr>
<td>CILSS</td>
<td>Comité Permanent Inter-états de Lutte contre la Sécheresse dans le Sahel, or Permanent Interstate Committee for drought control in the Sahel</td>
</tr>
<tr>
<td>USAID</td>
<td>US Agency for International Development</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1. Global distribution of tropical forests .......................................................... 7
Figure 2. Upper-Guinean Forest of West Africa in 2013 ............................................. 11
Figure 3. The location of the study area ...................................................................... 17
Figure 4. Ecoregions in Côte d’Ivoire .................................................................... 19
Figure 5. Landsat image of the study area in 1986 ................................................... 22
Figure 6. Landsat image of the study area in 1999 ................................................... 23
Figure 7. Landsat image of the study area in 2017 ................................................... 24
Figure 8. Heterogeneous landscape in the study area .............................................. 36
Figure 9. Interpreting forest fragmentation ............................................................... 36
Figure 10. Comparison of different land cover classes ......................................... 37
Figure 11. Steps in making a land cover map using the Rapid Land Cover Mapper add-in ................................................................. 38
Figure 12. Causes of forest decline ......................................................................... 41
Figure 13. Land cover map in the study area in 1986 ............................................. 43
Figure 14. Land cover map in the study area in 1999 ............................................. 44
Figure 15. Land cover map in the study area in 2017 ............................................. 45
Figure 16. Land Cover in the study area in 1986, 1999, and 2017 (all land cover classes) ......................................................................................................................... 46
Figure 17. Land Cover in the study area in 1986, 1999, and 2017 (small area classes) 47
Figure 18. Absolute land cover changes in the study area .................................... 49
Figure 19. Relative land cover changes in the study area .................................... 50
Figure 20. Land cover classes by polygon sizes in 1986 ....................................... 53
Figure 21. Land cover classes by polygon sizes in 1999 ....................................... 53
Figure 22. Land cover classes by polygon sizes in 2017 ....................................... 54
Figure 23. Land Cover in the Songan-Tamin reserved forest in 1986, 1999, and 2017 ................................................................. 55
Figure 24. Absolute land cover changes in the Songan-Tamin reserved forest .... 55
Figure 25. Relative land cover changes in the Songan-Tamin reserved forest ....... 56
Figure 26. Land Cover in the Mabi-Yaya reserved forest in 1986, 1999, and 2017 .... 58
Figure 27. Absolute land cover changes in the Mabi-Yaya reserved forest ......... 59
Figure 28. Relative land cover changes in the Mabi-Yaya reserved forest .......... 59
Figure 29. Land Cover in the unprotected zone of the study area in 1986, 1999, and 2017

Figure 30. Absolute land cover changes in the unprotected area

Figure 31. Relative land cover changes in the unprotected area

Figure 32. Heterogeneity of the degraded forest class in the study area in 2017

Figure 33. Forest cover change for three zones of the study area

Figure 34. Degraded forest cover change for three zones of the study area

Figure 35. Plantation cover change for three zones of the study area

Figure 36. Protected areas of Côte d’Ivoire

Figure 37. Number of forest reserves established in Côte d’Ivoire by decade

Figure 38. Cocoa bean production in Côte d’Ivoire

Figure 39. News headlines that illustrate the role of changes within global market on occupation and livelihood of farmers on Côte d’Ivoire

Figure 40. Rubber production in Côte d’Ivoire

Figure 41. Coffee production in Côte d’Ivoire

Figure 42. Temporal changes of the main economic activities in Côte d’Ivoire driven by the shift in the state’s economic priorities

Figure 43. Forestry production in Côte d’Ivoire during 1986 – 2017

Figure 44. Fragmented forest inside the Songan-Tamin forest reserve

Figure 45. Road inside the dense forest of the Mabi-Yaya reserve

Figure 46. Land cover on different sides of the road

Figure 47. The impact of infrastructure development on deforestation in the Amazon

Figure 48. Administrative division of the study area

Figure 49. Changes in settlement area in each zone of the study area

Figure 50. A settlement inside the Songan-Tamin forest reserve surrounded by tree plantations

Figure 51. Population changes in the study area from 2000 to 2017

Figure 52. Population changes in different zones of the study area from 2000 to 2017

Figure 53. Population density changes in different zones of the study area from 2000 to 2017

Figure 54. A small settlement inside the Mabi-Yaya forest reserve
Figure 55. A settlement in the buffer zone of the study area ................................................................. 94
Figure 56. Price of cocoa and total production of cocoa in Côte d’Ivoire ........................................ 97
Figure 57. Land use expansion approach ............................................................................................... 97
Figure 58. Price of rubber and total production of rubber in Côte d’Ivoire ............................................. 98
Figure 59. “Alternative commodity” scenario .......................................................................................... 99
Figure 60. A poverty-environment trap ..................................................................................................... 101
Figure 61. An inverted U-shaped environmental Kuznets curve for deforestation ...... 102
Figure 62. Priority regions of the Cocoa and Forests Initiative ............................................................... 104
Figure 63. Positive feedback loop of interaction between biophysical properties and human use of land that results in fragility ......................................................................................... 109
Figure 64. Topography of the study area .................................................................................................. 111
Figure 65. A casual chain that led to forest decline in Côte d’Ivoire .................................................... 113
Figure 66. Where Côte d’Ivoire exported cocoa beans to in 2017? ....................................................... 114
Figure 67. Where Côte d’Ivoire exported rubber to in 2017? ............................................................... 115
LIST OF TABLES

Table 1. Study area ............................................................................................................................................. 16
Table 2. Landsat images of the study area ........................................................................................................ 30
Table 3. Land cover classes in the study area .................................................................................................. 32
Table 4. Land cover conversions during 1986 – 1999 study period (area measured in sq km) .................................................................................................................................................. 51
Table 5. Land cover conversion during 1999 – 2017 study period (area measured in sq km) .................................................................................................................................................. 51
Table 6. Land cover conversions in the Songan-Tamin reserved forest during 1986 – 1999 study period (area measured in sq km) .................................................................................................................................................. 57
Table 7. Land cover conversions in the Songan-Tamin reserved forest during 1999 – 2017 study period (area measured in sq km) .................................................................................................................................................. 57
Table 8. Land cover conversions in the Mabi-Yaya reserved forest during 1986 – 1999 study period (area measured in sq km) .................................................................................................................................................. 60
Table 9. Land cover conversions in the Mabi-Yaya reserved forest during 1999 – 2017 study period (area measured in sq km) .................................................................................................................................................. 60
Table 10. Land cover conversions in the unprotected area during 1986 – 1999 study period (area measured in sq km) .................................................................................................................................................. 63
Table 11. Land cover conversions in the unprotected area during 1999 - 2017 study period (area measured in sq km) .................................................................................................................................................. 63
ABSTRACT
LAND COVER CHANGES WITHIN AND AROUND PROTECTED AREAS IN CÔTE D’IVOIRE FROM 1986 TO 2017: A CASE STUDY OF THE MABI-YAYA-SONGAN-TAMIN RESERVED FORESTS
OLENA BOIKO
2019

Tropical forests mitigate climate change, provide habitat for the most biologically diverse terrestrial communities, and yield ecosystem services that support human well-being. These forests are some of the most threatened ecosystems because of the increasing human impact on the environment. Côte d’Ivoire has one of the highest deforestation rates in sub-Saharan Africa, and the expansion of agriculture to produce cash crops, such as cocoa and rubber, is presented as the primary reason for forest loss. These changes are apparent even within the boundaries of the protected areas, which raises concerns about the effectiveness of the protection strategies. This project illustrates land cover changes on a local level that are associated with tropical forest decline within and outside the Mabi-Yaya-Songan-Tamin protected area complex in southeastern Côte d’Ivoire. To provide a context to local land cover changes, this thesis assesses the contribution of anthropogenic driving forces that led to forest degradation and deforestation. Land cover changes were quantified using the ArcMap add-in Rapid Land Cover Mapper for visual interpretation of the landscape and land cover classification of Landsat images for three study years: 1986, 1999, and 2017. Proximate and underlying driving forces of forest decline in reserved forests of Côte d’Ivoire were evaluated based
on scientific literature, news articles, government documents, and reports prepared by non-governmental organizations. The main findings revealed that forest degradation was the primary type of land cover change inside the reserves. The conversion was likely associated with multiple driving forces including the expansion of agriculture and forest exploitation for wood. Some of the most important underlying causes of forest decline in Côte d’Ivoire included institutional instability, population growth in the immediate surrounding of the forest reserves, migration patterns, demands for agricultural commodities, fluctuations of the trade markets, energy insecurity, lack of compliance to environmental law, and the absence of large-scale technological innovations to improve yields. Although the Mabi-Yaya reserve was generally better preserved than the Songan-Tamin reserve, it is unlikely that conservation practices helped to improve its resilience to human pressure.

Key words: Côte d’Ivoire, deforestation, forest degradation, land cover change, driving forces, anthropogenic impact, Rapid Land Cover Mapper, remote sensing, land cover mapping, land use.
CHAPTER 1. INTRODUCTION

1.1. Description of the problem

The image of a landscape is often constructed and perceived through the benefits it provides for humans called ecosystem services. Landscapes produce resources that are directly consumed by people, support and regulate natural processes, and possess aesthetic and spiritual values (Dempsey and Robertson 2012, 764). When deriving these benefits with little or no consideration for environmental externalities, human actions lead to undesirable changes to a landscape that result in ecosystem services decline and subsequent land degradation that varies across spatial and temporal scales.

Tropical forest decline is an example of land degradation that has multiple long-term and short-term consequences at local, regional, and global scales. Tropical forests produce valuable resources such as timber, resins, oils, latexes, fibers, fruits, and medicines (Grainger 1996, 185). Forests contribute to climate regulation by carbon dioxide absorption. Additionally, they provide habitat support for the most diverse terrestrial biological communities (FAO 2016, 2). Tropical forests are often converted to plantations and farms with the purpose of producing other commercially valuable resources. These benefits make forests the target for human exploitation, which results in ecosystem goods and services decline, such as decline of the capacity of forests to produce commercial products or the fertility of land that was converted to other land cover types. Natural resources are not infinite. At first forest use might allow people to obtain more economic benefits in the short term, but later the capacity of forests to serve humans might decrease (Ehuitché 2015, 105). That is why solving this problem resonates with balancing the health of the environment and the benefits it provides for humans.
Defining how, where, when and why forests change on a local and national level is the first step to proper management of forest resources globally.

The center of this study is the Upper-Guinean forest in Côte d’Ivoire, which has one of the highest rates of deforestation in sub-Saharan Africa (Ehui 1993). The economy of the country is based on agriculture, and therefore agricultural expansion is often presented as the main cause of this problem. Forest degradation can be attributed to demands from within and outside the country. The rate of population growth in Côte d’Ivoire is one of the highest in the world, which may result in equally rapid conversion of forests to farming fields. In addition, the country is one of the world’s leaders in producing cocoa and coffee beans, which are consumed far from where they are grown and result in indirect impact of countries-consumers on deforestation in Côte d’Ivoire. Other industries established here include timber harvesting, cotton, oil, and rubber production.

This research focuses upon detecting and quantifying changes associated with deforestation and tropical forest degradation in the Mabi-Yaya-Songan-Tamin reserved forests in southeastern Côte d’Ivoire from 1986 to 2017. The main goals are to compare the changes of degraded forest and land covers produced from forest land conversion inside and around this protected area complex and to identify the role of drivers of forest degradation and deforestation. The growth of degraded forest is expected to correlate with an increase of human-made land covers, such as farms, plantations, and settlements. This project offers a synthesis of a detailed interpretation of land cover change patterns on a local level and an overview of driving forces of forest decline in protected zones at a national scale. Integration of spatial and temporal perspectives allows one to address the
challenge of attributing significance to the dynamics of a changing planet – one of the core ambiguities that geographers seek to understand and clarify.

1.2. Research objectives

In this project, I am investigating land cover changes associated with deforestation and tropical forest degradation in protected areas of Côte d’Ivoire because I want to compare land cover changes in the Mabi-Yaya, Songan-Tamin reserved forests, and the unprotected area that surrounds them in order to evaluate the effectiveness of forest protection in these reserves. This thesis seeks to determine if the establishment of protected area has a positive effect on the conservation of natural resources, and if population growth and intensification of human activity in the unprotected area that surrounds forest reserves compromises conservation objectives. I address three main objectives:

(1) measure spatial changes in land cover in Mabi-Yaya, Songan-Tamin reserved forests of Côte d’Ivoire, and the unprotected area that surrounds them (10 km buffer zone) by interpreting remotely sensed images of the study area obtained for three study years: 1986, 1999, and 2017;

(2) compare and contrast spatial changes in land cover by identifying the extent of degraded forest and other land cover classes in Mabi-Yaya, Songan-Tamin reserved forests and the unprotected area around them;

(3) assess the connections of potential driving forces of forest decline and the landscape changes in Côte d’Ivoire at a national scale and in the study area at a local level.
The final product of this project is land cover maps for each study year, graphs that indicate temporal change in area of each land cover class, and contingency tables of land cover conversions. I explored socioeconomic, political, and environmental contexts of local land cover changes in the study area based on literature reviews to provide descriptions of drivers associated with tropical forest decline. In order to put the dynamics of forest degradation in a broader context of its surroundings, I identify the connection between the growth of human pressures outside the protected area to deforestation and forest degradation within it. This project demonstrates that monitoring of land cover changes around protected areas is indispensable for successful management of reserved forests and provides a baseline for future conservation of the Mabi-Yaya-Songan-Tamin protected area complex.
CHAPTER 2. LITERATURE REVIEW

2.1. Global tropical forest decline

2.1.1. Land cover changes and land degradation

Human activities cause substantial alterations to Earth’s land surface. Many of these changes can be visible on the land cover defined as the physical material of the Earth’s surface, for example, forest, water, and grassland. The concept of land cover change is used to describe an alteration of the physical surface of the Earth whether the change was desirable or unwanted. The term ‘land degradation’ is used to depict undesirable changes that result in decline of economic productivity caused by humans and therefore have environmental and social implications (Blaikie and Brookfield 1987, 1). Human impacts are distributed unevenly across the planet and are different from natural disturbances because they are greater in degree and limit the ability of natural systems to recover (Marsh 1965, 36-43). Not only is the change itself unsustainable but also the rate of land transformation is a matter of concern because of growing population and human pressure on the environment (Hooke, Martin-Duque, and Pedraza 2012).

Places differ in the value of resources they possess and in their connections to the surrounding area, which results in different levels of vulnerability. The decline of the ability of land to return to pre-disturbance ecosystem services delivery introduces the concept of ‘fragile land’. The land is fragile when it is highly sensitive to destructive forces and has low resilience. That means it is easily degraded and recovers slowly (Turner and Benjamin 1994, 112-114).
2.1.2. Drivers of global tropical forest decline

Tropical forests are among the most valuable and sensitive ecosystems. They are often put in the ‘fragile land’ category, because tropical soils are poor in nutrients and degrade easily when exposed to multiple anthropogenic pressures. It should be noted that fragility is not an intrinsic quality of ecosystems but rather an outcome of human intervention (Turner and Benjamin 1994, 105-106). In this case, mismanagement and clearing forests for agriculture, grazing, and urbanization transform primary forests into secondary or managed forests and lead to the loss of natural resilience and subsequent fragility (Johnson and Lewis 1995, 212). Nutrient deficiency of soils might contribute to acceleration of land degradation but only under the conditions of mismanagement of natural resources.

In order to confront the issue of tropical forest loss, it is critical to examine the relative contribution of agents of deforestation. The role of different factors varies historically and geographically. Temporal differentiation reveals that pre-1990 deforestation trends were attributed primarily to agricultural expansion driven by smallholders. After 1990, globalization caused enterprise-centered activities such as timber and palm oil industries to play a stronger role in deforestation than smallholders (Rudel et al 2009).

Studying deforestation and forest degradation through a geographic lens provides us with an opportunity to explore spatial variability of this problem. The majority of tropical forests today are located in Latin America, Africa, and Southeast Asia (Figure 1). These regions have different land-use histories, cultures, ecosystems structures, and connections. One result of these differences is that deforestation is driven by different
causes and events in different regions. Commercial logging and shifting agriculture contributed the most to tropical forest loss in Southeast Asia while expansion of cocoa planting appears to be the main driver of deforestation in West Africa.

![Figure 1. Global distribution of tropical forests](Cousineau 2019)

Scaling down to a continent level reveals additional variations. For example, the Upper-Guinean Forest of West Africa is not connected to the Congo Basin forest in Central Africa, which explains the establishment of different communities of species and different mechanisms of forest decline. Furthermore, national and administrative boundaries introduce different management opportunities and constraints. The Upper-Guinean forest has different drivers and implications of degradation in Liberia than it has in Côte d’Ivoire because of the different structure of the countries’ economies and land use histories (Tappan 2018). While pathways to deforestation lie through regional-specific land-use history, deforestation in each region originated not from a single driving force, but from a combination of multiple factors with different relative contributions,
including wood harvesting, permanent cultivation, grazing, and infrastructure development (Lambin and Geist 2003).

