Dissertationes Forestales 142

Valuation of ecosystem services for assessment of cost of deforestation, and analysis of its drivers with implications for sustainable forest management in Ghana

Lawrence Damnyag

School of Forest Sciences
Faculty of Science and Forestry
University of Eastern Finland

Academic Dissertation

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Author: Lawrence Damnyag

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Thesis Supervisors:
Professor Olli Saastamoinen
School of Forest Sciences, University of Eastern Finland, Finland
Professor Ari Pappinen
School of Forest Sciences, University of Eastern Finland, Finland

Pre-examiners:
Professor Finn Helles
Faculty of Natural and Bio Science, University of Copenhagen, Denmark
Adjunct Professor Markku Simula
Ardot Oy, Finland

Opponent:
Professor Markku Kanninen
Viikki Tropical Resources Institute (VITRI), University of Helsinki, Finland

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ABSTRACT

The aim of this thesis was to estimate the cost of deforestation and to identify its drivers in the high forest zone of Ghana. The purpose was also to raise awareness about the severity of deforestation and to offer suggestions for its control with a view to contributing to climate change mitigation. To compute the cost of deforestation, the values of four ecosystems' services were estimated, employing opportunity and replacement cost techniques. The costs of wildfires resulting from loss of food and tree crops of communities were also estimated and deforestation-related behavior modeled using questionnaire surveys. Total Economic Values Framework, von Thunen and Chayanov models formed the theoretical basis of this work. The data were analyzed using descriptive statistics, multinomial and ordinal logistic regression techniques.

The results show that US$133,650,000 of gross revenue from the four ecosystems' services is lost annually due to deforestation (Article I). In the study area, the annual loss in food and tree crops per farmer due to wildfires was US$232 (Article II). Furthermore, farmers who acquired land on either lease holding or sharecropping basis were more likely to engage in short-rotation farming system, which leads to deforestation, compared to those who acquired land as gift or inheritance or on customary basis (Article III). In the studied protected area (Article IV), subsistence agriculture and large in-migration of people were the most important driving forces behind deforestation.

It can be concluded that better employing the indigenous knowledge of how to mitigate and adapt to wildfires would provide a sound basis for an improved wildfire management strategy. To obtain a more equitable distribution of forest benefits, the local policies need to be reformed with particular attention to the sharecrop and leasehold farmland holding systems. Forest revenue sharing systems, including potential payments from Reducing Emissions from Deforestation and Forest Degradation (REDD), must include farmland holders under these holding systems. To enhance Ankasa Conservation Area's contribution to climate change mitigation, priority must be given to livelihood improvement and ecosystem services provision in its management.

Key words: Ecosystem services value loss; deforestation drivers; wildfire mitigation strategies; deforestation control; climate change mitigation; Ankasa Conservation Area

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Joensuu, January, 2012

Lawrence Damnyag

LIST OF ORIGINAL ARTICLES

This thesis is based on the following articles, which will be referred to by their Roman numerals, I-IV in the text. The articles (I-III) were reprinted with the kind permission of the publishers. Article IV is the author's version of the submitted manuscript.

I **Damnyag, L.**, Tyynelä, T., Appiah, M., Saastamoinen, O., Pappinen, A., 2011. Economic cost of deforestation in semi-deciduous forests—a case of two forest districts in Ghana. Ecological Economics 70 (12): 2503-2510. doi:10.1016/j.ecolecon.2011.08.012

II Appiah, M., **Damnyag, L.**, Blay, D., Pappinen, A. 2010. Forest and agroecosystem fire management. Mitigation and Adaptation Strategies for Global Change 15 (6): 551–570. doi: 10.1007/s11027-010-9236-z

III **Damnyag, L**. Saastamoinen, O, Appiah, M., Pappinen, A. 2012. Role of tenure insecurity in deforestation in Ghana's high forest zone. Forest Policy and Economics 14 (1): 90-98. doi:10.1016/j.forpol.2011.08.006

IV **Damnyag, L.**, Saastamoinen, O., Blay, D., Dwomoh, F., Anglaaere, L. C. N., Pappinen, A. 2011. Sustaining protected areas: Identifying and controlling deforestation and forest degradation drivers in the Ankasa Conservation Area, Ghana. Manuscript

The author's contribution

Lawrence Damnyag, who is the main author of this thesis, developed the research ideas for the four articles (I-IV) based on the RIFLAG project (no.121907). Lawrence Damnyag performed the research design, data collection and analysis and wrote the manuscripts for articles I, III and IV. The co-authors contributed to the writing through comments for improvement and by responding to the reviewers' queries. Lawrence Damnyag designed the research, collected the data and participated in the data analysis and writing of Article II, which was written by Mark Appiah and the other co-authors.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ACA	Ankasa Conservation Area
ADB	Asian Development Bank
C&I	Criteria and Indicators
CBD	Convention on Biological Diversity
CIA	Central Intelligence Agency
CIFOR	Centre for International Forestry Research
DFD	Deforestation and Forest Degradation
DFV	Degraded Forest Value
ESA	Ecosystem Services Approach
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FCPF	Forest Carbon Partnership Facility
FLEGT	Forest Law Enforcement Governance and Trade
GDP	Gross Domestic Product
GEPA	Ghana Environmental Protection Agency
GHG	Greenhouse Gas
GLOBE	Global Legislators Organization
GTC	Gigatonne of Carbon
ha	hectare
HFZ	High Forest Zone
IPCC	Intergovernmental Panel on Climate Change
ITTO	International Tropical Timber Organisation
IUCN	The World Conservation Union
m	meter
M^3	Cubic meter
MA	Millennium Ecosystem Assessment
MoFA	Ministry of Food and Agriculture
MWTP	Maximum Willingness to Pay
NA	Northern Ankasa
NFV	Natural Forest Value
NGOs	Nongovernmental Organizations
POM	Proportional Odd Model
PRP	Prince's Rainforest Project
REDD	Reducing Emission from Deforestation and Forest Degradation
SA	Southern Ankasa
SCBB	Secretariat of the Convention on Biological Diversity
tCO_2	Tonne of Carbon Dioxide
tCO_2e	Tonne of Carbon Dioxide Equivalent
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEF	United Nations Forum on Forests
UNFCCC	United Nations Framework Convention on Climate Change
UNFP	United Nations Environmental Programme

USA	United States of America
VPA	Voluntary Partnership Agreement
WA	Western Ankasa
WWF	Worldwide Fund for Nature

1. TROPICAL DEFORESTATION AS A MULTILEVEL PHENOMENON

1.1 Deforestation as a global issue

Tropical deforestation and forest degradation (DFD) has been on the agenda of international forest policy efforts for over four decades (Westoby, 1989; Palo, 2000; Humphrey, 2006; Olander et al., 2009; Saastamoinen, 2009) but, in particular, since 1992, when the UNCED drew up Agenda 21. During the past two decades, the focus has been increasingly directed toward the prevention of DFD and to the conservation of biodiversity. Most recently, DFD has again become a global concern largely due to its important role in global warming (Kanninen et al., 2007; Douglas and Simula, 2010). According to Houghton (2006), approximately 80% of the carbon emitted into the atmosphere from 1850-2000 came from the forests, while 18% came from land-use changes in the 1990s. Decreasing the atmospheric carbon emissions by controlling deforestation is widely considered to be a relatively low-cost and effective option for climate change mitigation (DeFries et al., 2010). Because of this potential, controlling DFD has become an essential component of the international climate change mitigation strategies. Tropical DFD contributes 20-25% of the annual global anthropogenic greenhouse gas (GHG) emissions (Grieg-Gran, 2006), and in many developing countries, it is the main source of emissions (Karousakis, 2006). As a result, the efforts aimed at the sustainable management of forests and at climate change mitigation are largely focused on controlling the tropical DFD. To this effect, national, regional and international initiatives on tropical and other forests are being created and the existing initiatives strengthened. Dam and Savenije (2011) identified 127 initiatives in total, classifying them into intergovernmental, national, private, NGOs and knowledge and capacity building initiatives.

Aside from mitigating climate change, tropical forests continue to be important not only for their unique hardwoods and non-wood forest products but also for protecting the most precious parts of the world’s biodiversity and other ecosystem services (ITTO, 2008; Laurence, 1999). However, these benefits are under threat because of the high level of deforestation occurring in these areas. According to Engel and Palmer (2008), tropical DFD has increased dramatically; it occurred at an average rate of 13 million hectares per year between 1990 and 2000 (FAO, 2006; 2010a). The causes of the continuing tropical forest losses are many and varied (Kaimowitz and Angelsen, 1998; Geist and Lambin, 2002). However, whether related to CO_2 emissions reduction policy, understanding these causes is important for the design of an effective policy to minimize their effects (Pearce, 2001; Boucher et al., 2011). More specifically, the identification of the underlying market and policy failures and an understanding of their relationship with the activities inside and outside of the forest sector is imperative (Engel and Palmer, 2008). This understanding is all the more important because the international, governmental and non-governmental efforts to minimize tropical deforestation and degradation, either through forest policy or through policies created in other sectors, have not been very successful due to inadequate funding, weak or uncommitted national institutions, internal conflicts, agenda-splitting, and fragmentation in the international efforts, to name a few reasons (Palo, 2000; Bulte and Engel, 2006; Humphrey, 2006; Karousakis, 2006; PRP, 2009; Saastamoinen, 2009; Douglas and Simula, 2010).

The policies and programs aiming at sustainable forest management are many and operate at global, regional, national and sub national levels (Palo, 2000; Humphrey, 2006; Saastamoinen, 2009; Pfaff et al. 2010; Rayner et al. 2010). Those policies and programs that target tropical deforestation and forest degradation are important in this study. While some have been launched earlier, e.g., the Convention on Biological Diversity (CBD), the International Tropical Timber Organization (ITTO), the United Nations Environmental Programme (UNEP), and the United Nations Forum on Forest (UNFF), new ones are also being created, e.g., the Global Legislators Organization (GLOBE) International Forestry Initiative, which aims to support the ongoing inter-governmental processes to reduce deforestation (Rayner et al. 2010; CIFOR, 2011; GLOBE International, 2011).

Among the climate policy-related initiatives are the Kyoto compliant initiatives of the United Nations Framework Convention on Climate Change (UNFCCC); the World Bank's Forest Carbon Partnership Facility (FCPF); the United Nations Collaborative Programme on Reducing Emission from Deforestation and Forest Degradation in developing countries (REDD+); The Prince's Rainforest Project (PRP); and the bilateral donors/non-Kyoto compliant (Voluntary Carbon Market) initiatives. The policies that are related to the illegal timber trade are the amended United States of America (USA) Lacey Act and the European Union (EU) Forest Law Enforcement Governance and Trade (FLEGT) action plan, which includes Voluntary Partnership Agreements (VPA) (Gulbrandsen and Humphrey 2006; FAO/UNDP/UNEP, 2008; Jindal et al. 2008; Madeira, 2008; Angelsen et al. 2009; Prince's Rainforest Project, 2009; Douglas and Simula, 2010; Lederer, 2011). In all of these initiatives and programs, including the C&I processes such as the national forest programs and forest certification schemes (Rayner et al. 2010), the control of tropical DFD holds center stage. However, the programs' effectiveness depends on the extent to which they address the drivers of tropical forest loss (DeFries et al. 2010).

1.2 Deforestation and forest degradation in Africa

The total forest area in Africa was estimated at 709 million ha in 2000 (FAO, 2010a). This area is largely located in the tropical ecological zone, and it is approximately one quarter of all of the rainforests in the tropics (FAO, 2001). In 2010, Africa's forest area was estimated to be 674 million ha (17 percent of the world's total), with the largest section of 328 million ha in Western and Central Africa (FAO, 2010a). Africa has the second highest deforestation rate in the world. From 1990-2000, the loss in forest area was 5.3 million ha annually, corresponding to an annual rate of 0.8% (FAO, 2001). From 2000-2010, the forest area loss was 3.4 million hectares annually, again corresponding to an annual deforestation rate of 0.5% (FAO, 2010a). The individual countries in Africa with the highest forest loss are Nigeria and Tanzania, with an annual forest area loss of 0.410 million and 0.403 million ha, respectively, for 2000-2010 (FAO, 2010a).

Deforestation plays an important role in the climate system because forests act as a major reservoir for carbon. Although global warming is often attributed to the burning of oil and gas, mostly in the developed countries (Kim, 2010), the contribution from deforestation in developing countries is also significant because it produces 1.6 billion tonnes of GHG into the atmosphere each year (Baumert et al. 2005; FAO, 2006). Partly as a result, climate change is imminent in Africa (EU, 2009). During the 21st Century, all of Africa is likely to become warmer, and the warming is likely to be higher than the global annual mean throughout the continent, with the drier subtropical regions warming up more than the more humid tropics (Christensen et al., 2007). In West Africa, for instance, the annual mean temperature is projected to increase by approximately 2.0 to 6.0^0 C from the present level (IPCC, 2007), while the mean annual precipitation is expected to decrease by 6-20% by 2025. As a result, the total loss in agricultural productivity is expected to increase to 2-4% of the national GDP (Nkem, 2007). Climate change is envisaged to bring about several other impacts, particularly on agriculture. These impacts on agriculture are expected to be accompanied by the increased use of nitrogen, minerals and pesticides, which is likely to lead to the leaching of these substances (Nkem, 2007).

1.3 Deforestation and forest degradation in Ghana

Not only is the basis for the estimates of deforestation rates in Ghana unclear, the rate is characterized by rapid changes so that the precise figures for the deforestation rates and for the actual size of the forest cover are difficult to determine (Leach and Fairhead, 2000; Benhin and Barbier, 2004; Hansen et al. 2009; FCPF, 2010). Despite this difficulty, many studies assert that at the beginning of the twentieth century, approximately one-third (i.e., 8.6 million hectares) of Ghana's land area was covered by tropical high forest (forest land inside reserves that are under protection and other forests outside the reserves (off-reserves)), while the remaining two-thirds (15.7 million hectares) was savanna woodland (Fairhead and Leach, 1998: Leach and Fairhead, 2000; Abeberese, 2002). According to Owusu (1998) and Abeberese (2002), deforestation was particularly rapid during 1950-1987, resulting in approximately a 75 percent loss of the original forest area. At the end of 1987, the estimate for the deforestation in the entire country was 65,000 ha per year, while that of the high forest zone was 22,000 ha per year (Abeberese, 2002). A recent estimate of Ghana's deforestation rate (using the FAO definition of 10% canopy cover, including plantations) is 135,395 ha per year, which results in a decrease in the forest cover (reserve and outside reserve forests in the high forest zone) from 7.5 million hectares in 1990 to 4.9 million hectares in 2010 (FAO, 2010b).

This rapid loss in the forest cover appears to be impacting the climate system. Ghana is already experiencing an increase in extreme weather conditions, with more frequent incidences and longer periods of drought, flooding, reduced food production and lowering of water levels, particularly in the Volta river delta, which provides approximately 80% of the national electricity supply (MoFA, 2007; World Bank, 2010; Cameron, 2011). The annual mean temperatures in the country have already warmed up by 1^0 C over the past 30 years (Cameron, 2011). The mean annual temperature in Ghana is projected to increase in the range of 0.6^0 C to 3.9^0 C between 2020 and 2080, while rainfall will decrease between 2.8% and 18.6% in the same period (GEPA, 2007). These warming and drying predictions are expected to increase the droughts that are already being experienced in the country (Antwi-Agyei et al., 2011). On the basis of these warning signs, severe economic consequences from climate change are predicted for the near future in Ghana (World Bank, 2010). Related to the impacts on forest ecosystems arising from climate change, the main concerns in Ghana are severe impacts on land use, biodiversity and soil fertility loss, increased deforestation and land degradation (Bamfo, 2008a; Cameron, 2011).

To address these problems, various measures, including policy and legislative reforms, capacity building, awareness creation, the establishment of a law enforcement unit to address illegal chainsaw lumber production and conventional logging activities, the implementation of a stricter wood procurement policy, consultation with stakeholders in resource management and the restoration of degraded forest lands are being pursued in Ghana (Bamfo, 2009; Hansen et al. 2009; Abbey, 2011). However, the desired results are yet to be achieved. With the emerging science and policy of Reducing Emissions from Deforestation and Forest Degradation (REDD), which Ghana is also embarking on, large capacity-building, institutional restructuring, and governance reforms will be required (Hoare et al. 2008; Pedroni et al. 2009; Douglas and Simula, 2010). A better understanding of the drivers and the costs of deforestation is also required, particularly at the forest/farm levels. With this understanding, a bottom-up approach to climate change mitigation could be tackled, instead of the top-down approach that appears to have been adopted (Guartey, 2010). This type of understanding is urgently needed to enable the needed reforms to be realized and to help in the control of deforestation. While these more localized factors and this scientific information can be important inputs for deforestation control and climate change mitigation, they are limited in scope and are not adequately tailored to provide the information required for the successful implementation of the REDD + strategies in Ghana. This study is an attempt to fill part of this knowledge gap with the scientific information that is needed to support the REDD + and other initiatives (e.g., EU VPA). To this effect, this study focuses on the economic aspects of deforestation and forest degradation (DFD) in Ghana, using information at the forest/farm level to complement the efforts in these initiatives towards the sustainable management of forests and climate change mitigation. However, before this analysis can be performed, a survey on the drivers of deforestation is needed.