2.1.3. Consequences of global tropical forest decline

The importance of the problem of tropical forest decline fits in a broader context of contemporary challenges because it has multiple outcomes such as loss of biodiversity, food insecurity, limited access to sustainable energy, climate change and its consequences, economic disruption, and various social, institutional, and political issues. These outcomes have other negative impacts that limit the ability of the environment and society to respond to these problems effectively (FAO 2016). Some of the impacts are irreversible by their nature, such as extinction of species, or become irreversible after reaching a tipping point as predicted for climate change. Last, but not the least reason to confront the problem of tropical forest decline, is the number of people affected. Tropical forests are often located in densely populated areas (Defries et al 2007, 1032). In addition, in a globalized world resources from tropical areas are consumed by people living far away from the hotspots of forest degradation. Finally, the population is growing and therefore the problem is expected to become more important over time (Napton 2018).

2.1.4. Role of protected areas for resources conservation

One of the Sustainable Development Goals set by the United Nations titled “Life on Land” is to “to conserve and restore the use of terrestrial ecosystems such as forests, wetlands, drylands and mountains (UNDP, 2018)”. This goal targets multiple other goals including climate change mitigation, poverty and hunger elimination, and reduction of global biodiversity loss. One way to address this goal is by reinforcing protected areas
that are dedicated to the protection of biological diversity, and of natural and cultural resources. Currently 14.5% of land is under protection (Lui and Comes 2016), but the effectiveness of protection strategies varies spatially because management opportunities and obstacles depend on socioeconomic settings and biophysical conditions (Defries et al 2007).

Given the current state of protection zones across the globe, one should understand that setting boundaries is not enough. First, the boundaries of most protected areas are not designed to encompass biophysical gradients in precipitation, elevation, and temperature that exist within the greater ecosystem that makes these boundaries insufficient to accomplish conservation missions (Defries et al 2007, 1033). Second, the socioeconomic context of protected areas is seldom considered for conservation purposes. It has been reported that one-third of global protected land is undermined by extensive human activity. Therefore, there is an urgent need to monitor the state of protected areas and implement management practices even beyond the boundaries of protected areas to ensure proper conservation (Jones et al., 2018). Comparison and contrast of land cover changes within and around protected area can serve as a baseline to address this problem.

2.1.5. Intensification of human activity around protected areas

Many protected areas around the world are likely to experience human pressure in response to the land use and socioeconomic dynamics of the regions where they are located. Protected areas particularly in developing countries are surrounded by densely populated areas where people depend heavily on local resources for food and energy needs. Other land cover changes in protected areas that affect the ability of an ecosystem
to maintain its ecological functions are triggered by a transition from subsistence to commercial agriculture that may result in land use intensification around protected areas (Defries et al 2007, 1032).

In the tropics, deforestation rates are generally lower within protected areas boundaries than in unrestricted areas that surround them (Lui and Comes 2016). Drawing conclusions about the success of protection inside the restricted zone, however, might not be justified. An alternative explanation is that deforestation that protected areas are intended to prevent can shift into unrestricted zones outside the boundaries of the protected areas, resulting in a phenomenon called “leakage”. Land use change in these unrestricted buffer zones, therefore, has detrimental effects on the edges of protected areas that might potentially reduce their core area (Dewi et al 2013).

2.2. Tropical forest in Côte d’Ivoire

2.2.1. Degradation of the Upper-Guinean Forest

The Upper-Guinean Forest of West Africa stretches over the territory of Guinea, Sierra Leone, Liberia, Côte d’Ivoire, Ghana, and Togo (Figure 2). It has been identified as a ‘global biodiversity hotspot’ because it has a high concentration of endemic species and at the same time rapidly growing human impact resulting in deforestation and biodiversity decline (Tappan 2018; CILSS 2016). The population density and population growth in this region are one of the highest in Africa, which leads to conversion of most of the forested lands into agricultural fields and subsequent degradation and fragmentation of forests (Liu et al 2016, 3). Apart from the threat presented by increasing population, this region is exploited by industries producing such commodities as rubber, cocoa, oil palm, and timber (CILSS 2016). To summarize, the Upper-Guinean Forest is a
place of special value and of growing concerns, because it responds to the needs of the local growing population, it is included in the global trade system, and it provides a habitat for a variety of endemic species, such as the white-collared mangabey (*Cercocebus atys lunulatus*), Roloway monkey (*Cercopithecus diana roloway*), Stampfl’s putty-nosed guenon (*Cercopithecus nictitans stampflii*), white-breasted guinea fowl (*Agelastes meleagrides*), rufous fishing owl (*Scotopelia ussheri*), and many others (CEPF 2000, 7-8).

![Map of Côte d'Ivoire](image)

**Figure 2. Upper-Guinean Forest of West Africa in 2013**

*CILSS 2016, 66*

2.2.2. Background to the study area

This research focuses on tropical forests in Côte d’Ivoire, a country in West Africa that covers 322,460 km² and has a population of 23,695,919 people (World Bank 2018). Côte d’Ivoire is characterized by three distinct types of landscapes. The southern
part is covered by tropical forests, towards the north there is a forest-savanna mosaic that turns into savanna and woodland landscape in the northern part of the country. The geographic focus of this research is the southern part covered by a portion of the Upper-Guinean Forest including remaining dense forest as well as degraded forest, plantations, and cropland covering the former tropical forest zone (Ehui 1993, 352-354).

The annual deforestation rate in Côte d’Ivoire in 2008 was estimated to be 3.1%, which is one of the highest in West Africa (Ehuitché 2015, 103-104). Another study suggested that the average annual deforestation rate increased from 2.4% in 1956 – 1965 to 7.3% in 1981 – 1985. The rate of deforestation expressed as a percentage is a major component to the understanding of forest changes dynamics but should be examined together with the absolute amount of forest changes to avoid misleading the representation of continuously increasing rate of forest loss as forest cover decreases. The most frequent estimation in the literature suggests that Côte d’Ivoire had between 14.5 and 16 million hectares of original forest in 1900, began to lose it rapidly around 1955, and by 1990 had only about 2.7 million hectares remaining (Leach and Fairhead 2000, 21). That indicates a forest loss between 81% and 83% from 1900 to the present. Based on the data reported by the government, Côte d’Ivoire had 16 million hectares of forest in 1900, 7.8 million hectares in 1990, and 3.4 million hectares in 2015 (Ministère des Eaux et Forêts 2018, 8, translated from French). Leach and Fairhead (2000) argued that most commonly used figures of 14.5 to 16 million hectares of original forest extent in Côte d’Ivoire originated from just a few sources and are likely exaggerated. To summarize, although all sources agree on the fact that forest cover in Côte d’Ivoire has been reduced substantially, the statistics of deforestation at a national level are inconsistent.
2.2.3. Socioeconomic context of deforestation in the study area

Land cover changes are a direct reflection of land use changes, and therefore the human component is the key factor in this study. What drives human behavior and choices is often translated into the way people treat their land. No wonder agricultural expansion and logging have been identified as main contributors to deforestation in Côte d’Ivoire. Less impactful drivers of deforestation are grazing and use of forests for fuelwood (Ehuitché 2015, 367). Land use pressure was intensified because of the high rate of natural increase of population combined with the effects of migration (Ehuitché 2015, 103-104).

The economy of Côte d’Ivoire is based on agriculture. Two cash crops critical for the country’s economy are cocoa and coffee (Ehui 1993, 359). The country is the largest producer of cocoa beans in the world (Higonnet et al. 2017, 3). The amount of cocoa beans exported from Côte d’Ivoire expanded rapidly in response to the growth of the global industry of chocolate. Coffee production is less common than cocoa, because it is more difficult to produce, and it is taxed more heavily. Other export commodities relevant for the country’s economy are rubber, oil palm, and timber. Food crops produced for consumption in Côte d’Ivoire include cassava, yams, cocoyam, maize, rice, sorghum, and bananas (Ehui 1993, 361-362).

2.2.4. Consequences of deforestation in Côte d’Ivoire

While examining environmental issues on a local scale, one should emphasize that the consequences are seldom limited by the borders of a defined study area, and therefore they may range from local to regional and global. One of the most prominent global consequences of deforestation is climate change. Clearing the forest leads to release of
carbon dioxide into the air, which disrupts the natural composition of the atmosphere and intensifies the greenhouse effect (Ehui 1993, 374-375).

A problem that is limited by the study area border is a decline in agricultural productivity and income. Deforestation intensifies soil erosion, which causes shifts in agriculture to less suitable areas. It has been estimated that an increase in the deforestation rate of 1% leads to about 5% decline in agricultural yield in Côte d’Ivoire (Ehuitché 2015). Also, any land use scenario is associated with opportunity costs that represent a loss of potential benefits from other land use alternatives (Napton, 2017). For example, uncontrolled clearing of forests decreases timber production potential and potential earnings from forest industry (Ehui 1993, 376-377).

Decline in available land that can be used for commercial activities is not just a cause of an economic loss; it almost inevitably leads to political conflicts. In 2002, ethno-regional division and civil war spurred from land-ownership conflicts fueled over-exploitation of tropical forests. The decline of forest resources originated from an easy access to forested land that was used primarily for cocoa growth (Woods 2003). One should understand that this situation cannot be simply described by a cause-and-effect relationship. While forest degradation contributes to political instability, it also induces a positive feedback loop that encourages change because consequences of initial change contribute to further transformation (Napton, 2018). In this case, conflict-related activities often result in further forest degradation through destruction of the habitat by armies, withdrawal of forest conservation agents, and activities of refugees that are harmful to the environment (Barima et al 2016, 85-86).
Apart from multiple social implications, forest degradation is often a direct cause of habitat destruction and subsequent loss of biodiversity that results in various local, regional, and global effects. Once covered by dense forest, Côte d’Ivoire had one of the highest rates of biodiversity in Africa. Today only a small portion of the country remains forested limiting the amount of land accessible to wildlife. Ivorian species threatened by the loss of their habitat include chimpanzees, elephants, pygmy hippos, flying squirrels, pangolins, leopards, and crocodiles (Higonnet et al 2017, 7).

2.2.5. Forest restoration efforts in Côte d’Ivoire

Successful restoration practices are typically based on efforts taken at different scales and collaboration between multiple participants. Therefore, political aspects are critical for managing land restoration efforts. The government of Côte d’Ivoire recognizes the necessity of addressing the issue of deforestation and forest degradation. In 2014, President Allassane Ouattara committed his country to Reducing Emissions from Deforestation and Forest Degradation known as the REDD+ program. Based on this commitment, the United Nations Environmental Programme – (UNEP) and Central and West Africa Forest Program of the World Conservation Union started developing the Restoration Opportunities Assessment Methodology (ROAM) with the purpose of building land restoration and forest protection strategies in Côte d’Ivoire (IUCN/UNEP-PCA 2016, 7).

Because tropical forests in Côte d’Ivoire have international value, some programs with the purpose of regeneration of degraded land are implemented in other countries. One of them is Sustainable and Thriving Environment for West African Regional Development (STEWARD) conceptualized by the US Agency for International
Development (USAID) and the US Forest Service. The primary goal behind this initiative is to reach a compromise between biodiversity conservation and improving the livelihood of the population. Coming from abroad, this program is an example of collaboration between countries on a global level, which may be necessary for addressing the problem of land degradation and ensuring global sustainability (USAID 2008).

2.3. Study area profile

2.3.1. The location of the study area

The study area is in the southeastern part of Côte d'Ivoire (Figure 3). It consists of four adjacent reserved forests: Mabi, Yaya, Songan, and Tamin that were created in 1929, 1957, 1955, and 1955 respectively (SODEFOR 1992) and a 10 km buffer zone around them to illustrate land cover in the unprotected area. These forest reserves later were combined into two: Mabi-Yaya and Songan-Tamin. Therefore, in this research three zones were examined separately: Mabi-Yaya, Songan-Tamin, and the unprotected zone (Table 1). I selected a 10 km buffer zone based on a review of the literature; Dewi et al (2013) studied protected areas in Africa and Asia-Pacific and demonstrated that a potential “leakage” zone of influence of at least 10 km outside the restricted boundary needs to be considered for quantification of the deforestation that might originate from forest protection inside the protected area.

Table 1. Study area

<table>
<thead>
<tr>
<th>Zone</th>
<th>Songan-Tamin reserved forest</th>
<th>Mabi-Yaya reserved forest</th>
<th>Unprotected zone</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area, sq km</td>
<td>920.25</td>
<td>902.75</td>
<td>2,845.75</td>
<td>4,678.75</td>
</tr>
</tbody>
</table>
Figure 3. The location of the study area

(Source: ArcGIS Online, United Nations Environment World Conservation Monitoring Centre, Software: ArcGIS by ESRI)
2.3.2. The ecoregion of the study area

The area of interest is limited to the southern part of the country that is or was covered by a portion of Upper Guinean forest including the dense tropical forest ecoregion (ZFT, Zone Forestière Tropicale in French) (Figure 4), although the boundaries are not strictly defined. The classification of ecoregions organizes land units by their dominant biotic and abiotic components that reflect the interdependence of environmental capacities and human pressure (Omernik and Griffith 2014, 2-5). One should understand that this organization is an attempt to attribute significance to patterns, and the transition between ecoregions is more often a zone of transition than a line. Furthermore, adding the temporal dimension contributes to the difficulty of delineating the ecoregions’ boundaries, because boundaries are often inconsistent and might change. Nonetheless, for the purposes of this study we consider that the study area is in the tropical forest ecoregion based on the classification system proposed by US Geological Survey (CILSS 2016) (Figure 4).

2.3.3. Physical geography of the study area

Tropical forests in this area present a land cover class of primary interest in this research. Temperatures through the year in this zone are fairly stable, ranging from 22 °C (72 °F) to 33 °C (90 °F) during the day. Humidity is high, and annual precipitation exceeds 1,800 mm (71 in). The climate is characterized by two rainy seasons from May to July and from October to November and two dry seasons from December to April and from August to September (Ehui 1993, 353-354).

Because of the north-south climate gradient, forest in southern Côte d’Ivoire transitions into savanna in the northern part of the country. Additionally, climate
determines the species composition and the type of the tropical forests of Côte d’Ivoire contributing to the heterogeneity within the tropical forest ecoregion. Evergreen rain forest in the southwestern and southeastern part of the country transitions into evergreen seasonal forest to the north and then farther north into semi-deciduous forest (Grainger 1996, 181). The focus of this study includes only the evergreen forest in the southeastern part of Côte d’Ivoire.

FD – degraded forest; FZM – mountain forest; PAVN – agricultural plateau of the Black Volta; PC – coastal plains; SBC – savanna of the Comoe basin; SBS – savanna of the Sassandra basin; ZACN – north-central agricultural zone; ZFT – tropical forest zone; ZT – transition zone

Figure 4. Ecoregions in Côte d’Ivoire

(CILSS 2016, 97)
2.3.4. Protection status of the study area

Protected areas differ in management objectives ranging from strict conservation areas to areas where certain human activities are permitted. Nonetheless, regardless of the conservation status, the primary goal of delineating protected area boundaries is to conserve natural resources within it (Jones et al. 2018, 788). Consequently, it is expected that conservation efforts should be apparent in any protected area. The Mabi-Yaya-Songan-Tamin protected area complex belongs to the “Forest Reserve” category (same as “Classified Forest”, “Reserved Forest”, “Community Forest”, and “National Forest”). Based on the definition provided in the Forestry Code of Côte d’Ivoire updated in 2014, “classified forest is a forested land defined and delimited in accordance with a law or regulatory system in order to give it the necessary legal protection” (Ministère Des Eaux Et Forêts 2014, 3, translated from French). In this area, wood exploitation is regulated but other activities, such as farming, grazing of livestock, fires, mining, hunting, and damage to natural resources are prohibited (CILSS 2016).