1.4 Factors and drivers influencing deforestation

According to numerous studies over several decades, including Westoby, (1989), Mather, (1992), Palo and Mery, (1996) and more recently, Humphrey (2006), Parker et al., (2008) and Douglas and Simula, (2010), the reasons and forces driving deforestation are complex and overlapping, but they are basically related to competition for land and resources. These drivers vary from country to country and even within countries (FAO/UNDP/UNEP, 2008). In the tropics, Kaimowitz and Angelsen (1998) and Geist and Lambin, (2002) have classified the causes of forest loss into proximate and underlying causes. The proximate causes that impact directly on the forests are agricultural expansion, infrastructure, wood extraction, grazing, mining and fuel wood collection, among others. The underlying causes in general terms include demographic trends, economic decisions, technological change, and policy and cultural factors (Geist and Lambin, 2002). Large-scale globalized agriculture drives deforestation in Asia and Latin America (Parker et al., 2008; Defries et al 2010). Although not yet an important issue, the increased demand for forest products, which drives deforestation in other regions, is feared to raise the rate of deforestation in the African countries that have large areas of forest but low deforestation rates (Boucher et al. 2011). The reason for this concern is the expansion of the Asian timber companies already into Congo (Rudel et al. 2009).

In Africa, unlike in Asia and Latin America, small-scale production of food and cash crops drives deforestation. The conversion of natural forests into agricultural lands, charcoal production, logging and timber production, fuel wood consumption, forest fires and human settlement have been identified as the direct causes of deforestation, while governance-related factors (corruption), poverty, inadequate participation and capacity, and inappropriate technologies are among the underlying causes (Verolme et al. 1999; Hofstad et al. 2009; Prince’s Rainforest Project, 2009). In Ghana, the direct causes of forest loss are the clearing of forests for cocoa and food crop farming, fuel wood harvesting, wildfires, infrastructure expansion, and logging (both legal and illegal). The underlying causes are a high international demand for timber, cocoa and minerals, poverty, corruption, the overcapacity of the forest industry, low forest fees, the low enforcement of forestry rules, a high population growth and urbanization and land and tree tenure issues, to mention a few (Palo and Yirdaw, 1996; Owusu, 1998; Abeberese, 2002; Benhin and Barbier, 2004 Appiah et al. 2009; Hansen et al. 2009).

1.5 Valuing forest ecosystem goods and services

The tropical forest ecosystem provides a range of goods and services, including provisions (e.g., foods and fibers), regulation (i.e., air, climate, water provision and purification), cultural (recreation and tourism), and support (nutrient and water cycling) services (Nasi et al. 2002; Prince’s Rainforest Project, 2009; Verweij et al., 2009). In the Amazon forests, the estimated benefit of the forests from erosion prevention, fire protection, carbon storage, and the pollination of coffee plantations is 238, 6, 70-100, and 49US$/ha/year, respectively (Verweij et al., 2009). However, because these goods and services do not have markets, they do not bear the kind of price tag that could alert society to a change in their supply (Verweij et al. 2009).

In sub-Saharan Africa, the value of these ecosystem services to the local livelihoods is not fully captured in the national development plans (Nkem et al. 2007). As a result, these services are being destroyed by a variety of human activities. For instance, in spite of the global decline in deforestation following the FAO’s (2007) global forest assessment, there was an increase in deforestation in Africa. This increase accounted for over 50% of the global damage to forests due to wildfires (FAO, 2007). According to Tacconi (2003), forest fires alone in Indonesia caused a total economic loss of USD 9.1 billion in 1997-1998, which included losses in plantations and agricultural areas. In Ghana, the annual revenue loss of merchantable timber alone due to wildfires was $24 million (ITTO, 2003).

According to the Prince’s Rainforest Project (2009), this destruction of ecosystem services occurs because of the financial interests of individuals, industries, local communities and governments, driven largely by international commodity demand. Reversing this trend of deforestation would require equally strong financial rewards to motivate countries to choose alternative, low deforestation paths of development. By implication, to reverse this deforestation trend, it is necessary to value and to pay for these ecosystem goods and services from the tropical forests of the world (Prince’s Rainforest Project, 2009). Valuing these goods and services in terms of their value loss (opportunity cost) to enable Guyana to switch to an alternative development path instead, the national estimates of the Government of Guyana provided values of between US$430 million and US$2.3billion per year (Prince’s Rainforest Project, 2008). Osafo’s (2005) estimates of the value of the ecosystem services for avoiding deforestation in agroforestry lands (small-scale maize and cassava agroforestry farms) and forest land (timber harvesting) is US$1776/ha (as Net Present Values at a 15% discount rate) in Ghana. However, the accuracy and the usefulness of these estimates depends largely on the assumptions that are made about the returns of the different types of agricultural activities, the patterns of land use in deforested areas, and the clear identification and costing of the amount required to tackle the drivers of deforestation (Hoare et al., 2008). The existing payments for ecosystem goods and services schemes in Central and South America could provide a useful guide to costing and administering a scheme to control deforestation (Grieg-Gran, 2006; 2008; Hoare et al., 2008).

As mentioned, the tropical forest plays a significant role in climate change mitigation, acting as a carbon sink and removing carbon from the atmosphere. For instance, FAO's (2007) estimates show that the total carbon mitigation from avoided deforestation in Africa during 2003–2012 could be 615.8 million tCO_2. In addition to this carbon mitigation benefit, the Prince's Rainforest Project (2009) estimates show that global emissions could be reduced to 5Gt of GHG per year through a significant reduction in tropical deforestation. According to Robledo et al. (2008), the climate change mitigation potential of forests could be further enhanced through afforestation and reforestation, biofuel plantations and substitution through wood products, forest management improvement, emissions reduction from deforestation, and forest degradation and forest restoration. However, deforestation appears to be revising this process of climate change mitigation by emitting carbon back into the atmosphere (Madeira, 2008).

1.6 Study aims and objectives

The aim of this study was to estimate the values of the forest ecosystem services to assess the cost of deforestation in the high forest zone of Ghana. The purpose was also to raise awareness about the severity of deforestation and to offer suggestions for its control with a view to contributing to climate change mitigation and other ecosystem benefits. To estimate the cost of deforestation, the values of the forest ecosystem goods and services lost due to DFD were estimated. A theoretical framework of deforestation was constructed and deforestation-related behavior was modeled to identify the important drivers/causal factors and to help to clarify the positioning of the separate studies in the effective control of DFD. The choice of this approach is motivated by the failure of society to account for the range of benefits that forests provide and to integrate these benefits into the measures of deforestation control. The specific objectives of this study were as follows:

i) To estimate the economic cost of deforestation (lost value of ecosystem services) and consequently the benefits of restoring degraded forest lands (Article I).
ii) To estimate the cost, identify the causes, and analyze the mitigation and adaption strategies for wildfires in the forest fringe communities to support effective control (Article II)
iii) To investigate the effects of land and tree tenure on deforestation in Ghana's high forest zone (Article III)
iv) To identify and control the drivers of deforestation and forest degradation in and around conservation areas (Article IV)

The reasons behind the selection of these specific objectives were the need to influence policy design based on adequate information on DFD consequences, the importance of tenure on DFD as identified in earlier studies, the importance of wildfires in the Ghanaian context and the problem of DFD in and around of conservation areas for the design of mitigation measures. It is assumed that researching and communicating the obtained results in these areas would support the efforts to address deforestation, to enable the forests in Ghana to contribute more to climate change mitigation and to enable the transition to sustainable forest management. The study hypothesizes that estimating the cost of deforestation and identifying the drivers of forest cover loss would raise awareness that could prompt the relevant stakeholders to take the desired actions for deforestation control.

The structure of the remainder of the study is as follows. Chapter 2 describes the theoretical framework and provides a schematic presentation of how the four articles are related to that frame. Chapter 3 presents the materials and methods, and chapter 4 presents the results of each article. Chapter 5 discusses the results, and chapter 6 contains the conclusion of the study.

2. THEORETICAL FRAMEWORK

2.1 A general framework of deforestation

The theoretical frame for this study is rooted in the theories of deforestation and, in particular, in the microeconomic theory of deforestation (Sills and Pattanayak, 2004), supported by von Thunen and Chayanov's theories and the Total Economic Value (TEV) framework (Pearce 2001; MA, 2005; Saastamoinen, 1997). The general framework is presented in Figure 1 (loops not included). The precise channels through which the causes bring about deforestation and the importance of each of the causes are quite complicated and not fully resolved in the literature (van Kooten and Folmer, 2004, p.439; Amacher et al. 2009, p.152). However, it is clear that as indicated in the theoretical framework (Fig.1), the causes of tropical deforestation can be classified into underlying, direct and agents (Kaimowitz and Angelsen, 1998; Geist and Lambin, 2002), even though some disagreements still exist regarding the direct and the agents, who are the final causers of the DFD.

The underlying causes arise as a result of national factors, including public policies and the political will (or lack thereof) of the government to take measures to control deforestation (Palo, 2000, p.13). The other causes are international factors and politics, including the demand for tropical forest goods and services. These underlying factors do not cause deforestation directly, but work through the direct or proximate causes of deforestation. According to van Kooten and Folmer (2004), building road infrastructure into the remote forest areas does not cause deforestation, but rather it is the final purpose for which the road is used by the agents of deforestation that causes the deforestation. The road, in this case, is the proximate or direct cause. Even among the deforestation agents, certain characteristics or parameters related to the proximate causes must prevail for the agents to bring about deforestation. In Figure 1, at the farm level, these parameters are the availability of off-farm employment, lower transportation costs, increased agricultural output prices and productivity. These factors could lead the agents to lower deforestation, while agricultural practices (e.g. slash and burn), population pressure and in-migration will lead to higher deforestation. The direction of causality for the other factors is mixed, e.g., increases in agricultural input costs (Kaimowitz and Angelsen, 1998, p.93). Better market access also has mixed effects on the forest, resulting in higher farm gate prices of agriculture and forest products and in higher demand. Increased demand for these products raises the incentives for long term management and, at the same time, heightens short-term exploitation, leading to deforestation (Argrawal and Angelsen, 2009).

The underlying causes are the reasons for government inefficiencies that have an adverse impact on income and revenues from the use of forest resources (goods and services of forests) and therefore, also, on economic growth. Many of these inefficiencies or specified government failures are closely related to the underlying causes and could even be named as a second level underlying cause. However, it is not always possible to draw a clear borderline between these and the direct or proximate causes of deforestation or between the latter and the underlying causes. The complexity of causes, their interchangeability and their context specificity is emphasized by Douglas and Simula (2010), among others. For example, tenure arrangements can be seen as an underlying cause rather than a proximate cause specified by the given conditions. Additionally, as mentioned above, this framework (Fig. 1) is simplified regarding the numerous feedback loops between the different boxes (such as the impacts of proximate causes on economic growth) because of a focus on the major causalities.

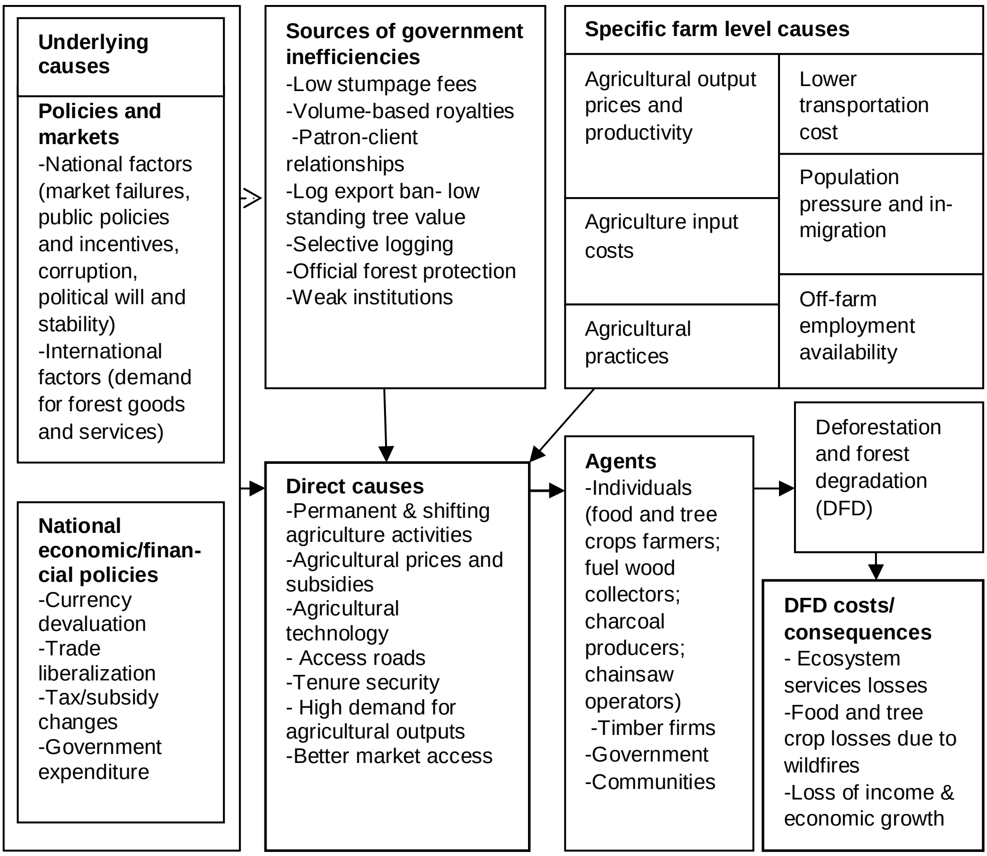

Figure **1:** Theoretical framework of deforestation as applied to Africa/Ghana

2.2 Microeconomic theories of deforestation

A number of analytical (Fig. 1), empirical and simulation models for analyzing and understanding tropical deforestation have been developed (Kaimowitz and Angelsen, 1998). While analytical models make use of the theoretical constructions of the interrelationships between the factors involved in deforestation, the simulation models use observed parameter values that are substituted in a theoretical model to analyze the outcomes of different scenarios. For the empirical models, statistical techniques are used to deduce the theoretical relationships between the factors from a large number of data sets (Gray, 2010). As Gray (2010) indicates, these models can further be classified into micro- and macroeconomic models. The former models address deforestation at the farm/forest level, as is done here (Article III, IV), while the latter analyze the aggregate data at a regional, national or global level. Another classification of these models divides them into time-series models (exploring trends in forest cover area over time), and cross-sectional models (addressing forest loss at a given point in time) (Gray, 2010).

As shown earlier in chapter 2.1, there are many forms of deforestation. As such, the choice of approach for analyzing the causes of deforestation or for predicting their extent depends on the location and the specific case that is being modeled (Gray, 2010). Each of these groups of models has its strengths and weaknesses. However, whichever case is under consideration, the microeconomic theory underlying all of these models in their explanation for the deforestation phenomenon pertains to the net benefits derived from the alternative uses of forest lands (Sills and Pattanayak, 2004). In the tropical high forest zone of Ghana, the alternative land uses are mostly agricultural, involving cocoa and food crop farming, engaged in by indigenous and migrant farmers. In clearing the forest lands for these farming activities, the farmers incur costs and benefits. The farmers also earn future streams of net benefits by engaging in these farming activities. Summing the discounted benefit minus the costs yields the marginal net benefit from these activities. These benefits decrease over time as more forest land is cleared (Sills and Pattanayak, 2004). However, the initial marginal net benefits of the uncultivated forest land in relation to the farming activities are almost zero but increase with the scarcity of forest land as more and more land is cleared for cocoa and food crop production (Sills and Pattanayak, 2004).

Forest clearing continues to an optimal point (from the farmer's perspective) where the marginal net benefits from these farming activities are equal to the marginal net benefits of maintaining the forest (Sills and Pattanayak, 2004, p.4). This optimal benefit/gain (i.e., the marginal net benefit from farming and forests) explains the deforestation of forest lands by individuals and farmers at the forest and farm level. The factors that determine these marginal net benefits of farming and forests provide the reasons for deforestation (Sills and Pattanayak, 2004) (Fig. 1). The von Thunen and Chaynov theories offer an explanation for the deforestation decisions of the agents at the forest and farm level (Angelsen et al. 2009; Sills and Pattanayak, 2004). In the von Thunen model, the distance of a given land to the market centers and cities is hypothesized to affect the agent's choice to deforest or not (Fig 2) (van Kooten and Folmer, 2004). The model is based on the assumption that there is a homogenous piece of land available that is fixed in supply and that it can be used for agriculture and forestry.

The allocation of land to each of these uses is based on the use option that yields the higher profit or rent (r). Allocating a fixed 1 ha of land for agriculture to produce output (q), the model assumes that labor (L) and capital (K) are combined with the land to produce output for sale at a given price (p). The transport cost (t) incurred depends on the distance (d) of the land away from the market center. The L and K prices are the wages (w) and the interest (i). On the basis of these assumptions, the farmer's rent is expressed as follows (Angelsen, 2007; Mkwara and Marsh, 2009):

$$r = pq\text{-}wL\text{-}iK\text{-}td. \qquad \{1\}$$

From this equation, the rent of the farmer declines the further the land is from the market center. Given the case that the land is so remote that the agricultural option for the use of land is not profitable with r = 0, then (Angelsen, 2007)

$$d = (pd\text{-}wL\text{-}iK)/t. \qquad \{2\}$$

From these derivations, the information that will encourage the agent at the farm/forest level to deforest are a higher output price (p), technologies that increase yield(q), a reduction in the input cost (w), a lower cost of K (i), access (lower transport cost (t)), and improved roads (Angelsen et al. 2009) (Fig. 1).

Another microeconomic theory of deforestation is originally Chayanov's theory about the peasant economy in Russia in the 1920's, which explains agricultural production as distinct from commercial production. It is a peasant farm theory that is based on rural family labor, inheritance problems and some related solutions (Thilakarathne and Yanagita, 1996). The theory assumes that the peasant household unit produces food to satisfy its consumption needs relying solely on family labor without resorting to outside wage labor. However, it does not exclude resorting to outside labor during peak harvesting season (Thilakarathne and Yanagita, 1996). The maximum amount of effort to be exerted on the land by the workers in the family unit to produce revolves around the family size, the consumer-worker ratio and the land ownership. In this way, the area cultivated varies directly according to family size. All of these (i.e. family size, consumer-worker ratio and land ownership) determine the increase/decrease of the family unit's labor effort in response to unfavorable/favorable market prices (Chayanov, 1966; Thilakarathne and Yanagita, 1996) (Fig. 1). Although the arguments in the theory are inconsistent with profit maximization in a capitalist enterprise, they are similar to the views of a peasant farmer's behavior expressed by a school of thought in economic anthropology (Dalton, 1961). Although Chayanov's theory is about a peasant economy, it appears to fit the modern rural economy of Ghana, particularly in the High Forest Zone of Ghana where the present study was conducted.