The goal of this research is to provide a detailed and location-specific story of deforestation and tropical forest degradation in the Mabi-Yaya and the Songan-Tamin reserved forests. A limited number of studies have been conducted directly in this area. Bitty et al. (2015) have shown that many forest reserves in Côte d’Ivoire, including Mabi-Yaya, are under human pressure from the combined effects of encroachment of agriculture, particularly production of cocoa, and illegal hunting that presents a threat to biodiversity inside these protected zones. Land cover patterns within Mabi-Yaya-Songan-Tamin complex and the trajectories of land use change around its boundaries remain understudied.
Visual analysis of satellite images reveals that this protected area underwent substantial alteration of forest cover from 1986 to 2017 (Figures 5, Figure 6, and Figure 7). On the other hand, we can still observe forest cover in the most recent study period. Land use history and its legacies often define the current state of the landscape (Napton 2018). It is, therefore, possible that the Mabi-Yaya and the Songan-Tamin reserved forests have been managed differently. Although initially reserved at different times, these protected areas have been managed by SODEFOR (La Société de développement des forêts in French, or the Forest Development Society), a government-funded agency that aims to protect forests, since 1966 (Ehuiitché 2015, 104). Therefore, the remaining forest might be potentially threatened by the same causes of forest degradation, unless it receives the attention necessary for proper conservation.
Figure 5. Landsat image of the study area in 1986
Figure 6. Landsat image of the study area in 1999
Figure 7. Landsat image of the study area in 2017
CHAPTER 3. METHODS

3.1. Geographic Theory

3.1.1. Framing human-induced environmental changes geographically

The man-land tradition is critical to the field of geography, because the discipline aims to incorporate environmental and social systems as a unity (Pattison 1990, 204). No wonder, one of the Big Questions in Geography is formulated as “How has the earth been transformed by human action?” (Cutter et al. 2002, 307). Two views signify the importance of addressing this question. The first is realization of human dependence on ecosystem services for obtaining food, heat, and shelter. The second is recognizing that the human impact on the environment is often a destructive force. Geographers contribute to the knowledge about the two-way connection between nature and society by employing approaches to explore the dynamics of environmental transformation, their spatial variability, and underlying causes (Cutter et al. 2002, 310-311). Problems at the core of geographic research that are actively targeted and solved are smaller in magnitude, spatial scale, and time frame, but their importance always resonates within the broader context of big problems, such as anthropogenic modification of the environment (Napton, 2018).

3.1.2. Semantic problems of defining ‘forest’ and ‘degraded forest’

Defining the problem is often a part of its solution (Napton, 2018). To build effective natural resources management strategies, we need to clarify such concepts as deforestation and forest degradation. These concepts have ‘forest’ in common. It is often challenging to define concepts that seem to be simple and are widely used, such as forest. Lund (2002, 23) identified 624 different definitions of forest depending on the purpose of
the definition, location, qualities of ecosystems services, significant thresholds, and context. Although multiple definitions appear to be overwhelming, the objective behind any scientific inquiry is not to substitute 624 versions with a single definition of a forest but to raise an awareness that oversimplification is a threat to clear communication and natural resources protection (Putz and Redford 2010, 10). Therefore, to ensure that every forest is equally recognized, valued, and protected we need to develop detailed and case-specific definitions (Chazdon et al. 2016, 547).

‘Forest degradation’ refers to the decline of the quality of the ecosystem services provided by the forest, and ‘degraded forest’ is the result of this action. The definition of ‘degraded forest’ is also not universal. While ‘deforestation’ typically refers to the decline in area covered by trees, degradation is often based on subjective values. It is uncertain what qualities to what degree have to decline in order to label a forest as degraded. To express forest degradation in a concrete form objectively, definitions typically include such indicators as decrease in canopy cover or trees per unit area, numbers of species lost, soil fertility, and others (Lund 2009, 6). Deforestation is often presented as an extreme form of ‘forest degradation’ when the density of vegetation cover has been reduced to zero (Grainger 1996, 184). For the purposes of this research, it is critical to distinguish ‘deforestation’ from ‘forest degradation’. I will use the term ‘deforestation’ when the forest has been completely cleared and replaced by a different land cover, such as farm, plantation, or settlement. If some patches of trees or highly fragmented forest is intermixed with cropland and tree plantations, I will classify this area as ‘degraded forest’. Additionally, any area in the tropical forest ecoregion that cannot be objectively attributed to any other class, will be classified as ‘degraded forest’ based on a
review of the literature that suggests that the original forest cover corresponds to the tropical forest ecoregion extent.

3.1.3. Integrating temporal and spatial analyses for land cover change detection

Change is integral to life. Unfortunately, it can be just as destructive as it is inevitable. Human intervention into natural systems always results in modification of a landscape, and this change is often undesirable (Johnson and Lewis 1995, 1-2). Placing human-environment interaction among core interests of geographers introduces the necessity to develop various theories, methodologies, and tools for tracking change. More specifically, observation, analysis, and representation of changes in the form of maps are important tools of geographic research.

Together with fieldwork and modeling, remote sensing technologies are a valuable geographic tool for change detection. Spatial analysis using remote sensing is focused on searching for patterns on maps. When spatial distribution of a phenomenon is not random, association and correlation between events and factors can be easily identified (NRC 2010, 35-37). For example, patterns are often useful for investigating spatial distribution of ecological communities shaped by external drivers such as climate conditions, topography, and human impact (Graf and Gobler 1995, 247). The temporal component of satellite imagery enables us to explore what changed, when it changed, and by how much. Additionally, by knowing when and how much something changed, we can identify the rate of change to address the question of how fast change happened. The rate of change matters especially for restoring ecological systems, because long-term and short-term land degradation have different mechanisms, and the time needed for a system to recover varies (Johnson and Lewis 1995, 6-8).
Satellite imagery provides a solid baseline for tracking change, but it does not reveal the driving forces that cause land cover changes nor does it assess the significance of change. Large amounts of data are obtained from satellites every day, and we need to improve our skills of analyzing and interpreting these data. Synthesis of data obtained from satellite images with other information, such as census data, often reveals a more detailed characterization of the landscape change. Therefore, the question *How to attribute significance to change?* remains as a challenge and a goal of geographic inquiry (NRC 2010,103).

3.1.4. Event ecology approach

Human-environment research can only be successful and significant if it has both natural and social sciences to agree on theories, ideas, and methodologies. Event ecology can be used to find a common ground between the social and natural sides of geography. As an approach to scientific inquiry, event ecology is guided by the question about *why* changes have occurred. Event here refers to a change and simultaneously a part of a causal chain, and therefore any event can be caused by and lead to other events. In the center of the event ecology approach is abductive reasoning that aims to explain cause-and-effect relationships based on observations. Having multiple explanations is typical for abductive reasoning (Walters and Vayda 2009). Such a holistic approach is needed for a human-environment research, because there is always more than one factor causing change, and the effect and relative contribution of a specific factor is often uncertain.

3.1.5. Theories of land-use change

A solid theoretical foundation on the causes of land use and land cover change is important for the development of sustainable land use practices. Land system science
emerges as a new field focused on the linkages between the patterns of land cover change and the drivers of land cover use. This field offers new methodological approaches, frameworks, and theories that examine complex interactions between land system processes (Meyfroidt et al 2018).

The human role in environmental change is perceived differently depending on the theory of land use change. Some theories describe land use expansion as a natural outcome of growing population pressure, and intensification to raise land productivity is preferred over expansion only when land resources become limited. Induced intensification theory complements this perspective by introducing the importance of technological, institutional, socioeconomic, and biophysical parameters that can trigger land intensification. Neoclassical economic theories are built on the assumption that land is used for the activity that will potentially generate the largest value. One example of such view is von Thunen’s theory that presents spatial organization of land uses around a central market that largely depends of the distance from the market, perishability, and bulkiness of the product affecting transportation costs (Meyfroidt et al 2018, 54-57).

With increasing impacts of globalization on land use patterns, it becomes important to consider the growing connections between distant places because direct intervention into land use practices in one place can be transferred to another place. Indirect land-use change theories attempt to explain these patterns. Conservation policies, such as REDD+ that aim to reduce tropical deforestation, present an effective mechanism of restricting land-use expansion. Apart from intentional conservation of forest resources in the countries that adopted this policy, such as Côte d’Ivoire, this type of intervention can induce a chain of other consequences including an increase in production costs, a price
increase that will subsequently affect demand, intensification of production, or land use expansion elsewhere (Meyfroidt et al 2018, 58-61). Although case-specific conditions define a path and a form of land cover change, theories of land use change provide us with a generalized knowledge of human-environment systems and offer a perspective on how to tell the story of land cover change.

3.2. Land cover analysis in the study area

3.2.1. Data Collection

Remotely sensed images taken from satellites were the main type of data required for this study. These data have been selected because satellites observe Earth’s surface consistently through time documenting multiple time periods over the same area, which is critical for studying change. Landsat images were used as a base for creating land cover maps in the Mabi-Yaya and the Songan-Tamin forest reserves and analyzing landscape alteration from 1986 to 2017 (Table 2). The source of data for this project is the US Geological Survey Earth Explorer website (http://earthexplorer.usgs.gov) that provides browse, discovery, and access to the Landsat collection from 1972 to 2018.

Table 2. Landsat images of the study area

<table>
<thead>
<tr>
<th>Year</th>
<th>Landsat image</th>
<th>Path/Row</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>LT05_L1TP_195056_19861220</td>
<td>195/56</td>
<td>Dec 20</td>
</tr>
<tr>
<td>1999</td>
<td>LT05_L1TP_195056_19990207</td>
<td>195/56</td>
<td>Feb 07</td>
</tr>
<tr>
<td>2017</td>
<td>LC08_L1TP_195056_20171225</td>
<td>195/56</td>
<td>Dec 25</td>
</tr>
</tbody>
</table>

The software used to process satellite images is ArcMap by ESRI. The bands of the images downloaded from the Earth Explorer website were composited for further
processing by using Band Composite tool in Arc Map that can be found by the following path: ArcToolbox > Data Management tools > Raster > Raster processing > Composite Bands. The standard combination of bands used for optimum visual image analysis and mapping with Landsat 8 images is 6-5-4 with Red-Green-Blue. The 6, 5, and 4 wavebands of the Landsat 8 images correspond to the shortwave infrared, near infrared, and red regions of the electromagnetic spectrum respectively. The equivalent combination for the Landsat 5 is 5-4-3 that correspond to the shortwave infrared, near infrared, and red regions of the electromagnetic spectrum respectively. To enhance the color contrast of land features and facilitate further interpretation, I applied Contrast and Brightness effects to each image.

Temporal and spatial delineation of the problem is necessary to present results in a concrete form and for measurement purposes. The choice of study years is based on the availability of cloud-free images of the area of interest. The study area includes a protected area complex and extends 10 km outside its boundary. Shapefiles of the boundaries of forest reserves were downloaded from the World Database on Protected Areas, which contains a comprehensive global dataset of the world's terrestrial and marine protected areas.

3.2.2. Land cover classes

Classification is a tool of organizing data to make observing more efficient (Gersmehl and Brown 1995, 79). The purpose of land cover classification is to detect and analyze land cover changes in the extent of tropical forest in the Mabi-Yaya and the Songan-Tamin reserved forest. It is a critical step in this project, because a too general or too detailed classification might be misleading or confusing. Therefore, I used seven land
cover classes to capture the changes of interest that are apparent on Landsat images and relevant to my study: forest, degraded forest, gallery forest, plantation, agriculture, water bodies, and settlement (Table 3). As in any land cover classification system, not all details can be captured in a generalized map of a highly heterogeneous landscape. For example, relevant classes, such as roads, have been omitted because they cannot be consistently detected on Landsat images and mapped.

Table 3. Land cover classes in the study area

*(based on the definitions proposed by US Geological Survey; CILSS 2016)*

<table>
<thead>
<tr>
<th>Land cover class</th>
<th>Images from the within tropical forest ecoregion in Côte d’Ivoire (Landsat and Google Earth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest - dense, closed canopy formation of evergreen or semi-evergreen broadleaf vegetation with a multiple strata structure.</td>
<td>![Image of forest area] Location: 7°7'24.704&quot;W; 6°5'5.557&quot;N</td>
</tr>
<tr>
<td>Settlement - built up areas comprising human communities in a village, town or city.</td>
<td>![Image of settlement area] Location: 7°2'26.52&quot;W; 6°10'19.589&quot;N</td>
</tr>
<tr>
<td><strong>Water bodies</strong></td>
<td>any area with permanent or semi-permanent surface water.</td>
</tr>
<tr>
<td>------------------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Location:</strong> 6°58'28.121&quot;W; 6°19'55.028&quot;N</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Plantation</strong></th>
<th>regular stands of trees planted for the purpose of producing food, beverages, vegetable oils, raw materials for industry, wood, or for protection against wind and water erosion.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Example 1 (large, industrial)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Location:</strong> 2°59'57.661&quot;W; 5°19'49.031&quot;N</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Plantation</strong></th>
<th>Example 2 (cluster of smallholder plantations)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location:</strong> 3°4'47.951&quot;W 5°20'56.526&quot;N</td>
<td></td>
</tr>
<tr>
<td>Type of Forest</td>
<td>Description</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Riparian forest</td>
<td>Forest formations forming a band or corridor of dense vegetation along permanent or temporary watercourses.</td>
</tr>
<tr>
<td>Degraded forest</td>
<td>Dense, evergreen broadleaf forest with closed or partially closed canopy whose integrity has been degraded by logging or other forms of exploitation (in case of the study area, other forms of exploitation also include land exploitation for agriculture and grazing).</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Cultivated areas, with crops dependent on rainfall.</td>
</tr>
</tbody>
</table>
3.2.3. Land classification approach

Remote sensing technology provides us with two main approaches towards land cover classification: visual interpretation and digital classification. The choice between these two methodologies or combination of both should be made based upon one’s specific study. Thus, knowing the characteristics of each land cover type in the study area is integral to successful land cover mapping (King 2002, 3526).

A visual interpretation method was selected for this study, because the area of interest is highly heterogeneous (Figure 8). Hence, while a digital classification is mainly based on the reflectance value of pixels, a visual interpretation method can consider not only color and tone but also texture, pattern, and spatial fragmentation of land features (Puig et al. 2002). Additional interpretation elements include size, shape, and shadow (King 2002, 3527). For instance, highly fragmented forest might be classified as dense if simply based on the reflectance value of pixels, while a visual interpretation allows one to recognize the spatial patterns of a fragmented landscape (Figure 9). Taking context into consideration helps to identify a type of land cover by comparison, for example, we can distinguish plantation from forest and degraded forest because the plantation typically has smoother texture (Figure 10).
Figure 8. Heterogeneous landscape in the study area


Figure 9. Interpreting forest fragmentation
(3°27'0.331"W; 5°53'0.206"N, Landsat image LC08_L1TP_195056_20171225, Google Earth high resolution image) (Patches of forest east of the river are too small to be classified as dense forest, although their color and the color of dense forest west of the river are the same)

Figure 10. Comparison of different land cover classes

(3°17'12.856"W; 6°5'43.339"N, Landsat image LC08_L1TP_195056_20171225, Google Earth high resolution image) (Plantations in the northern part of the image have smoother texture than degraded forest in the southern part)

3.2.4. The tool for land cover classification

The tool selected for this project is an ArcGIS Desktop add-in, the Rapid Land Cover Mapper (RLCM) – “a vector and raster hybrid approach that lends itself to multiple-resolution and time-series mapping” (Cotillon and Mathis 2017). It is based on visual interpretation, which is more reliable than automated classification for the study area (Tappan 2018). 1942). The RLCM add-in generates a grid of digital points, which overlays on Landsat imagery displayed in ArcGIS. The user selects the spacing between points. This tool allows an interpreter to identify a land cover class for each point based on the surface on which a point overlays on an underlying image (Figure 11).
The RLCM is an optimal tool for mapping multiple time periods, because the first classified image can be used as a baseline for the next one, and only pixels that have changed need to be reclassified, and the area covered by each land cover class can be found in the attribute table for quantitative comparison. RLCM allows one to create change maps between time periods to highlight the areas that underwent land cover alteration. Also, to improve the accuracy of visual interpretation of land cover classes for a recent study year, RLCM can be synchronized with Google Earth, which contains a collection of high spatial resolution images. The distance between grid points and consequently the resolution of final maps is 500 m based on the recommendations in the RLCM user manual appropriate to the study area size and spatial resolution of the satellite images (Cotillon and Mathis 2017).

Figure 11. Steps in making a land cover map using the Rapid Land Cover Mapper add-in

(Cotillon and Mathis 2017, 2)
3.2.5. Quantification of land cover change

After interpretation of land cover in the study area, I converted mapped output into raster and then vector maps to present different land cover classes as polygons. These maps serve as a foundation for further quantification of changes of each thematic category of land resources during the study period. I also created graphs that illustrate the changes in area of each land cover class for three study years and contingency tables illustrating land conversions to determine the proportion of each land cover class that has been replaced by a new land cover. To summarize, I compared spatial changes of land cover classes in three zones of the study area: Mabi-Yaya, Songan-Tamin, and the unprotected area.

3.3. Assessment of driving forces of land cover changes in Côte d’Ivoire

3.3.1. Methodological pluralism in land cover change studies

Land cover change patterns provide little information about the driving forces of change. Combining analysis of multi-temporal satellite imagery with information on drivers of change allows one to understand the underlying processes that create trajectories of land cover change. Driving forces are explored through “methodological pluralism” (Campbell et al. 2005) because there is always more than one factor; and each one of them might have a different impact in terms of scale, magnitude, and direction. Land uses and land covers change in response to various triggers and interactions between them. That is why single-factor based approach to land use and land cover changes has proved to be insufficient to explain these changes. Multiple-factor explanation, on the contrary, allows one to provide a constructive explanation of different causes of land cover changes and their contributions (Geist and Lambin 2002). The
approach adopted in this study is to use a narrative perspective in order to depict land cover changes in the study area through historical details and their interpretation (Lambin et al. 2003).