As described in Chayanov's theory, the rural household units in the HFZ are organized around simple farms, extended families, migrant and settler farmers, landowners, sharecroppers and leasehold farmland holders. Most of these household units are engaged in subsistence farming to meet their family consumption requirements. Coupled with the already challenging land tenure practices, particularly for the tenant farmers in this HFZ, these issues (household dynamics, land tenure, etc.) have a significant influence on land use and, consequently, deforestation in the HFZ (Brooks et al., 2009). As already seen in the context of Chayanov's theory, studies have called attention to the relevance of family labor, to the impact of dependency, and to links between a household's demographic life cycle and deforestation (Caldas et al., 2007). The land holding issues identified theoretically in these models inform the choice of variables included in the regression models of the present study in the analysis of the drivers of deforestation (Articles II, III and IV); see also Figure 3 later on.

2.3 An assessment of the values of forest ecosystem services and deforestation costs

Forest ecosystem goods and services are the economic benefits that people derive from nature (MA, 2005a; Ranganathan et al. 2008). As a link between the forest ecosystem (plant, animal and micro-organism communities interacting with each other and their physical environment (CBD, 1993; MA, 2005d)) and human welfare, the forest ecosystem services are defined as flows of benefits to human societies (MA, 2005d; TEEB, 2010). For the purposes of economic valuation or accounting, the ecosystem services are defined as those portions of ecosystem goods and services that are used actively or inactively to produce human well-being (Fisher et al., 2008). The services include goods and services in the agricultural and modified forest ecosystems.

To assess the ecosystem goods and services, several theoretical frameworks exist, such as the concept of the multiple use of forests (Gregory 1955; Saastamoinen, 1982), environmental economic valuation (Freeman, 2003), and the Total Economic Value of forest (Pearce et al. 2006, p.88; Saastamoinen, 1997). However, there is a growing interest in the use of the Ecosystem Services Approach (ESA) (Ranganathan et al. 2008; TEEB, 2010). ESA is a framework by which ecosystem goods and services are incorporated into the private and public decision-making processes. The guidelines for categorization and methods are provided for the economic assessment of these goods and services. For instance, MA's (2005a) four broad categories for the ecosystem services are provisioning, regulating, cultural and supporting services (Fig. 2). Five steps are outlined to guide the assessment (i.e., identify the ecosystem services in question, screen them for relevance, assess the condition and trends of the relevant services, assess the value of the services, and identify the risks and opportunities of these services) (MA, 2005a; Ranganathan et al., 2008). The important issues considered in the assessments are the methods and techniques to assess the ecosystem services (Pagiola et al., 2004; MA, 2005c) and the development of the indicators to assess the quantity and quality of the services (MA, 2005b). For the latter, expert and stakeholder consultation is recommended for the identification of relevant, understandable and measurable indicators (Ranganathan et al. 2008).

Economic valuation in the context of ESA means assigning the quantitative economic values to those ecosystem services that do not have market prices. Economic valuation thus provides a way to compare the costs and benefits associated with the forest ecosystem. The valuation is performed by measuring the costs and benefits of the ecosystem goods and services and expressing them with a common denominator (Pagiola et al., 2004). Although the process is optional for reaching the decision maker's goal in the ecosystem services assessment, the economic valuation has a number of useful purposes. The valuation could be used to evaluate the forest ecosystem services as opportunity costs associated with forest land conversion to alternative uses. The values of the ecosystem services are evaluated using various economic valuation methods (MA, 2005b; TEEB, 2010). These values are classified into direct use, indirect use and non-use values and combined to make up the total economic value (Fig. 2). The total economic value (TEV) is hinged on utilitarian value theory and built on the assumption that individuals derive utility from the consumption of marketed goods and ecosystem services (Richardson, 2010). In microeconomics, indifference curves are used to represent the set of combinations of these goods and services that maximize the utility of the individual (Richardson, 2010). The maximization of the utility subject to the budget constraint of the individual under neoclassical economic theory yields the demand curve for these marketed goods and ecosystem services (Richardson, 2010). The individual demand curve is expressed by his or her marginal willingness to pay (MWTP) or marginal willingness to accept compensation (MWTA) for incremental amounts of these goods and services (Pearce et al., 2006, p.158; Fisher et al., 2008).

Economic valuation is usually seen as a way to support the health of the forest ecosystem because the value estimates of the ecosystem services provide reasons to conserve the forest (Pearce, 2001). The economic valuation techniques and the other means available are needed for sustainable management and the conservation of forest. These techniques demonstrate that forest loss does not only affect the utility that the individual directly derives but also the overall well-being of the individuals due to potential damage to the goods and services that the individuals indirectly depend on. However, with the use of TEV, only the lower-bound estimates of the ecosystems' service values are generally

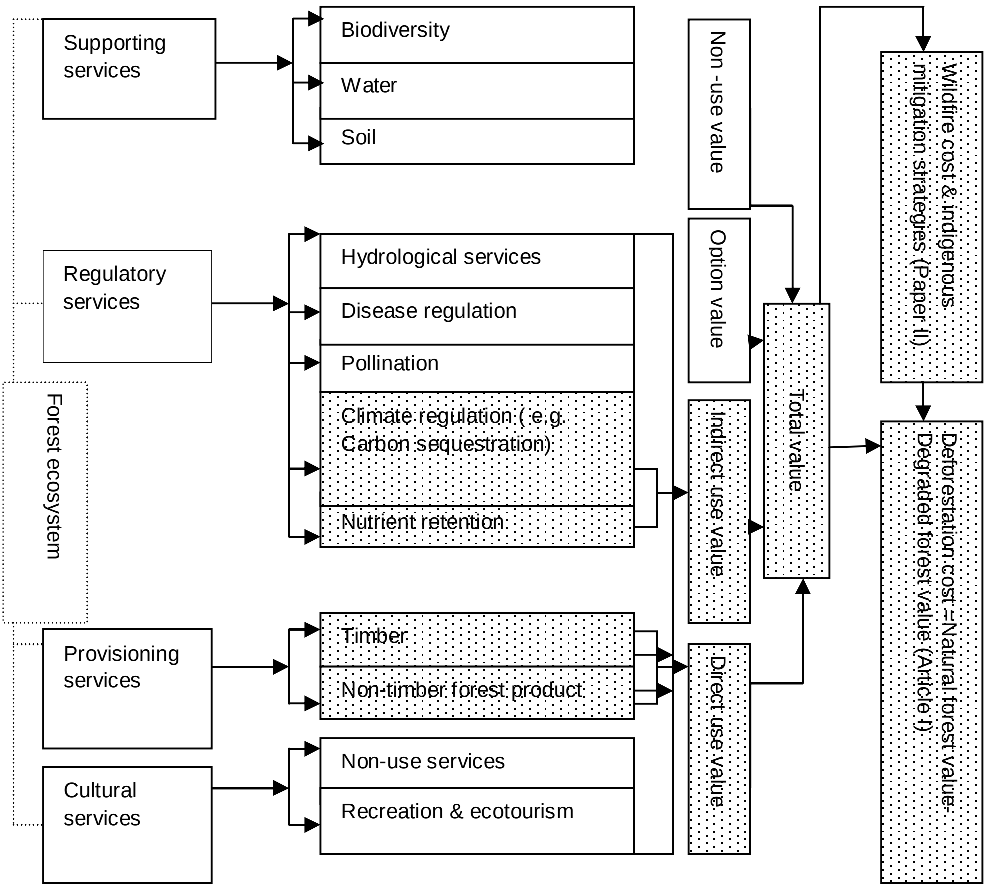

Figure **2**: Framework for the valuation of ecosystem services (as an opportunity cost of deforestation) and estimates of farmers' food and tree crop losses due to wildfire (Article I, II) produced, as it is virtually impossible to reliably assign values to all of the components of the TEV (Pearce et al, 2006, p. 174; Fisher et al., 2008; TEEB, 2010). Furthermore, these value estimates are often associated with inaccuracies and uncertainties because of insufficient knowledge regarding the complex ecosystem processes (Ranganathan et al. 2008; Richardson, 2010).

The costs of deforestation (Article I) were estimated by valuing the ecosystem goods and services in degraded, plantation and natural forests (Fig. 2, also Fig. 1). The ecosystem goods and services that were valued are those in the darker boxes indicated by arrows connecting to the total value. Those services in the lighter boxes without arrows were not valued, although they do form a part of the total economic value of the forest ecosystem. Not all ecosystem services in the boxes were valued because it is impossible to estimate the values of all of the ecosystem services in the forest due to data constraints and the lack of knowledge regarding some of these services. For the same reasons, the estimates for the economic losses/costs associated with forest fires (Article II) were made based on food and tree (timber, non-timber forest products) crops on farm lands (Fig. 2).