3.3.2. Proximate and underlying forces of land cover change

Causes of land cover change are divided into two categories: proximate causes and underlying forces. Proximate causes are immediate actions that directly affect land cover. Underlying causes are fundamental forces that create a medium of systemic human-environment relations from which proximate causes originate. The spatial scale of proximate causes is local while underlying causes can operate at the regional and global levels (Lambin et al. 2003, 216-217). This constitutes one of the key challenges in the investigation of driving forces – different causes interact with each other across multiple spatial scales that may complicate the interpretation of outcomes.

Another challenge is a common misconception that population growth and poverty are major underlying causes of land change (Lambin et al 2001). Many local studies of forest cover change are based on a predefined assumption that a growing population inevitably leads to increased deforestation and forest degradation. In reality, people – forest relationships are variable and non-linear. Studies show that farmers’ practices often promote reforestation and afforestation to improve soil fertility. Similarly, macroeconomic projects intended to produce cash crops might also have positive effects depending upon the ecological and social settings (Leach and Fairhead 2000).

3.3.3. Framework on the causes of land cover change in the study area

The general framework to explain land cover changes in the Mabi-Yaya-Songan-Tamin reserved forests is based on a set of multiple explanatory variables that act
together to produce land cover change (Figure 12). The main sources of data for this analysis include scientific literature, government documents, news articles, and reports prepared by non-governmental organizations. Each category of driving forces will be evaluated based on the information provided in these data sources in order to select the strongest forces and depict their combination in the reserved forests of Côte d’Ivoire.

Figure 12. Causes of forest decline

(Geist and Lambin 2002, 144)
CHAPTER 4. RESULTS

4.1. Land cover change analysis in the study area

4.1.1. Land cover description and land cover change over time

Land cover maps are a source of information on land cover patterns that can be observed visually (Figure 13, Figure 14, and Figure 15). These maps provide knowledge on the current state of the landscape and serve as a baseline to measure how the conditions have changed during the study periods. Changing conditions are quantified through the comparison of land area of each thematic category used for classification: forest, degraded forest, gallery forest, water bodies, plantation, agriculture (cropland), and settlement. That is why graphs have been added to complement land cover maps with detailed quantification of temporal changes of different land cover types (Figure 16 and Figure 17).

At the beginning of the study period, dense forest was the dominant land cover class inside the reserves (Figure 13). The area covered by other land cover classes was not substantial inside the reserves in 1986. The landscape was more heterogeneous outside the reserves, where degraded forest was intermixed with tree plantations and agriculture. Clusters of tree plantations were found in the northern portion of the Songan-Tamin reserve and south of the Mabi-Yaya reserve. The area of plantations and agriculture was likely underestimated, because the land cover map for 1986 was based just on the Landsat image, and no historical images with higher spatial resolution were available.
Figure 13. Land cover map in the study area in 1986

(Software: ArcMap by ESRI)
Figure 14. Land cover map in the study area in 1999

(Software: ArcMap by ESRI)
Figure 15. Land cover map in the study area in 2017

(Software: ArcMap by ESRI)
The most apparent change is an increase in area of degraded forest that became the only dominant land cover class in 2017 (Figure 15). Another critical change is a decrease in forest cover area. Although forest is one of the two main land cover classes in each study year, its area was reduced substantially. Another prominent growth in land cover characterizes change of plantation area, in particular in the northern portion of the Songan-Tamin reserve and south of the Mabi-Yaya reserve (Figure 13, Figure 14, and Figure 15). In 1986, land covered by plantations was significantly smaller than land covered by dense forest. At the end of the study period, forest and plantation areas had comparable values (Figure 16).

![Figure 16. Land Cover in the study area in 1986, 1999, and 2017 (all land cover classes)](image)

Gallery forest cover decreased slightly during the study period, although this change is not substantial (Figure 17). Change in area covered by water is not substantial and is related to slight expansion of an artificially created reservoir in the southeastern part of the study area. The area covered by settlements gradually increased but it did not
cover a large portion of the study area even at the end of the study period. Human settlements typically occupy relatively small area of the land, and their role is not apparent through direct land conversion but rather through indirect anthropogenic factors and transformation of urban-rural linkages. The impacts of human settlements are disproportionate to the amount of land used because they are more permanent and produce more intensive land uses. That is why even slight expansion of area covered by settlements might have consequences in the entire study area.

Figure 17. Land Cover in the study area in 1986, 1999, and 2017 (small area classes)

Crop field area increased over the period 1986 – 1999 and decreased during 1999 – 2017 (Figure 17). This can be attributed to several factors. First, some fields were converted into more profitable tree plantations to produce cash crops. Second, shifting cultivation is a common practice in the study area, therefore the location and area of crop fields varies temporally. Additionally, the point sampling method is less suitable for identification of classes with smaller area than for classes with larger areas. Only the
points that fall directly on a farming field can be identified as *Agriculture*. Therefore, cultivated area was more likely to be underestimated in the study area than classes that cover more land, such as forest.

Land cover change can be quantitatively presented as absolute change or relative change. Given the necessity to compare changes in area and changes in proportion of area covered by each thematic category of land resources, I used two change indicators. Absolute change is defined here as the difference between the area of land cover class in earlier and more recent years:

$$\Delta = S_{old} - S_{new}$$

where $\Delta$ - absolute change, $S_{old}$ is the area covered by a land cover type in earlier study year, and $S_{new}$ is the area covered by a land cover type in more recent study year. Negative values for absolute change correspond to decreases in land cover while positive indicate increases. To describe the percentage of land cover change, I used relative change $\partial$ that can be calculated by the following formula:

$$\partial = \frac{\Delta}{S_{old}} \times 100\%$$

The highest increase in absolute value of land area is observed for the dominant land cover type - degraded forest during 1986 – 1999, but the highest relative change that describes the rate of growth characterizes plantations during both 1986 – 1999 and 1999 – 2017 (Figure 18 and Figure 19). Change detection helps to quantify deforestation that is defined as a decrease in dense forest cover; 863.50 sq km and 529.75 sq km of forest were lost during the 1986 – 1999 and 1999 – 2017 study periods respectively (Figure 18). Decrease in forest cover was more prominent during 1986 – 1999 than 1999 – 2017,
although relative change was similar for both study periods. It should be stressed that a
decrease in the area of forest cover can be attributed not only to deforestation, but also to
forest degradation that characterizes a conversion of forest cover into degraded forest
cover. Therefore, quantification of these patterns requires not only absolute and relative
changes of each land cover type, but also an analysis of land cover conversions over time.

Figure 18. Absolute land cover changes in the study area

(Key: F – Forest, DF – Degraded Forest, P – Plantation, W – Water, GF – Gallery
Forest, S – Settlement, A – Agriculture)
4.1.2. Quantification of land cover conversions over time

Land cover conversion refers to a replacement of one land cover type by a different type. Based on the data derived from the land cover maps, 790.5 sq km of forest in 1986 was converted to degraded forest during 1986 - 1999 (Table 4). This number quantifies forest degradation. Deforestation, on the other hand, is the area that can be attributed to all other forest conversions, such as forest to plantation. It was stated earlier that 863.50 sq km of total forest cover has been lost. That means that the area attributed exclusively to deforestation equals:

\[
863.50 \text{ sq km} - 790.5 \text{ sq km} = 73 \text{ sq km}
\]

The same analysis for 1999 - 2017 study period reveals that 521.25 sq km of forest was modified into degraded forest (Table 5). Deforested area in this case equals:
529.75 sq km – 521.25 sq km = 8.5 sq km

These figures illustrate that the majority of forest cover is not fully cleared to be replaced with a different land cover for production purposes, but it has been gradually modified into degraded forest. That means that patches of trees remain in coexistence with cropland and tree plantations constituting a heterogeneous and disturbed landscape.

Table 4. Land cover conversions during 1986 – 1999 study period (area measured in sq km)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>1259.5</td>
<td>790.5</td>
<td>67.25</td>
<td>2</td>
<td>0</td>
<td>0.25</td>
<td>3.5</td>
</tr>
<tr>
<td>Degraded Forest</td>
<td>0</td>
<td>1868.75</td>
<td>105</td>
<td>3.25</td>
<td>0</td>
<td>6</td>
<td>22.5</td>
</tr>
<tr>
<td>Plantation</td>
<td>0</td>
<td>28</td>
<td>256.5</td>
<td>0.25</td>
<td>0</td>
<td>0.25</td>
<td>0</td>
</tr>
<tr>
<td>Water Bodies</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>121.75</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gallery Forest</td>
<td>0</td>
<td>9.5</td>
<td>0</td>
<td>0</td>
<td>46.25</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Settlement</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0</td>
<td>3.5</td>
<td>0.75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>48.5</td>
</tr>
<tr>
<td>Total in 1999</td>
<td>1259.5</td>
<td>2700.25</td>
<td>429.5</td>
<td>127.25</td>
<td>46.25</td>
<td>31.5</td>
<td>74.5</td>
</tr>
</tbody>
</table>

Table 5. Land cover conversion during 1999 – 2017 study period (area measured in sq km)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>729.75</td>
<td>521.25</td>
<td>3</td>
<td>1.25</td>
<td>0</td>
<td>0</td>
<td>4.25</td>
</tr>
<tr>
<td>Degraded Forest</td>
<td>0</td>
<td>2419.25</td>
<td>219.75</td>
<td>9</td>
<td>0</td>
<td>4.5</td>
<td>27.75</td>
</tr>
<tr>
<td>Plantation</td>
<td>0</td>
<td>30.75</td>
<td>397.75</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Water Bodies</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>127.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gallery Forest</td>
<td>0</td>
<td>8.25</td>
<td>1</td>
<td>0</td>
<td>37</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Settlement</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>31.5</td>
<td>0</td>
<td>31.5</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0</td>
<td>27</td>
<td>11.75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>35.75</td>
</tr>
<tr>
<td>Total in 2017</td>
<td>729.75</td>
<td>3006.5</td>
<td>653.25</td>
<td>137.5</td>
<td>37</td>
<td>37</td>
<td>67.75</td>
</tr>
</tbody>
</table>

4.1.3. Size distribution of land cover classes over time

Analysis of the changes of the sizes of polygons with different land cover classes over time is a simple and effective tool to provide an overview to the patterns of fragmentation. Forest fragmentation is a dynamic process in which dense cover is gradually reduced to smaller patches. It is challenging to analyze these patterns, because
different stages and types of forest fragmentation can occur simultaneously within the boundaries of the study area. The majority of polygons of all land cover classes are relatively small (< 0.5 sq km), which illustrates that the study area is heterogeneous and fragmented (Figure 20, Figure 21, and Figure 22). This characterization of the landscape follows the same pattern for all study periods. One prominent change is a decrease in the number of small polygons (< 0.5 sq km) for forest cover (26, 8, and 5 polygons for 1986, 1999, and 2017 respectively) and consequently a decrease in the percentage of the number of small polygons. Given that no increase in forest cover was observed in the study area, this fact signifies that already fragmented forest is more susceptible to degradation or more likely to be converted to a different land cover type. Additionally, large polygons of dense forest cover decreased in size from > 1000 sq km to < 1000 sq km from 1999 to 2017. The largest forest polygon in 1986, 1999, and 2017 equals to 1,951 sq km; 1,139.25 sq km; and 590.5 sq km respectively. The percentage of polygons with the size of <1000 km increased from 1986 to 2017, but this can be explained by the overall decrease in the number of polygons of all sizes.
Figure 20. Land cover classes by polygon sizes in 1986

Figure 21. Land cover classes by polygon sizes in 1999
4.2. Land cover change analysis in different zones of the study area

4.2.1. Land cover change analysis in the Songan-Tamin reserved forest

Within the boundaries of the Songan-Tamin reserved forest, no changes in the area of agriculture, settlements, and gallery forests were observed, and these classes had small area (Figure 23). The area of land with surface water was relatively small and did not change substantially. The most prominent change in absolute values of land area is a decrease in forest cover during both study periods and an increase in degraded forest area that corresponds to the visual illustration on land cover maps. In 1986, forest was the dominant land cover type, and at the end of the study period degraded forest covered a larger amount of land than any other class (Figure 23). Plantation growth was more substantial during 1986 – 1999 (117.92%) than during 1999 – 2017 (19.12%) (Figure 24 and Figure 25).
Figure 23. Land Cover in the Songan-Tamin reserved forest in 1986, 1999, and 2017

Figure 24. Absolute land cover changes in the Songan-Tamin reserved forest

Land conversion patterns in the Songan-Tamin reserved forest reveal the role of deforestation and forest degradation in this zone (Table 6 and Table 7). Amount of land that underwent forest degradation equals 282.5 sq km and 279.25 sq km during 1986-1999 and 1999-2017 respectively. Considering that the total area of forest loss equals to 335 sq km and 279.5 sq km (Figure 24), deforested area equals to:

335 sq km – 282.5 sq km = 52.5 sq km during 1986 – 1999 study period

279.5 sq km – 279.25 sq km = 0.25 sq km during 1999 – 2017 study period

These figures indicate that most of the forest area loss has been modified into degraded forest, and some has been converted into plantations in the northern portion of...
the forest reserve that underwent substantial growth during 1986 – 1999 study period (117.92%, Figure 25).

Table 6. Land cover conversions in the Songan-Tamin reserved forest during 1986 – 1999 study period (area measured in sq km)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1986 Forest</td>
<td>395.5</td>
<td>282.5</td>
<td>52.25</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>730.5</td>
</tr>
<tr>
<td>1986 Degraded Forest</td>
<td>0</td>
<td>102.5</td>
<td>19.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>121.75</td>
</tr>
<tr>
<td>1986 Plantation</td>
<td>0</td>
<td>0.75</td>
<td>59.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>60.00</td>
</tr>
<tr>
<td>1986 Water Bodies</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>6.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6.25</td>
</tr>
<tr>
<td>1986 Gallery Forest</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0</td>
<td>1.75</td>
<td>0</td>
<td>0</td>
<td>1.75</td>
</tr>
<tr>
<td>1986 Settlement</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>1986 Agriculture</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Total in 1999</td>
<td>395.5</td>
<td>385.75</td>
<td>130.75</td>
<td>6.5</td>
<td>0</td>
<td>1.75</td>
<td>0</td>
<td>920.25</td>
</tr>
</tbody>
</table>

Table 7. Land cover conversions in the Songan-Tamin reserved forest during 1999 – 2017 study period (area measured in sq km)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1999 Forest</td>
<td>116</td>
<td>279.25</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>395.5</td>
</tr>
<tr>
<td>1999 Degraded Forest</td>
<td>0</td>
<td>349.75</td>
<td>35.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>385.75</td>
</tr>
<tr>
<td>1999 Plantation</td>
<td>0</td>
<td>8.5</td>
<td>122.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>130.75</td>
</tr>
<tr>
<td>1999 Water Bodies</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>6.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6.5</td>
</tr>
<tr>
<td>1999 Gallery Forest</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>1.75</td>
<td>0</td>
<td>0</td>
<td>1.75</td>
</tr>
<tr>
<td>1999 Settlement</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td>1.75</td>
<td>0</td>
<td>1.75</td>
</tr>
<tr>
<td>1999 Agriculture</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Total in 2017</td>
<td>116</td>
<td>637.5</td>
<td>155.75</td>
<td>6.5</td>
<td>0</td>
<td>1.75</td>
<td>0.5</td>
<td>920.25</td>
</tr>
</tbody>
</table>

4.2.2. Land cover change analysis in the Mabi-Yaya reserved forest

Forest cover loss in the Mobi-Yaya reserved forest is significant in absolute values but only a small proportion of the total area has been lost (Figure 26, Figure 27, and Figure 28). Growth of plantations is not significant (from 2 to 4.25 sq km), although it appears to be relevant based on the relative change depiction (200% and 141.67%). These examples illustrate the importance of including both absolute and relative values of change to capture a detailed illustration of land change patterns.
The amount of land that underwent forest degradation equals 99 sq km and 158.75 sq km during 1986-1999 and 1999-2017 respectively (Table 8 and Table 9). Given that the total area of forest loss was 100 sq km during 1986-1999 and 161.5 sq km during 1999-2017 (Figure 27), deforestation is quantified in the following way:

100 sq km – 99 sq km = 1 sq km during the 1986 – 1999 study period

161.5 sq km - 158.75 sq km = 2.75 sq km during the 1999 – 2017 study period

Similar to changes in the Songan-Tamin, the major change in the Mabi-Yaya was the modification of forest into degraded forest cover. On the other hand, the magnitude of change in the Mabi-Yaya was smaller than in the Songan-Tamin, and dense forest remained the dominant land cover type in this zone of the study area (Figure 26).

Figure 26. Land Cover in the Mabi-Yaya reserved forest in 1986, 1999, and 2017
Figure 27. Absolute land cover changes in the Mabi-Yaya reserved forest


Figure 28. Relative land cover changes in the Mabi-Yaya reserved forest

4.2.3. Land cover change analysis in the unprotected area

Degraded forest remained the dominant thematic category in the unprotected area during the study period (Figure 29). Forest loss quantified by the total area and as a percentage was more significant during 1986 – 1999 than during 1999 – 2000. Degraded forest area increased during 1986 – 1999 and decreased during 1999 – 2016 (Figure 29, Figure 30, and Figure 31). This decrease is explained by a transition of degraded forest into plantations with the purpose of bringing land into commercial use. At the beginning of the study period, settlements and agriculture occupied more land outside the protected area than within its boundary, and the changes in the area of these land covers were more prominent in the unprotected zone than in the forest reserves.
The area that underwent conversion from forest to degraded forest equals 409 sq km and 83.25 sq km during 1986 – 1999 and 1999 – 2017 respectively (Table 10 and Table 11). Subsequently, the deforested area equals:

\[
428.5 \text{ sq km} - 409 \text{ sq km} = 19.5 \text{ sq km} \text{ during 1986 – 1999 study period}
\]

\[
88.75 \text{ sq km} - 83.25 \text{ sq km} = 5.5 \text{ sq km} \text{ during 1999 – 2017 study period}
\]

These figures illustrate that the patterns of land cover change in the unprotected zone are generally similar to the changes within forest reserves; only a small proportion of forest loss was directly attributed to a conversion of forest cover into commercial uses, such as cash crops production.

![Diagram showing land cover changes in the unprotected zone of the study area in 1986, 1999, and 2017](image)

*Figure 29. Land Cover in the unprotected zone of the study area in 1986, 1999, and 2017*
Figure 30. Absolute land cover changes in the unprotected area

(Key: F – Forest, DF – Degraded Forest, P – Plantation, W – Water, GF – Gallery
Forest, S – Settlement, A – Agriculture)

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>DF</th>
<th>P</th>
<th>W</th>
<th>GF</th>
<th>S</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>change 1986-1999</td>
<td>-428.50</td>
<td>333.50</td>
<td>71.75</td>
<td>5.00</td>
<td>-9.50</td>
<td>6.50</td>
<td>21.25</td>
</tr>
<tr>
<td>change 1999-2017</td>
<td>-88.75</td>
<td>-103.75</td>
<td>192.25</td>
<td>10.25</td>
<td>-9.25</td>
<td>5.50</td>
<td>-6.25</td>
</tr>
</tbody>
</table>

Figure 31. Relative land cover changes in the unprotected area

(Key: F – Forest, DF – Degraded Forest, P – Plantation, W – Water, GF – Gallery
Forest, S – Settlement, A – Agriculture)

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>DF</th>
<th>P</th>
<th>W</th>
<th>GF</th>
<th>S</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>change 1986-1999</td>
<td>-72.78</td>
<td>18.54</td>
<td>32.03</td>
<td>4.55</td>
<td>-17.35</td>
<td>27.96</td>
<td>46.20</td>
</tr>
<tr>
<td>change 1999-2017</td>
<td>-55.38</td>
<td>-4.87</td>
<td>65.00</td>
<td>8.91</td>
<td>-20.44</td>
<td>18.49</td>
<td>-9.29</td>
</tr>
</tbody>
</table>
Table 10. Land cover conversions in the unprotected area during 1986 – 1999 study period (area measured in sq km)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>160.25</td>
<td>2132.5</td>
<td>160.25</td>
<td>71.5</td>
<td>409</td>
<td>83.75</td>
<td>15</td>
<td>1.5</td>
<td>15</td>
<td>1.5</td>
<td>0.25</td>
<td>2.25</td>
<td>21.5</td>
<td>0</td>
<td>6</td>
<td>2.75</td>
<td>588.75</td>
<td>1799</td>
</tr>
<tr>
<td><strong>Forest</strong></td>
<td>160.25</td>
<td>2132.5</td>
<td>160.25</td>
<td>71.5</td>
<td>409</td>
<td>83.75</td>
<td>15</td>
<td>1.5</td>
<td>15</td>
<td>1.5</td>
<td>0.25</td>
<td>2.25</td>
<td>21.5</td>
<td>0</td>
<td>6</td>
<td>2.75</td>
<td>588.75</td>
<td>1799</td>
</tr>
<tr>
<td><strong>Degraded Forest</strong></td>
<td>0</td>
<td>1684.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1799</td>
<td></td>
</tr>
<tr>
<td><strong>Plantation</strong></td>
<td>0</td>
<td>27.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>54.75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>224</td>
<td></td>
</tr>
<tr>
<td><strong>Water Bodies</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>110</td>
<td>45.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td><strong>Gallery Forest</strong></td>
<td>0</td>
<td>9.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>54.75</td>
<td></td>
</tr>
<tr>
<td><strong>Settlement</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>23.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>23.25</td>
<td></td>
</tr>
<tr>
<td><strong>Agriculture</strong></td>
<td>0</td>
<td>2.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td><strong>Total in 1999</strong></td>
<td>160.25</td>
<td>2132.5</td>
<td>1999</td>
<td>115</td>
<td>45.25</td>
<td>29.75</td>
<td>67.25</td>
<td>29.75</td>
<td>67.25</td>
<td>2845.75</td>
<td>2845.75</td>
<td>2845.75</td>
<td>2845.75</td>
<td>2845.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 11. Land cover conversions in the unprotected area during 1999 - 2017 study period (area measured in sq km)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forest</strong></td>
<td>71.5</td>
<td>83.25</td>
<td>2.25</td>
<td>1.25</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>160.25</td>
<td>160.25</td>
<td>160.25</td>
</tr>
<tr>
<td><strong>Degraded Forest</strong></td>
<td>0</td>
<td>1891.75</td>
<td>203.25</td>
<td>0</td>
<td>0</td>
<td>4.5</td>
<td>24</td>
<td>2132.5</td>
<td>2132.5</td>
<td>2132.5</td>
</tr>
<tr>
<td><strong>Plantation</strong></td>
<td>0</td>
<td>22.25</td>
<td>272.5</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>295.75</td>
<td>295.75</td>
<td>295.75</td>
</tr>
<tr>
<td><strong>Water Bodies</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>115</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>115</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td><strong>Gallery Forest</strong></td>
<td>0</td>
<td>8.25</td>
<td>1</td>
<td>0</td>
<td>36</td>
<td>0</td>
<td>0</td>
<td>45.25</td>
<td>45.25</td>
<td>45.25</td>
</tr>
<tr>
<td><strong>Settlement</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>29.75</td>
<td>0</td>
<td>29.75</td>
<td>29.75</td>
<td>29.75</td>
</tr>
<tr>
<td><strong>Agriculture</strong></td>
<td>0</td>
<td>23.25</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>61</td>
<td>67.25</td>
<td>67.25</td>
<td>67.25</td>
</tr>
<tr>
<td><strong>Total in 2017</strong></td>
<td>71.5</td>
<td>2028.75</td>
<td>488</td>
<td>125.25</td>
<td>36</td>
<td>35.25</td>
<td>61</td>
<td>2845.75</td>
<td>2845.75</td>
<td>2845.75</td>
</tr>
</tbody>
</table>

4.3. Summary of the results

The analysis of land change patterns reveals that forest degradation is a more significant problem than deforestation in each zone of the study area. It is important to emphasize that the term for deforestation used in this research simplifies the mechanism of forest cover change in the study area, because it implies a complete loss of forest cover and a replacement of forest with a different land cover type. The landscape in the study area is highly heterogeneous, and it is best described as a mosaic of different land cover classes that are intermixed, which complicates delineation of their boundaries. Forest degradation, defined here as a transition of forest into a mosaic of non-mature, sometimes thinned trees that have been anthropogenically changed, must also be viewed cautiously.
because it provides a limited description of the land-cover uses in the study area. What was classified in this project as a degraded forest is an intermix of fragmented patches of trees along with field crops and plantations that were intermixed with the fragmented forest landscape. As a result, the heterogeneity of the degraded forest landscape and the proportion of cropland and plantations intermixed with fragmented forest varied across the study area (Figure 32).

*Figure 32. Heterogeneity of the degraded forest class in the study area in 2017*
To compare land cover changes in different zones, I analyzed the changes in area of the main land cover types: forest, degraded forest, and plantation (Figure 33, Figure 34, and Figure 35). Comparison of the forest area changes reveals that all three zones – Mabi-Yaya, Songan-Tamin, and the unprotected area, had similar amounts of forest area at the beginning of the study period, and over time forest cover was reduced substantially in the Songan-Tamin and the unprotected zone, but not as radically in the Mabi-Yaya reserved forest (Figure 33).

![Forest cover change for three zones of the study area](image)

**Figure 33. Forest cover change for three zones of the study area**

The amount of land covered by degraded forest at the beginning of the study period was significantly larger in the unprotected zone than in reserved forests that could be explained by land management decisions made prior to 1986 that resulted in three different landscapes. The changes during the study period reveal that degraded forest cover remained relatively stable in the unprotected zone and increased in the protected areas (Figure 34). Similarly, many plantations were established before the beginning of
the study period, and the changes captured during 1986 – 2017 illustrate their expansion. Land occupied by plantations has increased significantly in the unprotected zone and the Songan-Tamin forest reserve, and it remained a minor land cover class in the Mabi-Yaya reserve (Figure 35).

Figure 34. Degraded forest cover change for three zones of the study area
To summarize, land cover change patterns demonstrate that forest degradation has not been effectively prevented in the Songan-Tamin reserve because land change patterns in this area resemble the patterns in the unprotected zone. On the other hand, two forest reserves are adjacent to each other; that means that relatively small changes in the Mabi-Yaya and significant changes in the Songan-Tamin occurred within the same context of the unprotected area outside the boundaries of these reserves. It is possible that protection policies were implemented more effectively in the Mabi-Yaya. On the other hand, remaining forest might be under threat in the future. This information cannot be derived from land cover change patterns, therefore, in the next section I assess the potential causes of forest cover change in protected areas of Côte d’Ivoire that are applicable to the study area.
CHAPTER 5. Driving forces of forest decline in Côte d’Ivoire

5.1. The role of forest reservation in Côte d’Ivoire

5.1.1. Background to forest reservation

Currently 231 protected areas in Côte d’Ivoire are listed as reserved forests. That makes them the primary type of protected area in the country; others include national parks, national reserves, and World Heritage Sites (Figure 36). All reserved forests fall within the category of Permanent Domain intended to preserve natural forests as opposed to Rural Domain where agricultural activities are permitted. Management of reserved forests by the state is realized through the work of the SODEFOR (Forest Development Society, or Société de Développement des Forêts in French), a government-funded agency under the Ministry of Water and Forests (Yao and Bernard 2007, 65). To examine the process by which current geographical and legal landscapes of forests in Côte d’Ivoire were constructed, I provide a brief historic review of forest reservation on a national scale.

An initial motivation to establish forest reserves in Côte d’Ivoire at the beginning of 1900s by the colonial administration had little to do with the intention to preserve biodiversity or regulate ecosystem services delivery for the benefit of local populations. Verdeaux and Alpha (2004) concluded that this action was an exclusion practice intended to prevent local populations from having access to forest resources and forested land for cultivation, thus preserving forests for wood exploitation, which was the primary source of economic profit to benefit the colonial administration. In fact, these political practices of nature conservation were not unique to Côte d’Ivoire; they were widespread in colonial Africa as “a component of the broader process of colonial appropriation of land
and natural resources” and “a symbolic legitimation of that process” (Neumann 1998, 34-35). Not surprisingly, the largest number of forest reserves in Côte d’Ivoire was classified from 1930 to 1940 (Figure 37). During this period coffee and cocoa cultivation was becoming more common, which resulted in a competition between forestry and agriculture sectors for available labor and raised concerns over land availability in the future (Verdeaux and Alpha 2004, 55).

Figure 36. Protected areas of Côte d’Ivoire

(Data Source: UNEP-WCMC 2019, ArcGIS Online, Software: ArcMap by ESRI)
Only one forest reserve was classified during 1960 – 1970 (Figure 37). Although the connection between the forest reservation and the establishment of a new legal framework in Côte d’Ivoire that achieved its independence in 1960 has not been addressed in the literature, these data present a possible correlation between changes within the government structure and forest management practices. The first president of Côte d’Ivoire, Félix Houphouët-Boigny, is known for leading his country to a great economic success supported by the growth of export commodities production. More focus on achieving economic prosperity from land exploitation might be associated with less effort to preserve the land and the forest in their natural state.

The period with the lowest number of reservations was followed by a decade with a fairly large number – 38 during 1970 – 1980 (Figure 37). The question arises whether or not this increase can be explained with a conceptual framework, for example by the
model of forest transition. The hypothesis at the base of the forest transition model is that deforestation could slow down with economic development. Forest resources scarcity and increased awareness of dependence on these resources can induce policy interventions to reduce forest loss (Culas 2012, 45). The absence of data after 1980 and recent evidence of further forest decline, however, does not follow the predicted pattern of forest restoration.

Economic motivations seem to significantly influence forest management whether they initiated a shift of priorities toward planning to preserve forests or the absence of preservation practices to ensure a greater access of the public to forest resources and forested land. There is more emphasis on environmental dimensions of this problem in today’s approach toward forest reservation. The government of Côte d’Ivoire made a commitment to reduce carbon emissions from deforestation and forest degradation under the REDD+ policy in order to mitigate global climate change (SEP REDD+ 2017). Within the context of this strategic vision, forest reserves are recognized as critical areas to reach this environmental objective.

5.1.2. The current state of forest reserves

Although reserved forests are the primary category of protected area in Côte d’Ivoire (Figure 36) and are important for the successful implementation of sustainability-driven policies, convergence of evidence from different sources suggests that the remaining forests are not effectively preserved. Changes in the Mobi-Yaya-Songan-Tamin protected area complex remain understudied, however some sources focused upon biodiversity assessment reported a general decline in forest cover in this area. For instance, in 1996 the International Union for Conservation of Nature conducted
a survey to identify sites for primate conservation in southern Côte d’Ivoire, and their key recommendation was better conservation of the Mabi-Yaya-Songan-Tamin, where chimpanzees were the least common compared to the rest of the forested Côte d’Ivoire. This report not only revealed degradation within forest reserve, but also stated that the main problem is “a general lack of interest in this area” (IUCN 1996, 28). To confront this problem, one of the tasks of my research is to give this area necessary attention and to discuss its changes within the context of national degradation of forest reserves.

Not surprisingly, patterns of land cover changes in the Mabi-Yaya-Songan-Tamin area examined in this study resemble changes documented in many other reserved forests across Côte d’Ivoire. Washington, DC-based global environmental campaign organization, Mighty Earth, conducted an investigation in 2017 to evaluate the state of forest reserves of Côte d’Ivoire and to examine the links between forest degradation and cocoa production (Higonnet et al. 2017). Protected areas that were investigated included Scio, Goin Debé, and Cavally reserved forests of southwestern Côte d’Ivoire. The findings of this field trip suggested that illegal deforestation triggered by expansion of cocoa production is a known fact in the entire chocolate supply chain. Global cocoa traders - Olam, Cargill, and Barry Callebaut are buying cocoa grown in protected areas. These traders are selling cocoa to the world’s largest chocolate companies, such as Mars, Hershey, Mondelez, and Ferrero. The protection of forests by the SODEFOR is largely absent. In fact, based on the interviews of locals, the SODEFOR is profiting from illegal deforestation by accepting (and expecting) bribes from farmers (Higonnet et al. 2017).

One year after Mighty Earth released their investigation report Chocolate’s Dark Secret, the researchers revisited their study area to document any changes in the state of
forest reserves, agricultural practices, and the perception of forest resources by the local population. A new report, *Behind the Wrapper: Greenwashing in the Chocolate Industry*, was released on December 7, 2018 (Higonnet et al. 2018). A follow up investigation to forest reserves of Côte d’Ivoire revealed that there were no significant changes either in the state of forest reserves, nor in the attitudes of the populations who settle and farm in the restricted zones. Although SODEFOR agents responded to the findings of the first investigation and destroyed some of the cocoa plantations inside the forest reserves, these actions were insufficient to maintain ecological integrity without compromising human rights (Higonnet et al. 2018).