2.4 The impacts of uncontrolled forest fires on the forest ecosystem

The direct and underlying causes of uncontrolled forest fires on forest ecosystems and the human beings living near these systems have been identified. The direct anthropogenic causes in the tropics include land clearing with fire, fire used as weapon in land-tenure and land-use disputes, accidental fires and fires for resource extraction (SCBD, 2001; Suyanto, 2006). The underlying causes include inadequate forest management and facilities to prevent and suppress accidental or escaped fires in plantations and natural forest and financial incentives or disincentives created through the increased profitability of alternative land use, among others. These causes have a significant negative impact on the forest ecosystem, including its biodiversity (SCBD, 2001).

The socioeconomic impacts of the forest fires have been of equal concern, but estimating the economic losses to society associated with these impacts is difficult because of the numerous ecosystem services involved. However, some conservative estimates on the tropics exist (ADB, 1999; de Mendonca et al. 2004). Very relevant to the present study (Article II) (Fig. 2 and 3) is the estimate of the economic losses associated with forest fires for the local communities because of their dependence on the forest for its numerous goods and services (Nepstad et al. 1999). These estimates are important for raising the awareness of what is lost through forest fires so that people can become more committed to controlling these forest fires. Forests act as an irreplaceable carbon sink (IUCN/WWF, 2000; SCBD, 2001), but forest fires that burn most of this biomass are turning forests into significant sources of carbon emissions, thus worsening the global warming situation (Hofstad et al. 2009).

2.5 General framework of the study

This study focused on the deforestation issues shown in the darker boxes in Figure 3. The deforestation cost estimates focused on the ecosystem’s goods and services losses and the farmers’ food and tree crop losses due to wildfires (Articles I and II). The identification and the analyses of the drivers of deforestation were focused more on the direct causes of deforestation at the farm level (Articles II, III, and IV) (Fig. 3).

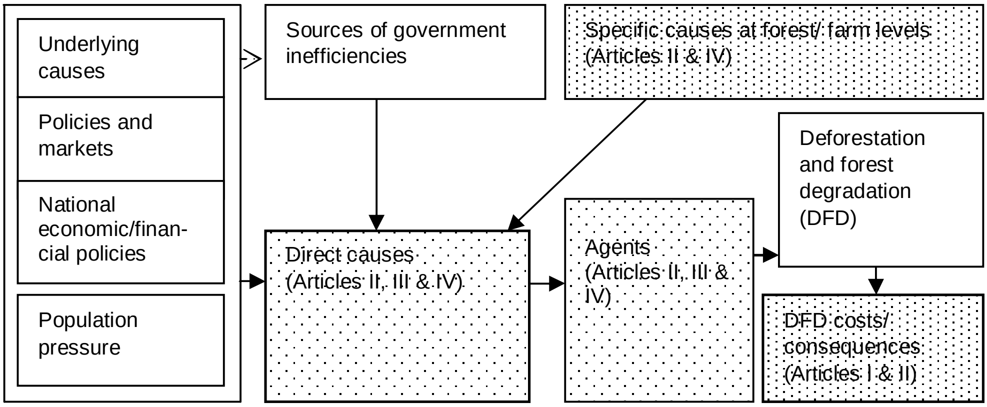

Figure 3: Schematic representation of the study

3. MATERIALS AND METHODS

3.1 Study areas

Ghana (4^{o} 44'N-11^{o}11' N; 3^{o} 11'W-1^{o}11' E) is a West African country (Fig 4). It shares borders with the Republic of Togo to the east, Burkina Faso to the north, and La Cote d'Ivoire to the west. The Gulf of Guinea (the Atlantic Ocean) lies south of the country, stretching along a coastline of 565 km (World Bank, 2010). Ghana covers a total area of 23.9 million hectares (World Bank, 2010), and has a population of 24.2 million people (2010 estimate). The mean per capita GDP (purchasing power parity) is $2,500 (CIA, 2011). The contribution of agriculture to Ghana's GDP is 44% and employs approximately 70% of the labor force (MoFA, 2007). Aside from the agricultural sector, which comprises food crops, livestock, cocoa, forestry, logging and fishing, the other sectors of Ghana's economy are industry (mining and quarrying, manufacturing, electricity and water, and construction) and services (transport and communications, wholesale and retail trade, finance and insurance, real estate, business and government services). While agriculture accounted for 32% of the economy in 2008, services and industry accounted for 42% and 26%, respectively (World Bank, 2010). With timber, cocoa, minerals and fish representing 48% of the GDP, Ghana's economy depends heavily on these natural resources, and it is the world's second largest producer of cocoa (FAO, 2007).

The country is divided into 10 administrative regions that are subdivided into 170 districts. This study was performed in the southern part of Ghana in 33 administrative districts spread across 5 administrative regions, which include the Brong Ahafo, Ashanti, Eastern, Central and Western Regions. The corresponding capitals of these regions are Sunyani, Kumasi, Koforidua, Cape Coast and Takoradi (Fig. 4). Ghana is divided into six ecological zones, with varying rainfall patterns and amounts (Fig. 4). The study sites were located in the forest-savanna transition (3), the semi-deciduous forest (4), and the high rainforest (5) zones in the high forest zone (HFZ) of Ghana (Fig. 4). The HFZ covers approximately 7% of Ghana's land area (Agidee, 2011). This study was limited to the HFZ because formal forestry in Ghana is concentrated in this zone (Kotey et al. 1998).

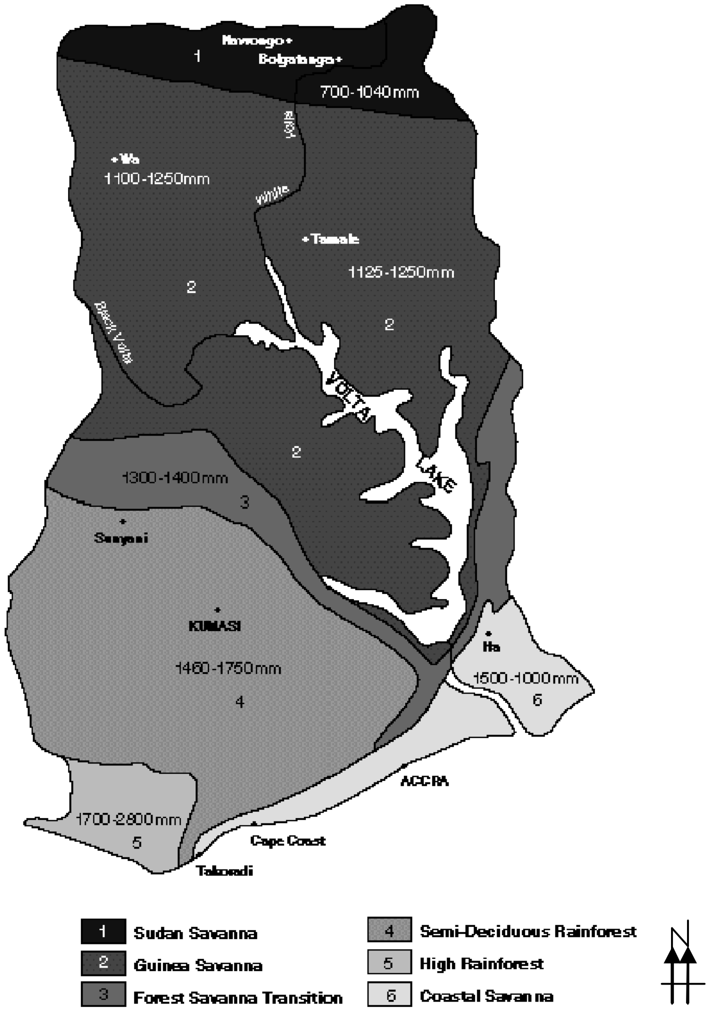

Figure **4**: Map of Ghana showing the HFZ where the study sites are located (Timbilla and Braimah, 1989)

This zone was also selected because most of the economic activities (e.g., timber, cocoa, oil palm, rubber, and mining) in the country are concentrated in this zone. In the HFZ, the areas for forest reserves and wildlife conservation that are permanently protected under state management are approximately 1.64 million and 136,000 hectares, respectively (Kotey et al. 1998; Boakye and Affum-Baffoe, 2008). The area outside of these reserves (off-reserves) where timber is also harvested is approximately 315,000 hectares (Boakye and Affum-Baffoe, 2008). Deforestation is also high in the HFZ due to farming and unsustainable timber harvesting practices. The effects of these practices are further worsened by bushfires and illegal chainsaw operations that are reported to supply over 70% of the domestic lumber requirements (World Bank, 2010).