Given that the fairness of SODEFOR’s practice of authority was questioned, it is worth examining the links between protecting the environment and protecting people. Many sources suggest that government actions with the purpose of eviction of the local population from protected areas were accompanied by violation of human rights in a form of rape, looting of homes, and theft (EIJ 2013). Human Right Watch (HRW 2016) conducted their field investigation in the same reserved forests as the Mighty Earth team: Scio, Goin Debé, and Cavally in May 2015 and March 2016. They have reported inadequacy of SODEFOR’s measures to evict local populations, many of whom settled in these areas before they were recognized as protected. As a result, protected area-centered conflict somehow evolved into a more complex problem that today encompasses a gradual degradation of remaining natural resources, persistence of rural poverty, struggles over land and authority, and abuse of human rights (HRW 2016).
5.2. Proximate causes of forest decline in reserved forests of Côte d’Ivoire

5.2.1. Agricultural expansion

Multiple sources indicate that agricultural expansion in Côte d’Ivoire is the primary reason behind forest decline. To evaluate the approaches of agricultural production in Côte d’Ivoire, I used data from the Food and Agriculture Organization of the United Nations (FAOSTAT) and made graphs for the main export crops in Côte d’Ivoire with these main indicators: production quantity, area harvested, and yields. If the growth of production quantity is accompanied by an increase in yields, the path might indicate either sustainable or unsustainable agricultural practices oriented toward land use intensification. If, however, the area harvested increases with an increase in agricultural production leading to land use expansion, the practices are clearly unsustainable because they heavily depend on a limited resource – land, and compromise the delivery of ecosystem services by forests that occupy potentially cultivable land. An example of such an agricultural approach is adopted by cocoa farmers in Côte d’Ivoire (Figure 38).

Growth of export-oriented agriculture to expand cocoa production was expected to stimulate modernization of methods and intensification of production, but in practice cocoa expansion was achieved by land use extension (Verdeaux and Alpha 2004, 56). In fact, land shortages led to production of cocoa in restricted zones. It has been estimated that 40% of country’s cocoa is grown in protected forests (BBC 2016, Reuters 2018).
Although the total production for cocoa in Côte d’Ivoire grew during the study period, Ivorian farmers reported low returns from cocoa farming that led them to not only expand the land used for production, but also to attempt diversification of agricultural commodities. One alternative rapidly adopted by farmers was rubber (Reuters 2013). Unfortunately, the hope to make a better living from the rubber industry failed many Ivorian farmers because of volatile prices and falling demand that led them to look for alternative commodities or other solutions again (Reuters 2016, Figure 39). These facts indicate that although farmers are recognized as actors responsible for deforestation in Côte d’Ivoire, they do not act as independent agents, and their decisions are often shaped by external drivers of global trade markets.

(Data Source: FAOSTAT)
Figure 39. News headlines that illustrate the role of changes within global market on occupation and livelihood of farmers on Côte d’Ivoire
The conditions of global trade markets define *what* to produce, for example rubber instead of cocoa, based on global demand, price, and potential profit. Another question not directly dictated by the global market conditions but central to shaping the image of the landscape is *how* to produce – with the focus on either land use expansion or land use intensification, as monoculture or an agroforestry system, with or without adding artificially produced fertilizers, and so forth. Although this question appears to be under the control of farmers, their choice is limited to a set of available options instead of all possible options. Not surprisingly, similar to cocoa production, an increase in the production of rubber was fueled by land consumption instead of land use intensification (Figure 40). A different pattern is observed for coffee production, which is becoming less popular; production quantity decreases, yields and area harvested were highly variable during the study period (Figure 41).

To summarize, the type of agriculture is a relevant proximate force of deforestation, but it is a part of a casual chain leading to forest loss rather than the actual cause. This overview, therefore, should be complemented with a narrative on underlying forces that lead to certain agricultural practices. These forces supply energy to deforestation practices by imposing opportunities and constraints that guide farmers’ decisions, however they are often overlooked because their role is not apparent on the landscape and is difficult to interpret.
**Figure 40. Rubber production in Côte d’Ivoire**

(Data Source: FAOSTAT)

**Figure 41. Coffee production in Côte d’Ivoire**

(Data Source: FAOSTAT)
5.2.2. Wood exploitation

Although now central to the economy of Côte d’Ivoire, the production of agricultural export commodities was not always the primary source of country’s wealth. At the beginning of the twentieth century, economic growth heavily depended on wood exploitation regulated by the colonial administration. In fact, the country was often perceived as a forest colony. When coffee and cocoa frontiers appeared on the landscape, wood exploitation started to become less important. The initial coexistence of two economic activities – agriculture and forestry – gradually evolved into an agriculture-based economy because of depletion of mature forests and competition for land resources and labor (Verdeaux and Alpha 2004, Figure 42).

![Figure 42. Temporal changes of the main economic activities in Côte d’Ivoire driven by the shift in the state’s economic priorities](image)

(Data Source: FAOSTAT)
As documented by policymakers in the report prepared to implement REDD+, forestry activities are a less important factor of the country’s economy than agriculture, but they still have an impact on deforestation. All forestry products produced in Côte d’Ivoire can be divided into two categories: first is wood for industrial purposes, and second is wood fuel and wood charcoal. No significant changes in the production quantities are apparent for industrial wood while wood charcoal production increased during the study period by 44% (Figure 43). This product is not an export commodity and is used primarily for domestic purposes, which indicates a growing demand inside the country. Policymakers recognize that wood charcoal exploitation remains one of the main unregulated sectors in the country’s economy that contributes to the forest decline (SEP REDD+ 2017, 17-18).

Based on the finding of this project, the main transformation in the study area was modification of forest into degraded forest, particularly inside the Songan-Tamin forest reserve. Although degraded forest presented a complex agriculture/tree plantations/degraded forest mosaic, forest degradation in some areas was not associated with other land uses (Figure 44), and it can be attributed to forestry production, particularly to increased production of wood charcoal and commercial logging shown in Figure 43. This landscape might also indicate use of land for grazing. No regrowth of tree cover occurred inside the protected area indicating the disbalance between loss and gain of tree cover. To summarize, although agriculture is the most prominent factor leading to forest loss in Côte d’Ivoire, this case study reveals that forest degradation resulted from multiple proximate causes including forest exploitation for wood.
Figure 43. Forestry production in Côte d'Ivoire during 1986 – 2017

(Data Source: FAOSTAT)
5.2.3. Infrastructure extension

Infrastructure extension is not presented in the literature as a driving force of deforestation in Côte d’Ivoire, partly because road networks have not been densely developed in rural areas, and because infrastructure development facilitates rather than drives deforestation. Roads sometimes have no effect on the surrounding forest resources (Figure 45), but they often shape the patterns of land cover changes, because they can change the accessibility of land and separate different land uses. For example, Figure 46 illustrates a landscape in the study area where there is an extensive cropland on one side of the road that falls within the unprotected zone and dense forest on the other side that falls within the protected area. It should be acknowledged that the conclusion made here about the varying impact of road networks on land cover change patterns in Côte d’Ivoire is site-specific, not universal.
Depending on the region and on the type of infrastructure (transportation, market, settlement, and private enterprise) the impact of infrastructure on the landscape varies (Geist and Lambin 2001, 27-28). To present a contrasting case, I use an example from the
Amazon where infrastructure development is a strong proximate force of deforestation (Figure 47). In the dense and sparsely populated Amazon forest, a new road provides an access to otherwise impassable forests. In case of Côte d’Ivoire, however, the context is radically different because of high population density and forest scarcity.

![Image](image.png)

**Figure 47. The impact of infrastructure development on deforestation in the Amazon**

*Google Earth high resolution imagery in the Amazon 4° 3’46.40”S 54°42’21.00”W*

5.3. Underlying causes of forest decline in reserved forests of Côte d’Ivoire

5.3.1. Demographic factors

Population growth is often presented as the main underlying force driving tropical deforestation (Lambin et al. 2001, 262 - 263), however the links between demographic and environmental changes are difficult to quantify. Population growth might correlate with deforestation and forest degradation. For example, the description of wood exploitation as a proximate force of forest degradation in the previous section is associated with increased energy demand that was likely driven by population increases.
It should be stressed, however, that correlation and causation are two distinct types of relationship. While correlation implies a mutual relationship between two variables, causation indicates that one event (effect, here deforestation) directly results from another event (cause, here population growth). It is important to examine how this idea originates and what the challenges are to providing clear linkages between demographic and environmental changes. I use the case study of this research as an example.

The main challenge to studying the environmental impacts of population changes is related to scale constraints and data availability. Different portions of the Mabi-Yaya-Songan-Tamin reserved forests fall within three different administrative regions, and the boundaries of the protected areas and administrative boundaries are not the same (Figure 48). When it comes to collecting population data, the relevant boundaries are administrative; census data are aggregated spatially and do not represent the spatial distribution of the population within the administrative unit (Wardrop et al. 2018, 3530).
Figure 48. Administrative division of the study area

(Data Source: United Nations World Conservation Monitoring Centre, ArcGIS

Online, Software: ArcMap by ESRI)
Information on the number of people living in each administrative region is easily accessible; as of 2014 the regions of La Mé, Indénié-Djuablin, and Sud-Comoé had estimated populations of 514,700; 560,432; and 643,620 respectively (Côte d’Ivoire Data Portal 2014). This information does not provide any knowledge on the number of people within and outside the protected area boundary, the distribution of population, or its role on shaping the landscape. Additionally, these administrative boundaries were established in 2011 under the broader political intervention to decentralize and provide local authorities with financial independence (Sanogo 2019, 206). Because of the recent changes to administrative divisions, it becomes more difficult to obtain a detailed description of demographic changes and to compare them temporally or spatially.

Another way to derive knowledge on demographic changes is through detecting changes in the area covered by settlements. The quantification of land cover maps reveals that there were no settlements in the Mabi-Yaya reserved forests and some settlements in the Songan-Tamin, however most settlements in the study area were found in the unrestricted zone (Figure 49). One might find correlation between the absence of settlements in the Mabi-Yaya and less substantial forest degradation compared to other zones. On the other hand, area covered by settlements is much smaller in the Songan-Tamin than in the unrestricted zone, but both areas underwent similar forest loss (Chapter 4 Results). Additionally, this analysis does not reveal the impact that local populations who live in the unprotected zone have on neighboring forests in protected areas, nor does it suggest a clear link between population pressure and forest degradation. Although this research neither disproves nor substantiates the detrimental effect of population growth on the environment, it highlights the viewpoint that a complex relationship between
forests and people cannot be objectively evaluated just with census data and land cover maps.

Figure 49. Changes in settlement area in each zone of the study area

The connection examined here between the population and the area of settlements did not lead to a meaningful conclusion, however it has the potential to shed the light on the demographic changes when the requirements of data sufficiency and technological capacity are met. As a significant area of active research, bottom-up approaches for estimation of population in data-poor areas offer this possibility. These methods typically involve micro-census surveys in selected representative samples across an area of interest that allows an extrapolation of the results to a spatial extent of the entire area of interest. The accuracy of this approach depends on correctly quantified relationships between the population density and built-up areas, areas of specific land use types, count of housing units, socioeconomic characteristics, and other parameters (Wardrop et al. 2018). High spatial resolution imagery is a valuable data source of the number of buildings in a
settlement and the land cover types associated with a settlement (Figure 50), but there is a need to construct a cultural and socio-economic context of the study area for more accurate estimation of demographic variables.

Figure 50. A settlement inside the Songan-Tamin forest reserve surrounded by tree plantations

(Google Earth high resolution imagery, Digital Globe; 6° 7'47.84"N, 3°20'15.69"W)

One example of a high resolution population distribution data source is the LandScan dataset produced by the Oak Ridge National Laboratory (https://landscan.ornl.gov/). At an approximately 1 km spatial resolution, it provides global population distribution data from 2000 to 2017 at 1-year intervals. These raster data were extracted to allow temporal and spatial comparison of population changes in the study area (Figure 51).
Figure 51. Population changes in the study area from 2000 to 2017

(Data Source: LandScan by the Oak Ridge National Laboratory; Software: ArcMap by ESRI)
Visual interpretation of the population distribution maps suggests that the relative homogeneity of population distribution changed during the 2000 – 2017 study period (Figure 52). At the beginning of 2000, population distribution was more homogeneous, while in 2017 populations were less evenly distributed with prominent clusters of densely populated areas around protected zones. To complement this visual interpretation, I extracted yearly data from the LandScan dataset for the study area to create graphs and compare temporal population changes in different zones of the study area (Figure 52 and Figure 53). Overall, the proportion of population was much higher outside the protected area than inside both Mabi-Yaya and Songan-Tamin reserves. General trends of population changes outside the protected area illustrate an increase in population, while the number of people living inside the reserves slightly decreased after 2000. A decrease in total population during 2002 – 2004 was likely linked to a civil war that started in 2002. After 2004, populations remained relatively stable inside the reserves and started growing in the unprotected areas.
Figure 52. Population changes in different zones of the study area from 2000 to 2017

(Data Source: LandScan by the Oak Ridge National Laboratory)

Figure 53. Population density changes in different zones of the study area from 2000 to 2017

(Data Source: LandScan by the Oak Ridge National Laboratory)
The reason why the majority of settlements inside the reserves were not classified in this project (look Chapter 4 Results) is the size and the distribution pattern of these settlements, which are relatively small and distant from each other (Figure 54). Larger clusters of populations identified in this project were found outside the protected areas (Figure 55), which corresponds to the patterns of population distribution extracted from the LandScan dataset. As for the implications of these data, although the proportion of populations outside the protected area is much higher than inside, there is a disconnect between the environmental objectives of the government to restrict access to forest reserves and the reality of settlement patterns. It is unclear whether a relatively small number of people living inside the reserves or the growing populations in the buffer zones had a more significant impact on forest degradation. It is, however, evident that the presence of populations inside the reserves does not explain the contrasting landscapes of the Mabi-Yaya reserve, which still has a significant amount of dense forest, and the Songan-Tamin, which contains predominantly degraded forest, because the number of people living in each reserve is similar.
Figure 54. A small settlement inside the Mabi-Yaya forest reserve

(5°59'41.57"N, 3°27'14.36"W, Google Earth high resolution imagery, imagery date: 1/12/2013; red line has a length of 72.4 m)

Figure 55. A settlement in the buffer zone of the study area

(5°46'17.11"N, 3°45'21.94"W, Google Earth high resolution imagery, imagery date: 1/4/2015; red line has a length of 2,120 m)
To further explore the significance of demographic changes obtained from high quality spatially disaggregated population data, we rely on other secondary sources, such as reviews of scientific literature that help to investigate population growth impacts on land cover changes at multiple spatial scales. When looking at the drivers of tropical deforestation at a global scale, Geist and Lambin (2002, 147) argued that a common idea that population growth is a primary driver of deforestation is misleading; it is mentioned only in a small number of local case studies, and it is always associated with other driving forces. Furthermore, Leach and Fairhead (2000, 30-31), in their study about forest changes in West Africa, have presented evidence of positive effects that local population can have on reforestation through farming practices that enhance soil fertility and planting trees in the marginal zones between forest ecoregion and savanna.

An obvious question that would complement this analysis is whether or not different sources of population growth might affect natural resources differently. Apart from demographic changes fueled by the natural growth of population, environmental changes might originate from migration from within and outside the country. In fact, both the scientific literature and reports prepared by policymakers agree on the significant impact of migration patterns on forest degradation in Côte d’Ivoire because of increased competition for available resources that evolved into civil war (SEP REDD+ 2017, 20-21; Woods 2003). Vast forest resources for years attracted migrant labor from the northern region of Côte d’Ivoire and neighboring Burkina Faso and Mali. The government supported and encouraged (and some suggest even forced) migration because of perceived economic benefits of further forest exploitation. This period is referred in the literature as an “Ivorian miracle”. When no restrictions were enforced to control
growth, migration and economic prosperity gradually drove environmental degradation. Once forested land became rare and less suitable to grow cash crops, pressure to control land access increased and intensified environmental degradation (Woods 2003).

5.3.2. Economic and technological factors

5.3.2.1. The role of external drivers

Farmers operate in economic and political contexts that create opportunities and constraints to land use decisions that makes farmer-driven agricultural expansion an incomplete reason to fully explain deforestation. The price of agricultural commodities, the demand, and the conditions of the global market play a critical role in regulating agricultural production in Côte d’Ivoire. Although the price of cocoa experienced significant changes after the 1960s, the data indicate that despite low commodity prices cocoa remains an important crop for Côte d’Ivoire economy (Figure 56). To cope with changing cocoa price, farmers cultivate more land or adopt alternative technological solutions. In the first case, a larger area harvested potentially indicates a bigger threat to forests that occupy cultivable land (Figure 57). Although widely applied, this approach is not an optimal solution because of opportunity costs related to deforestation that imply lost opportunities of other land uses including maintaining natural forest cover. This decision results in disruption to ecosystem services delivery supported by forests including regulation of erosion, water purification, and climate regulation. To avoid further land exploitation, the government supported the distribution of hybrid cocoa seedlings and other advanced technologies, but this intervention did not prevent growing cocoa inside protected areas and resulted in overproduction, which led to lower cocoa prices. To cut overproduction, the government recently decided to stop helping farmers
improve yields (Reuters 2018 b). These events indicate a connection between the production of agricultural commodities, prices, and political interventions.

**Figure 56.** Price of cocoa and total production of cocoa in Côte d'Ivoire

*(Data Source: World Bank, FAOSTAT)*

Cocoa price decreases → Production increases to compensate for loss

Area harvested increases → Opportunity costs of deforestation

**Figure 57.** Land use expansion approach
The trend in production of another important commodity – rubber – reveals that the production of rubber increased, but the prices underwent a gradual decrease, increased after 2000, and started decreasing again in 2012 (Figure 58). An attempt to diversify agricultural production did not improve the resilience of farmers to changes within the global market, because rubber price is also subject to price fluctuations (Figure 58). This scenario is also associated with opportunity costs of deforestation (Figure 59), and future trends of rubber production remain to be seen.

Figure 58. Price of rubber and total production of rubber in Côte d'Ivoire

(Data Source: World Bank, FAOSTAT)
An alternative to the diversification of commodities and land expansion has been offered by the Ivorian government in a form of sustainable agroforestry practices. Agroforestry systems are created with the purpose of retaining a diversity of trees through thinning of original forest canopy and planting useful fruit and timber species inside cocoa plantations (Smith et al. 2014, 1048). Instead of evicting local populations who have no alternative livelihoods from protected areas, cocoa plantations might potentially be legalized inside some protected areas if new trees are planted to shade cocoa plants resulting in less harm to biodiversity, more fertile soils, and less deforestation. This plan has a significant economic constraint of its own; the government and chocolate industry were initially reluctant to finance the project (Reuters 2018 a).

On the other hand, it has been found that many cocoa farmers in Côte d’Ivoire already practice sustainable agroforestry despite the dominance of full sun cocoa cultivation across the country. Some farmers decided to keep trees on their farms because they recognized the benefits associated with adopting agroforestry practices. Trees
provide a source of fuel wood and fruit, protect cocoa trees from heat stress, and improve soil fertility. On a larger scale, agroforestry systems are important because they constitute reservoirs for biodiversity and have higher carbon storage potential than monoculture systems (Smith et al. 2013; Ruf and Varlet 2017, 90).

To summarize, there are different stories that relate economic and technological forces with geographic landscapes of forests across Côte d’Ivoire. The relationships between poverty and environmental degradation originates from choices and tradeoffs available to the poor that largely depend on the natural resources (Barbier 2010), therefore the conflict between the environmental objectives and the goals to overcome rural poverty is central to these stories.

5.3.2.2. Poverty-environment trap or environmental Kuznets curve?

Any attempt to create a model of interaction between economic triggers and environmental changes will always be incomplete and yet can be an insightful tool to explore this interaction. One such example is a poverty-environment trap that presents a vicious cycle that prevents farmers in developing countries from winning the fight against poverty (Barbier 2010). It involves a positive feedback loop between environmental degradation and the persistence of rural poverty (Figure 60). The livelihood of rural residents in many developing countries, including Côte d’Ivoire, directly depends on natural resources. Living in fragile environments, people are forced to overuse their resources to support themselves, and this undermines the flow of ecosystem services on which they depend, which makes the future of rural communities even more uncertain. Barbier (2010) has demonstrated that the constraints at the base of this cycle are interwoven with external forces that shape farmers’ decisions. These forces include the
lack of access to markets for credit, insurance, and land, and high transportation and transaction costs. A more optimistic theoretical interpretation of relationship between the environment and the economy is presented in a form of Kuznets curve (Figure 61) suggesting that an initial increase in per capita income is fueled by an increase in deforestation rate, however after a certain turning point the deforestation rate decreases because forest scarcity reduces incentives to deforest and can lead to reforestation (Culas 2012).

![Diagram of poverty-environment trap](image_url)

*Figure 60. A poverty-environment trap*

*(graphics based on the explanation provided by Barbier 2010)*
Although these models imply different consequences for the society and the state of the environment, the literature suggests the applicability of both scenarios in the case of Côte d’Ivoire. The outcomes of both the environment-poverty trap and the environmental Kuznets curve heavily depend on the external forces, whether these forces contribute to further deforestation in the form of poor accessibility to markets or promote forest growth by providing incentives to protect natural resources. In fact, the only difference between the pathways depicted here is that in the case of Kuznets curve, the country manages to reach a development potential, otherwise it might get “trapped” in a poverty-environment cycle.

5.3.3. Policy and Institutional factors

The most prominent institutional driving forces recognized by policymakers that led to forest degradation in Côte d’Ivoire include institutional instability and weak
synergy between public administration and sectoral policies. The role of the national government in forest resources management has been recognized as too weak to ensure public respect of regulations (SEP REDD+ 2017, 20). Institutional instability leads to social and economic insecurity of the population and contributes to an absence of proper management of natural resources.

When institutional forces are too weak to enforce proper regulations, some policies may exist as elements of the legal landscape that might not lead to action but have the potential to affect the geographic landscape directly or indirectly. For instance, if enforced effectively the Forestry Code of Côte d’Ivoire could have a direct positive influence on management of forest resources. Other policies might be oriented toward land management or the production of agricultural commodities and have an indirect impact on the way forests are treated by the state, public, and individuals. Some policies might act synergistically and reinforce each other, while others might have opposing effects. The scale of implementation might also create varying outcomes; for instance, some policies incorporate different spatial scales by determining priority regions for conservation.

One such example is the *Cocoa and Forests Initiative* adopted by the Ministry of Water and Forests and the World Cocoa Foundation that was announced at the end of 2018 (IDH 2019). Although the scale of collaboration is international, the effect of the policy is expected to be the most apparent in the priority regions. Mapping these regions revealed two important geographical patterns (Figure 62).
Figure 62. Priority regions of the Cocoa and Forests Initiative

(Data Sources: UNEP-WCMC 2019, ArcGIS Online, IDH 2019; Software: ArcMap by ESRI)
First, the majority of these regions are concentrated in the southwestern Côte d’Ivoire, which has some of the largest protected areas in the country including Tai National Park. Second, the Mabi-Yaya forest reserve in the La Mé region is included in the priority territory, but not the Songan-Tamin, an adjacent forest reserve that lost most of its forest cover as was documented in this project. Although La Mé is spatially separated from other regions, its value was likely defined by the amount of existing forest cover. These facts indicate that the priority regions are the ones that still have forest to preserve and might be under increased risk of forest degradation because of external forces.

Apart from focusing on selected regions, another key recommendation to future management of forest resources in Côte d’Ivoire mentioned by the scholars and policy makers is to redefine and map the boundaries of protected areas. The current definition for reserved (classified) forest provided in the Forestry Code of Côte d’Ivoire updated in 2014, is “classified forest is a forested land defined and delimited in accordance with a law or regulatory system in order to give it the necessary legal protection” (Ministère Des Eaux Et Forêts 2014, 3, translated from French). Although these forests are legally recognized as restricted zones, there is a need to add more clarity regarding what activities are restricted and permitted. Additionally, whether the project to support agroforestry promoted by the Cocoa and Forests Initiative is successful or not, maps of the boundaries of protected areas should be updated. This might potentially lead to reclassification of some reserves from Permanent Domain managed by the state to Rural Domain where expansion of agriculture is permitted.
Furthermore, it appears that the separation between the Rural and Permanent Domain is not only subject to future change; it already has fluid boundaries in terms of public respect because of the frequently reported fact that cash crops are planted inside the protected areas (BBC 2016, Reuters 2018). A critical force that constructed these conditions is the insecurity of land tenure – one of many indirect forces that affect forest landscape by dictating land management practices. The absence of secure ownership leads to uncertain ties of people to the forest that may result in detrimental effects on the economy, society, and the environment. For example, the absence of ownership might discourage farmers from investing in long-term sustainable practices to improve yields and contributes to land expansion approaches to increase production.

A major source of land insecurity in Côte d’Ivoire is land transactions that happen outside the legal framework. Although informal land markets pay a critical role in the economic development where resources are not evenly distributed, they do not provide legal support to ensure security (Colin, 2013). The link between land tenure insecurity and public disregard of conservation policies is embedded in the perception of forests as an open access resource. In spite of the strong dependence on forests and forested land, farmers might not develop a sense of deep attachment and a desire to implement long-term vision strategies on a land they do not formally own.

To confront the issue of insecure land tenure, the state implemented the Rural Land Law in 1998. However, instead of solving the conflicts on the base of land ownership, the law highlighted the tension between indigenous Ivorians and foreigners, which contributed to further conflicts. Under this policy, only individuals who can prove Ivorian nationality can acquire land ownership rights; this shifted land ownership
disputes in favor of Ivoirian nationals regardless of any previous agreements (Babo 2013, 101-102). By restoring the rights of Ivorian indigenous people, the law “legalized a form of abuse” to foreign farmers who had acquired the land before the act and had to pay twice to the same people, who were recognized as legal owners. Restoring “fairness” was not seen as fair to everyone and even contributed to discriminatory and xenophobic attitudes that evolved into political unrest during 2002 – 2004 and 2010 – 2011 (Babo 2013, 110-111).

5.3.4. Cultural factors

Although most sources focus on underlying economic factors of land cover changes, it is important to consider the cultural realities that evolve from certain attitudes, values, and beliefs and influence the behavior of public or individuals. Some sources suggest that one such type of behavior that contributed to forest degradation in Côte d’Ivoire was rent-seeking (Woods 2003, Ruf 2017). This behavior can be expressed through an individual's or public's use of resources to obtain economic gain without reciprocating any benefits to others through wealth creation (Investopedia 2019).

In the context of agricultural production in Côte d’Ivoire, rent-seeking behavior took the form of exploitation of abundant forest resources with little to no consideration of environmental externalities and future land shortages. Land and forests were perceived as a “limitless resource”. In fact, this type of attitude was encouraged by the government of newly independent Côte d’Ivoire in a famous slogan pronounced by the Head of State Houphouet-Boigny “land belongs to those who make it produce” (“la terre appartient à ceux qui la cultivent”) (Woods 2003, 645). Although the consequences of this behavior were not predicted, they were certainly not unpredictable. Social science theories
describe this situation as “the tragedy of the commons” when common resources are
exploited by collective action of individuals who act according to their self-interest (Ruf
and Varlet 2017, 89).

In contrast, Wood (2003, 652-653) argues that the state and individuals
recognized structural limits and the carrying capacity of forest resources, but external
forces, such as changing commodity prices, undermined the efforts to diversify
agricultural production and led to further land use expansion as a coping mechanism to
market fluctuations. Whether cultural factors or economic constraints played a more
defining role on agricultural practices shaping the landscape, it is clear that no single
force would have resulted in forest degradation of this magnitude and scale if not
reinforced by other factors.

5.4. Other Factors

5.4.1. Pre-disposing environmental factors

If the land has low agricultural productivity, one might assume that land
characteristics determine the fragility of this land. In practice, biophysical factors are
intrinsic properties of land, but fragility is not. These factors create pre-disposing
environmental conditions that lead to certain agricultural practices that eventually might
result in fragility. Thus, fragility can be defined as a potential for environmental
deterioration through human use (Turner and Benjamin 1994, 105-106). In the case of
Côte d’Ivoire, because soils are poor in nutrient content, farmers adopt shifting
cultivation practices. Nutrients are available when forested land has been burned, but
after a few production cycles the fertility of soils decreases. Then farmers abandon
previously cultivated land and allow it to return to its natural state. This system can work
effectively without leading to land deterioration when the population is small relative to the forest area, which permits a lengthy time for forest regrowth. On the other hand, when the land is scarce, the length of time between cultivation is reduced leading to environmental degradation and a decline in agricultural productivity (Ehui 1993, 370). This interaction initiates a positive feedback loop where nutrient deficiency of soils is both a reason and an outcome of deforestation (Figure 63).

Figure 63. Positive feedback loop of interaction between biophysical properties and human use of land that results in fragility

Topography presents another important land characteristic that affects patterns of agricultural activities and subsequent forest loss. Researchers suggest that clearing of
tropical forest for agriculture starts from more favorable areas, such as lowlands and more fertile uplands. When land becomes scarce, less favorable areas for agriculture, such as steep slopes, might also undergo deforestation (NRC 1993, 45). Spatial variability of topography in the study area reveals no significant topographic variations between the reserves (Figure 64). This fact does not support a possible explanation that forest inside the Mabi-Yaya was better preserved than in the Songan-Tamin because of unfavorable topographic conditions for farming. It is possible, however, that the most suitable land was deforested prior to 1986, which marks the beginning of the study period, and therefore topography is no longer an important factor. Additional variations in physical geography conditions could be presented by soil quality differences, however good quality soil data were not available for the study area at a fine spatial resolution, which is one of the biggest challenges of working in a data-poor, understudied area.
5.4.3. Social trigger events

While most factors that lead to deforestation in reserved forests of Côte d’Ivoire are persistent and long-lasting, others might be abrupt but no less devastating. These are social trigger events, such as war, revolution, and social disorder (Geist and Lambin 2002, 144). A study conducted in the reserved forest in the center-west of Côte d’Ivoire explored the role of direct and indirect war-related activities on the forest resources. Habitat destruction by armies is an example of direct impacts, while indirect impacts can be associated with activities of refugees. The authors of this study reported a significant

*Figure 64. Topography of the study area*

*(Data Source: US Geological Survey, Software: ArcMap by ESRI)*
decline in the forest cover during the recent period of political unrest and concluded that conflicts contributed to forest fragmentation, loss of biodiversity, and modification of Haut-Sassandra forest reserve into a “vast cacao plantation” (Barima et al. 2016).

5.5. Summary

5.5.1. Interactions between driving forces

There is a reason why, regardless of the discipline, scientists who focus on anthropogenically driven environmental changes are also systems thinkers. Nothing in nature happens in isolation, and most drivers operate through a range of interactions facilitating each other. By considering the relationship between different elements of a coupled human-environment system, we acknowledge the interaction between these elements and the flow of energy within them. These interactions were simplified in this study because of the descriptive and exploratory approach that was based primarily on evaluating secondary data and on the reviews of literature, including scholarly articles, policy reports, and news articles. This approach, however, allows one to search for a convergence of evidence presented in different sources of data and to incorporate this evidence into theoretical interpretation of driving forces.

Based on the synthesis of systems theory and empirical evidence, it is obvious that forest degradation in reserves of Côte d’Ivoire is a product of multiple causal chains and their interactions. For instance, forest decline from war-related activities was fueled by other events that were driving forces of forest loss on their own (Figure 65). For example, political unrest was induced by ethnic conflicts between Ivorian citizens and migrants because of increased competition for land access. The origins of ethnic tensions came from earlier migrations when migrants were used as a labor supply to fuel the
“Ivorian miracle” of a newly independent and economically promising African country. Furthermore, the nutrient deficiency of soils in the context of marginal tropical land contributed to and was reinforced by forest cover loss. This and other explanations will only be partial and yet informative narratives on the topic of land cover changes in Côte d’Ivoire.

Figure 65. A casual chain that led to forest decline in Côte d’Ivoire

(solid lines used for driving factors, dashed lines for facilitating factors)

The interactions between different factors should also be analyzed through the unifying theme of globalization. For instance, agricultural commodities were produced to meet demands from outside Côte d’Ivoire (Figure 66 and Figure 67). Cocoa beans remain the main export commodity of Côte d’Ivoire and generate the most export income (37%, 2017 estimate) followed by rubber (11%), cocoa paste (10%), cocoa butter (6%), and other commodities (Simoes and Hidalgo 2011). The livelihood of farmers in Côte d’Ivoire depends, therefore, not only on land access and changing prices but also on the
demand for their products in distant places. Subsequently, the uncertainty related to the ecological integrity of forest resources in Côte d’Ivoire originates from a complex interplay between local and global forces.

Figure 66. Where Côte d’Ivoire exported cocoa beans to in 2017?

(Data Source: Simoes and Hidalgo 2011, Software: ArcMap by ESRI)
Figure 67. Where Côte d’Ivoire exported rubber to in 2017?

(Data Source: Simoes and Hidalgo 2011, Software: ArcMap by ESRI)

This analysis raises an obvious question about the changes of spatial scale in this research from local to national and global. Although the central problem was at the spatial scale and temporal dimension of the Mabi-Yaya-Songan-Tamin protected area complex and its buffer zone from 1986 to 2017, it was not possible to investigate the driving forces of forest changes without going back in time and outward in space to find connections between effects and causes. Here I provided a discussion of forces that led to forest degradation in many forest reserves of Côte d’Ivoire rather than in the study area not only because of data insufficiency but also because it would be incomplete to ignore
the similarity of land cover changes and their drivers across the country. This critical connection also underlines the importance of this research. What matters in the Mabi-Yaya-Songan-Tamin might also be reflected through changes in the Cavally forest of southwestern Côte d’Ivoire, protected areas of the Upper-Guinean Forest in Ghana, and the tropical forests of Indonesia. Only by searching for these patterns, we can reach a deeper understanding of tropical forest decline in the context of global environmental transformations and construct better strategies to avoid or to adopt to undesirable changes.