3.2 Estimating deforestation and wildfire costs (Article I, II)

3.2.1 Estimates of the economic cost of deforestation (Article I)

In Article I, MA's (2005a) approach was used to identify and estimate the values of four ecosystem goods and services in degraded, plantation, and natural forests in six different sites in the semi-deciduous forests in the HFZ of Ghana. These sites were the Mpameso natural forest and the Pamu Berekum degraded and Plantation forests in the Dormaa Forest Districts. The other sites were the Southern Scarp Degraded forest and Plantation forest and the Worobong South natural forest in the Begoro forest districts of Ghana. One hectare plot was laid in each of the six sites, the timber trees enumerated and their diameter at breast height was measured. The edible fruit trees that were found in these plots were also counted and soil samples in 10 different spots at two different depths (1-10 cm, 10-20 cm) were taken. The ecosystem services assessed were carbon sequestration and soil fertility (indirect-use value) and timber and non-timber forest products (direct-use value) (Fig. 2). The value differences of these services in the degraded and the natural forests were obtained as the cost of deforestation in Ghana, in terms of the opportunity cost of the degraded forest areas.

The loss of gross forest land output (GAIL) in a year due to deforestation in the preceding year was obtained (Bojö, 1996) as GAIL = PdQ, where P is the economic price per unit of the ecosystem services identified, and dQ = current volume/quantity of the studied ecosystem services lost due to deforestation. The value of GAIL was then obtained for each of the ecosystem services studied (i.e., stumpage revenue, fruit tree value, carbon storage value and soil fertility value) as a value difference between a hectare of degraded and natural forests. The resulting value difference was multiplied by 128,733 hectares (the average annual forest loss in Ghana in 1990-2005 (FAO, 2006)) of the degraded forest area to obtain the national estimates of the monetary cost of deforestation and degradation in terms of each ecosystem service studied. For example, to estimate the dQ to obtain the stumpage value losses, Wong's (1989) timber tree volume equation (Volume = (a) diameter^{b}) for estimating timber tree volume in Ghana was used. The diameter measurements of each timber tree obtained from the field plots were substituted into this equation to obtain the volume of each tree in cubic meters. The respective average stumpage prices obtained from the Forestry Commission (FC) of Ghana were multiplied by the corresponding tree volumes. An adjustment was made based on the level of biological scarcity and the market demand for each timber tree using the rates (%) of adjustment that the FC has established for these timber trees.

To obtain the dQ for the above-ground carbon storage value estimate, an allometric equation (Brown et al. 1989) that relates tree dry biomass (Kg) and the tree diameter at breast height (cm) was used. The carbon stock in each timber tree studied was converted to tCO_2e. An average price of US$6 per tCO_2e in the carbon market (over-the-counter) (Hamilton et al., 2010) was used and multiplied by the obtained tCO_2e of each tree to obtain their carbon storage value in monetary terms. A sensitivity analysis was performed using a minimum and a maximum price of US$2.68 and US$13.33 per tCO_2e, respectively, to determine the extent to which the cost of deforestation could vary with the changes in the prices in the carbon market. A similar procedure was used to obtain the dQ to estimate the fruit tree value loss. The annual fruit yield for each fruit tree found during the tree enumeration was determined in focused group meetings with community members. The fruits' corresponding sale prices were obtained in the local markets. These were deflated by 30%, according to Abane, (2009) to obtain their forest gate prices. The resulting forest gate price was then used. It is worth noting that while stumpage prices were used for the timber revenue, the forest gate prices were used for the fruit tree revenue. The former are administrative prices that are kept below their market prices, while the latter are determined by free market forces. For measuring the soil fertility value loss, a replacement cost technique was used (Bishop, 1999). The soil sample was analyzed in a laboratory to obtain the main components of Nitrogen (N), Phosphorous (P) and Potassium (K). The P and K were converted to Kg/ha (SWATLAB, 2009). These soil components were related to a 50 kg bag of fertilizer (sulfate of ammonia) tagged 15-15-15 (Niskanen, 1998) to obtain the monetary value of the soil nutrients using nutrient-fertilizer conversion ratios (Nahuelhual et al, 2006).

3.2.2 Wildfire cost estimates and indigenous mitigation strategies (Article II)

In Article II, the losses that the communities incur in terms of food and tree crops due to wildfires encroaching on their farms and fallow lands were estimated over a five-year period. The farmers' common mitigation and adaptation strategies to wildfires were also identified and analyzed to support strategies for managing uncontrolled fires. The heads of households in communities living nearer to the selected forest reserves that are prone to forest fires in the HFZ of Ghana were surveyed on the issues that are related to the cost of the wildfire, their perceptions of causes, and their mitigation and adaptation strategies. A pre-coded questionnaire was designed based on community meetings and pretested. Two hundred and sixty six (266) individual respondents were selected randomly from within the sampled 12 communities in six administrative districts, i.e., the study sites. These sites were the sites for a pilot wildfire project that was financed by the International Tropical Timber Organization (ITTO). The selected heads of households were interviewed face-to-face using the local dialect (Twi) of the area during February 2006. The data were analyzed using correlation analysis, simple frequencies, analysis of variance, and X^2 squared statistical techniques. The price data for the food and tree crops were obtained from the Ministries of Food and Agriculture and Forestry of Ghana to estimate the costs/value of the losses incurred by the surveyed farmers.

3.3 Identifying and mitigating the deforestation drivers (Articles III, IV)

3.3.1 The influence of land and tree tenure on deforestation (Article III)

In Article III, land and tree tenure was identified as one important cause of deforestation, and its significant influence on the REDD+ processes is examined here in detail. The communities living close to the forests were sampled in the HFZ of Ghana and surveyed. This survey was nationwide, covering the ten administrative regions of Ghana and was conducted in 2005 by the Institute of Statistical Social and Economic Research (ISSER) of the University of Ghana. The survey was focused on land degradation, including tenure issues, and covered the heads of 2690 households. This number was obtained from one randomly selected electoral area in each of the five randomly sampled administrative districts in each of the 10 regions of Ghana. A subsample from this nationwide survey was obtained. It covered the heads of 756 rural households in the HFZ of Ghana. Their responses to those aspects of the questionnaire that covered land and tree tenure issues were used for this article. Some of the questions used in this study were i) whether the respondent has acquired land for farming and ii) the conditions governing the farmland holdings. The data obtained were analyzed using descriptive statistics, X^2 squared statistical techniques and multinomial logistic regression techniques.

3.3.2 Identifying and mitigating deforestation drivers in conservation areas (Article IV)

For Article IV, the drivers of deforestation were identified and analyzed in the Ankasa conservation area (ACA) in Ghana. The communities living nearer to this conservation area were divided into three clusters, North (NA), South, (SA) and West (WA)), and sampled. The communities were surveyed on the direct and underlying causes of deforestation in this conservation area, as well as on their perception of the extent of DFD in this area. A pre-coded questionnaire that was designed based on community meetings and pretested was used. To select the individual respondents, a multistage sampling technique was used. Of the seven protected areas in Ghana, the ACA was selected based on its high ecosystem services and biodiversity value compared to the other areas and because of the already existing management structures that were in place. Because this area is located in one region (the Western region of Ghana), the administrative districts in this region that border this conservation area were selected. The communities in these districts and in these clusters were selected on the basis of nearness (1-7 km) and accessibility. The individual respondents (292) were randomly selected from these clusters and interviewed. The data were analyzed using X^2 squared (Kruskal Wallis H and Mann Whitney U) statistics, an independent sample t-test, and ordinal multinomial logistic regression techniques. The Statistical Package for Social Sciences (SPSS) software was used for the analysis.

4. RESULTS

4.1 The deforestation cost and the estimates of food and tree crop losses due to wildfire (Article I, II)

4.1.1 The economic cost of deforestation estimated as ecosystem services losses (Article I)

Due to deforestation, stumpage revenue losses ha^{-1} were US$178.91 in the Mpameso natural forest when compared to the Mpameso degraded forest and US$135.51 in the Worobong South natural forest when compared to the Southern Scarp degraded forest reserves (study sites) (Table 1). With regard to the edible fruit trees, US$777.08 gross value ha^{-1} was lost annually due to deforestation when the natural forest is compared to the degraded forest. With respect to the carbon stock value, a US$323.40 ha^{-1} loss was recorded when the carbon storage values in the degraded forests in the Mpameso were compared to the natural forests in the Mpameso, while a US$666.06 ha^{-1} loss was recorded

Table **1**: Stumpage fees (US$) per hectare and tree information used to calculate the economic cost of deforestation in terms of carbon stocks in the different study forest reserves, Ghana

	Plantation forest		Degraded forest		Natural forest	
Species category for stumpage fees(US$)	Pamu Berekum	Southern Scarp	Mpameso	Southern Scarp	Worobong South	Mpameso
High demand species	8.79	38.5	56.69	-	31.44	206.74
Moderate demand species	3.05	90.87	81.34	95.43	157.96	173.31
Low demand species	0.85	7.6	73.33	51.13	81.89	12.66
Others: Low demand species	7.66	7.75	2.43	3.95	14.73	0.01
Total	20.35	144.72	213.8	150.51	286.02	392.71
Tree information for carbon emission calculation	Pamu Berekum	Southern Scarp	Mpameso	Southern Scarp	Worobong South	Mpameso
Stems/ha	211	276	139	82	277	230
Biomass (kg/ha)	6,105	35,614	550	58,523	118,474	105,823
tCO_2e/ha	11.2	65.35	140.29	107.39	217.4	194.18
Value(US$6[a])/ha	67.22	392.11	841.71	644.34	1,304.4	1,165.11
Sensitivity analysis using minimum and maximum values of US$2.68 and US$13.33/tCO_2e, respectively						
Value (US$2.68)/ha	30.02	175.14*	375.96	287.81	582.63	520.42
Value (US$13.33)/ha	149.33	871.13*	1,870	1,431.51	2,889.9	2,588.48

[a] US$6 is the mean price per tCO_2e, * 175.14 and *871.13 are the right values

when the Southern Scarp degraded forest was compared to the Worobong south natural forest (Table 1). The sensitivity analysis results show that, on average, between the degraded and the natural forests, losses as low as US$ 219.64 ha^{-1} and as high as US$1088.46 ha^{-1} could be recorded depending on the price/tCO_2e in the carbon market (Table 1). In the case of soil fertility, very low values on average for the P and N studied were found. For instance, US$0.70 ha^{-1} was calculated to replace soil fertility loss in the degraded forests, US$0.71 ha^{-1} in the natural forest and US$0.74 ha^{-1} in the plantation forest (I, Table S4).