5.5.2. Why do buffer zones matter?

Ecosystem management is a wicked problem because ecosystems are dynamic and unpredictable. One way to approach ecosystem management is through adaptive management that considers and values the context in which ecosystems evolve that includes the biophysical characteristics and socioeconomic realities of a larger landscape (DeFries and Nagendra 2017). No protected area can be effectively managed if surrounded by a degrading natural environment, because a protected area is a functional unit of the landscape (Palomo et al. 2014, 184). The case study of the Mabi-Yaya-Songan-Tamin reserve illustrates that the most significant changes in man-produced land cover types (agriculture, plantations, and settlements) occurred in the unrestricted zone that resulted in contrasting landscapes within and outside the protected area. These land cover types are significant footprints of human activity, but how did they undermine the ecological integrity inside the protected area?

The findings of this study suggest that the most significant transformation inside the protected area was a transition from dense forest into degraded forest mixed with
cropland and plantations. In case of deforestation, when forest is completely replaced by a different, typically productive land cover type such as agriculture, the human-environment link is apparent on the landscape. Forest degradation implies a less evident connection between human pressure and demands, and land cover changes, and in this case study it resulted in a highly fragmented forest cover mixed with cropland and plantations. This was attributed to the expansion of agriculture and wood exploitation to support a growing population outside the protected area. The explanation of forest degradation inside the protected area would be even more ambiguous if we excluded the changes in the buffer zone that were critical to this research. To conclude, the changes outside the protected area provided the necessary socio-ecological context that leads us to question the rigid administrative structure of protected areas and to consider their potential management through organized landscape planning.
CHAPTER 6. CONCLUSIONS

How did the story of forest degradation in the Mabi-Yaya-Songan-Tamin of Côte d’Ivoire begin? Did it start with practices of individual farmers or legal regulations imposed by the government? Was the land naturally fragile and unsuitable to withstand human pressure or was there an absence of strategies that incorporated the potential productivity and carrying capacity of land and forest resources? There are many stories that attempt to explain that the current image of the landscape in forest reserves of Côte d’Ivoire has been constructed through interactions and feedbacks among multiple driving forces. More importantly, what will these stories mean in the future? Implications of forest degradation will likely extend outward in space and time through the trajectories of environmental processes associated with habitat loss that threatens chimpanzees, elephants, and other species of the Upper-Guinean Forest of West Africa. Forest degradation and resources scarcity also trigger social and economic changes that include limited access to land and subsequent food insecurity because agriculture is a primary source of livelihood for rural populations of Côte d’Ivoire. This project was focused primarily on the past; it integrated an interpretation of land cover changes and an investigation of the driving forces of these changes. However, now it leads to a question of what will be the future of the Mabi-Yaya-Songan-Tamin and other forest reserves of Côte d’Ivoire if no force changes the current trend of forest degradation?

6.1. The importance of the research

Geographic research that focuses upon tropical forest transformation is becoming increasingly important because of rapid deforestation at a global scale and increases in populations who directly depend on the ecosystem goods and services delivered by these
forests. Apart from providing wood, tropical forests are a source of other tangible goods, such as fruits, medicines, resins, oils, latexes, and fibers. These forests also mitigate climate change, stabilize hydrologic systems, prevent soil erosion, and support the most diverse terrestrial biological communities. There is also one critical forest resource that is often used at the expense of all other benefits. This resource is forest land; when people clear the forest for alternative land use types, such as agriculture or grazing, they lose the benefits of maintaining natural forest cover. Conversion of forested land into alternative land uses contributes to some of the most critical contemporary environmental challenges, including climate change and biodiversity loss, and these challenges have social implications, such as poverty, energy insecurity, and food shortages.

To enhance our understanding of global triggers and consequences of tropical forest decline there is a need to construct detailed stories of forest changes at different spatial scales. This study offered a rare opportunity to incorporate remote sensing technical capabilities to interpret land cover changes with a narrative approach to assess driving forces of these changes. I explicitly addressed the local, national, and global spatial scales in order to explore the significance of a local case of the Mabi-Yaya-Songan-Tamin reserve within the context of national trends of land cover changes in Côte d’Ivoire and global drivers of tropical forest decline.

Côte d’Ivoire has one of the highest deforestation rates in sub-Saharan Africa, which draws attention to this understudied area. The Mabi-Yaya-Songan-Tamin reserve of southeastern Côte d’Ivoire presents an interesting case study to explore the connections between local changes and their drivers. The study area contains two adjacent forest reserves: the Mabi-Yaya and the Songan-Tamin. Although these reserves
constitute the same protected area complex, they have contrasting landscapes. Songan-Tamin lost most of its forest cover, while Mabi-Yaya still has a significant amount of the remaining forest. This area is mentioned in a limited number of studies that were mostly focused upon biodiversity assessment and reported decline in populations of many endangered species, such as the roloway monkey (*Cercopithecus roloway*), sooty mangabey (*Cercocephus atys lunulatus*), western red colobus (*Piliocolobus badius*), and others. Population growth in Côte d’Ivoire might result in an increased pressure of agricultural activities on the remaining forest resources and a decline in the subsistence capacity of rural populations if land degradation occurs. The consequences of the local changes in the study area have global implications, primarily because a large proportion of agricultural commodities produced in Côte d’Ivoire is exported to meet the demand in other countries. To summarize, this research is important because the consequences of land cover changes in the study area extend beyond the local spatial scale, the number of people affected increases, and some of these changes might be irreversible, such as the loss of biodiversity. People depend on forests in a number of ways, and these connections between people and forests were among the most important motivations behind this research.

### 6.2. Research objectives and summary of the main findings

#### 6.2.1. Summary of land cover changes interpretation

The first objective of this project was to measure and interpret spatial changes in land cover inside and outside the Mabi-Yaya-Songan-Tamin protected area complex of southeastern Côte d’Ivoire. The results were presented in maps that provided a visual illustration of these changes and graphs that depicted these changes quantitatively. To
reach my second objective, I compared the documented land cover changes spatially and temporally. Spatial comparison of land cover inside the two restricted zones – Mabi-Yaya, Songan-Tamin, and in the 10-km buffer zone outside the protected area revealed that the most significant increase in the area of degraded forest occurred inside the Songan-Tamin forest reserve. Additionally, the homogeneity of the landscape varied spatially; although transformation of forest into degraded forest was the most common type of land conversion in the study area, these changes resulted in contrasting landscapes in different zones. The dominant land cover class in the unprotected zone was degraded forest intermixed with tree plantations, cropland, and settlements. Dense forest remained the primary land cover type in the Mabi-Yaya at the end of the study period, while in the Songan-Tamin the remaining forest was highly fragmented and mixed with cropland and therefore classified as degraded forest. Temporal comparison revealed that forest decline in the study area was more substantial during 1986 – 1999 than during 1999 – 2017. No conclusions were drawn from these numbers because the study periods were not even, and a decrease in absolute forest loss during the second period does not necessarily mean that forest conservation was more effective. Slower decline could also be associated with scarcity of forest resources, decline in suitability of degraded land for agricultural activities, and other reasons.

6.2.2. Summary of driving forces assessment

To address the third objective – investigation of the driving forces of the changes observed and documented in this project – I discussed multiple pathways to deforestation and forest degradation in Côte d’Ivoire and their applicability to the study area. The most significant proximate cause of deforestation observed outside the protected area was the
expansion of agriculture, especially in the form of tree plantations. Forest decline inside
the reserves was also related to the expansion of plantations, because cropland and tree
plantations are a major component of the degraded forest landscape. Additionally, forest
exploitation for wood also contributed to forest degradation inside the reserves. Although
the changes documented here are anthropogenically driven, the responsibility for these
changes is not attributed solely to people who live inside and near the reserves. They
were the actors of change, but their actions were strongly shaped by external forces, such
as economic constraints and uncertainties, and social changes. The description of
underlying forces of land cover changes provided an insight into these forces.

Economic context matters for land cover changes in the study area because the
economy of Côte d’Ivoire is based primarily on agriculture. Côte d’Ivoire produces 40%
world’s cocoa beans (2017 estimate) and 6.5% of rubber (2017 estimate) that makes it the
leading producer of cocoa beans and forth largest producer of rubber. Europe, the United
States, and Southeast Asia are the primary destinations of these export commodities from
Côte d’Ivoire. To meet the demands from outside the country and to cope with changing
prices, farmers seem to gravitate towards unsustainable agricultural practices by choosing
land expansion instead of improvement of yields to increase production.

Coping mechanisms with changing prices of cocoa revealed that farmers did not
adopt more sustainable and more resilient agricultural practices even when they started
growing rubber as a perceived “stable alternative” to cocoa. Similar to cocoa production,
farmers achieved an increase in rubber production through land expansion. Technological
improvements that would make a difference at a national scale were ineffective because
of a lack of synergy between institutions and the public sector. One attempt of political
intervention to help maximize cocoa yields by distributing hybrid cocoa seeds failed because overproduction led to a decline in prices of cocoa and contributed to the expansion of agricultural plantations inside the forest reserves. These facts demonstrate high uncertainty in projecting future economic and environmental trends that makes planning to increase resilience and adaptability of farmers a difficult issue on both individual and national levels.

Demographic and social changes are no less important to the story of a changing landscape in Côte d’Ivoire than economic factors. Population data revealed that the number of people living in the study area decreased during the civil war from 2002 to 2004. After 2004, the population remained relatively stable inside the forest reserves and started increasing outside the reserves. Furthermore, the population was relatively small inside the protected forests compared to the unprotected zone of the study area. For example, in 2017 population density was approximately 6, 15, and 70 persons per square kilometer in the Mabi-Yaya, Songan-Tamin, and the unprotected zone respectively. This fact suggests that the population growth outside the reserves might be equally as important or in some cases have a more substantial impact on forest degradation than relatively stable small populations within the reserves.

Not all drivers act through a domain of a specific underlying force; for instance, the issue of land ownership stands at the intersection of economic, social, and policy changes. At the beginning of the 20th century, land in Côte d’Ivoire was regulated through the customary land ownership system for social rather than economic reasons, because land was abundant and therefore was not seen as an economically valuable resource. During the colonial period the traditional system underwent statutory tenure
transformation, however, uncertainty of land ownership rights remained an important issue even after the country gained its independence in 1960. The issue of land ownership in Côte d’Ivoire is a sensitive topic that relates property rights to migration patterns and ethno-cultural identity. When land was abundant, migrants supplied labor to fuel economic development of Côte d’Ivoire and contributed to gradual exploitation of its natural resources. When land became scarce, the issue of land ownership rights introduced policy interventions that shifted land decisions in favor of Ivorian citizens that drove ethnic tensions between native and nonnative farmers. This contributed to an eruption of civil war and further land and forest degradation at a national scale.

Some of the forces examined above might also be important in other places, but their combination in Côte d’Ivoire constitutes a unique geographic setting in which changes of the Mabi-Yaya-Songan-Tamin occurred. Several reasons determined the transformation of dense forest into degraded forest. They included expansion of agriculture, insecurity of land tenure, institutional instability, population growth in the area immediately surrounding the forest reserves, nutrient deficiency of tropical soils, migration patterns, global demands for agricultural commodities, fluctuations of the trade markets, energy insecurity, lack of compliance to environmental law, and the absence of large-scale technological innovations to improve yields. This list does not encompass all possible driving forces that contributed to the changes documented in this project, but it reveals many layers to the story of land cover changes in the Mabi-Yaya-Songan-Tamin.

6.3. Importance and Implications of the results

This thesis provides an addition to already existing scientific literature on tropical forest transformations and their drivers in the context of the rapidly changing global
environment. The results of this project are important, because they illustrate that the uncertainties of detecting land cover change patterns are numerous, as are the difficulties of establishing cause and effect. More importantly, the results reveal that the conservation strategies in Côte d’Ivoire were not implemented successfully in the study area. This story is not unique to the study area and to Côte d’Ivoire; it highlights the global necessity of integrating protected areas into the management of the surrounding landscape instead of attempting to isolate these areas. It is important to stress that the new approach should be oriented towards sustaining ecological integrity without compromising human rights to subsistence.

The hypothesis at the base of this thesis was that the establishment of protected areas has a positive effect on the conservation of natural resources. Although this may be applicable to some places, we can reject this hypothesis for the Mabi-Yaya-Songan-Tamin because the success of conservation objectives was not guaranteed by the legal decision to conserve land, but heavily depended on management strategies, enforcement of conservation policies, and practices of individuals. The second part of this hypothesis stated that human activity outside the protected areas compromises conservation objectives. The evidence of human presence inside and outside the forest reserves supports this statement, although the trajectories of anthropogenic land cover changes are not driven exclusively by decisions of individuals, because they were shaped by multiple underlying forces.

The investigation of the driving forces of land cover changes did not provide a sufficient explanation of contrasting landscapes in the Mabi-Yaya and the Songan-Tamin at the end of the study period. Although the Mabi-Yaya still had a significant amount of
forest, this study finds no evidence to suggest that it is more resilient to human pressure than the Songan-Tamin. Topographic data helped to reject the hypothesis that the area inside the Mabi-Yaya is less suitable for agriculture because of topographic variability. No differences were found in the management practices or enforcement of policies in these reserves. Settlements, as the most evident footprints of human presence, were found in both reserves, and the population data revealed that the number of people living in the Mabi-Yaya and the Songan-Tamin is similar. In fact, in 2000 the population density inside the Mabi-Yaya was slightly higher than in the Songan-Tamin, but after the civil war populations of the Mabi-Yaya declined more. The main implication of these results is that the landscape of the Mabi-Yaya might experience the same changes as already degraded forest reserve if current trend continues. This area, however, may recover in the future, because it was included inside the priority region of the Cocoa and Forest Initiative implemented by the government of Côte d’Ivoire and cocoa industry in 2018. These future changes remain to be seen.

6.4. Contribution of this research

This study contributes to geographic research centered on human-environment interactions and to assessing the success of Côte d’Ivoire’s contribution to manage and protect globally significant areas of tropical forest. Its core idea – sustainable management of natural resources – links this research to global projects that have the same objective. One such example is the Sustainable Development Goals developed by the United Nations. Although I specifically addressed Goal 15 “Life on Land”, these goals are interlinked and cannot be implemented in isolation. Moving towards goal 15
will also help with climate change mitigation (Goal 13), provision of clean water (Goal 6), and poverty and hunger elimination (Goals 1 and 2).

The findings provide a baseline to future conservation of the Mabi-Yaya-Songan-Tamin by illustrating its changes within a local context of the unprotected area and within a national and global contexts of driving forces that shaped the landscape in Côte d’Ivoire. This research gives an example of an exploratory approach that can be implemented to other studies focused on land cover change issues. Instead of separating the interpretation of land cover changes and assessment of drivers of those changes as two separate projects, I used multiple methods to show that these two aspects are the parts of the same story. By demonstrating that the current protection strategies are ineffective and that the drivers of land cover changes originate from the basic subsistence needs of local populations, from the disconnection between institutions and the public sector, and from large-scale patterns of global trade, I added the context that is often incomplete or absent in similar studies but critical to sufficiently understanding land cover changes and proper management of global protected areas.

6.5. Suggestions for further research

One of the strongest assets of geographic research is the opportunity to incorporate approaches developed by both natural and social sciences. Although remote sensing methods are a powerful tool used for land cover changes interpretation in the Mabi-Yaya-Songan-Tamin protected area complex, a field trip to the study area would add even more value to this project. A qualitative approach in a form of surveys, interviews, and focus groups would help to explore the ties of people to the land and forest resources in the study area. A direct observation would also help to evaluate the
quality of land cover maps produced in this project and to shed light on the agricultural and wood exploitation practices adopted by the locals and how they transform forest resources. This study can also be strengthened by interpreting spatial changes in land cover in other forest reserves of Côte d’Ivoire and comparing them to the changes of the Mabi-Yaya-Songan-Tamin protected area complex to map and assess spatial variability of land cover change patterns across the country.

To conclude, this research provided a local case in the context of national trends of anthropogenic transformation of tropical forests within the framework of larger geographic research centered on human-environment interactions. The questions triggered by this study go beyond the fundamental inquiry about the ways in which humans transformed the environment. This research was also concerned with the questions of how to leave natural landscape unchanged and why conservation attempts fail. The ultimate goal of geographic research focused upon human-environment interaction is a productive harmony between people and nature, but more work needs to be done to learn how to set aside protected zones effectively for the benefit of all life on Earth.


Lui Gillian V., and Coomes David A. 2016. Tropical nature reserves are losing their buffer zones, but leakage is not to blame. *Environmental Research* 147: 580–589.


Ministère des Eaux et Forêts. 2018. Politique nationale de préservation, de réhabilitation et d’extension des forêts. 24


Napton, Darrell. 2018. Lecture material in the course Research and Writing.


SEP REDD+ (Secrétariat Exécutif Permanent REDD+). 2017. Stratégie Nationale REDD+ de la Côte d’Ivoire.


Tappan, Gray. 2018. Personal communication.