4.1.2 Local community's food and tree crop losses due to wildfires (Article II)

Based on the annual economic losses as a result of damage to the farmers' food and tree crops by wildfires (Table 2), a farmer lost approximately US$232 annually as an overall average in the five-year period from 2001-2005. Among the 5 staple food crops, including maize, plantain, and cassava, cocoyam and yam, a farmer lost annually on average 437, 415, 363, 206, and 123 US$, respectively. The loss in yam was the lowest, even though yam is a highly sought-after staple food crop. It could be that wildfires have rendered the microclimate unsuitable for yam cultivation in these study areas because its average loss per farm per year fell from US$288 in 2001 to US$90 in 2005 (Table 2). With respect to the tree crops that involve cocoa and timber plantations, the loss is 205 and 264 US$ per farmer annually on average. The losses in all three food staples are higher than those for cocoa, which is a cash crop.

4.2. Knowledge of the causes of wildfires and the mitigation and adaptation strategies to wildfires and the land and tree tenure effects on deforestation (Articles II, III and IV)

4.2.1 Wildfires causes, prevention, detection, suppression, and education (Article II)

The results show that wildfires occur at least once every year in the study areas (II, Table 1). With regard to the causes of wildfires, including the misuse of fire on farms, fire-related hunting, and setting fire as an attack or as revenge, there were significant differences between the studied districts, with the exception of slash-and-burn, which was common to all (X^2 =0.17, p =0.37) (II, Table 1). Regarding the causes of wildfire and the frequency of occurrence, there were significant differences between the four causes and the occurrence of wildfire once a year in the study sites (II, Table 2). The traditional rules and regulations for wildfire prevention centered on prohibition, as over 68% of the respondents noted that it was an offense to use fire for the preparation of farmlands during the driest months of the year (II, Table 4). Apart from these rules, other methods for preventing wildfires at the community level were the use of silvicultural techniques, including the creation of fire belts around farms and the cleaning of the forest boundaries (II, Table 4).

The equipment for wildfire prevention and suppression were mainly cutlasses, sticks, freshly cut leaves and backpack water pumps (II, Table 4). The majority of the respondents could predict the period of high fire risk by observing the trees and their reactions to the

Table **2**: Monetary value of the losses incurred by some farmers in Ghana over a 5-year period (2001-2005) in terms of agricultural and tree crops

Crop/tree resources	Year 1 (*n*=81)		Year 2 (*n*=41)		Year 3 (*n*=56)		Year 4 (*n*=48)		Year 5 (*n*=45)		5-year
	Mean ¢(S.E)	US$	Mean ¢(S.E)	US$	Mean ¢(S.E)	US$	Mean ¢(S.E)	US$	Mean ¢(S.E)	US$	Mean US$
Maize (*Zea mays L.)*	513(2.6)	570	245(1.2)	272	561(1.1)	623	499(3.3)	554	151(5.5)	168	437
Plantain (*Musa spp*.)	489(0.8)	543	149(0.9)	166	775(13.4)	861	252(7.3)	280	201(1.9)	223	415
Cassava (*Manihot esculenta*)	450(1.8)	500	265(2.7)	294	630(2.8)	700	123(1.1)	137	165(2.3)	183	363
Cocoa (*Theobroma cacao*)	361(2.1)	401	301(1.2)	334	259(3.2)	288	0	0	0	0	205
Groundnut (*Arachis hypogaea*)	18(0.1)	20	0	0	299(5.2)	332	156(1.2)	173	0	0	105
Cocoyam (*Colocasia and Xanthosoma spp.*)	265(0.9)	294	35(0.9)	39	228(3.8)	253	86(0.7)	96	315(2.1)	350	206
Yam (*Dioscorea rotundata*)	259(1.2)	288	45(3.6)	50	115(2.9)	128	53(1.4)	59	81(3.2)	90	123
Tomato (*Solanum lycopersicum*)	0	0	100(1.9)	111	0	0	524(7.5)	582	112(1.3)	124	163
Pepper (*Capsicum spp*.)	108(0.2)	120	0	0	61(0.9)	68	500(10.5)	556	0	0	149
Oil palm (*Elaeis guineensis*)	69(0.5)	77	0	0	23(0.5)	26	150(7.1)	167	100(0.7)	111	76
Tree plantation	300(1.1)	333	100(0.8)	111	190(1.4)	211	150(7.8)	167	450(2.8)	500	264
Total	257(5.9)	286	113(5.0)	126	286(1.0)	318	227(6.0)	252	158(6.2)	176	232

N Number of observations; *S.E.* Standard error of mean; Exchange rate was based on the bank rate in February 2006 different seasons of the year, the incoming of the harmattan wind, the fruiting of certain tree species, and the browning of leaves, among other indications (II, Table 5). The wildfires were detected by visual sightings of smoke and voluntary patrol groups in the community (II, Table 5). With regard to wildfire suppression, an immediate response to an outbreak would be alerting the community members through the beating of a local drum (Talking drum) (II, Table 5). The next step was the responsibility sharing between the men and the women (II, Table 5), which means that fighting wildfire in these communities requires collective action by the members. For the community members studied, the preferred fire education channel was through a community meeting, involving trained relatives and farm groups, compared to the education by Ghana National Fire Service (GNFS) staff (II, Table 6).

4.2.2 Land and tree tenure effects on deforestation (Article III)

The multinomial regression results in Article III show that the farmers who acquired land on either a leasehold or a share cropping basis were more likely to engage in deforestation related short-rotation farming systems, compared to those who acquired lands on a gift, customary or inheritance basis (odds ratio of 2.90, p= 0.001; odds ratio of 2.34, p=0.01, respectively). Regarding the informal rules that affect farmers and discourage them from tree planting, 74% and 18% of the respondents indicated that sharecropping and the non-transferability of the rented farmlands, respectively, were the most important rules.

Table **3**: Formal and informal rules for holding farmland in the five study regions

	Western	Central	Brong Ahafo	Ashanti	Eastern	Total
Rules to observe on borrowed farmlands	% total respondents (N=119)	% total respondents (N=264)	% total respondents (N=158)	% total respondents (N=129)	% total respondents (N=63)	% total respondents (N=733)
Prohibited from farming on specific days	29	16.7	5.1	2.3	7.9	12.8
Plant specific crops	5.0	7.2	11.4	19.4	4.8	9.5
Do not plant specific crops	14.3	14.4	5.1	24	1.6	13.0
Land not transferable	36.9	0.2	0.04	0.1	0.24	18.3
Land cannot be sold	-	0.4	-	-	-	0.1
Sharecropping	47.1	74.2	89.9	78.3	71.4	73.7
Free/No rules	0.8	0.8	3.8	1.6	9.5	2.3
Return land after harvest	5.0	1.5	3.8	7.0	-	3.4
Do not sublease land	-	0.8	2.5	2.3	3.2	1.5
No permanent structures on the land	-	3.8	1.3	-	-	1.6
Return land when land value increases	-	-	1.3	-	-	0.3
Payment in kind	11.8	1.1	1.9	28.7	-	7.8
Observe taboos in relation to land	4.2	1.9	0.6	0.8	-	1.6
Do not harvest tree crops on land[a]	-	0.8	0.6	4.7	-	1.2
Do not burn bush[a]	0.8	-	-	-	-	0.1

[a]Both formal and informal rules

These rules were followed by no opportunity to plant specific crops (13%) and directives to plant specific crops (10%) on the rented farmland (Table 3). Another significant adverse rule that affected farmers was the loss of rented land to the land owner in a given year if it is not cropped. Aside from affecting the farmers, one effect of these adverse rules on the holders of farmlands was the insecurity of tenure, which was indicated by over 24% of respondents (III, Fig. 2). The other effects were the forcible engagement in intensive cultivation (10%), the inability to cultivate the desired crops (6%), and the payment of high tenancy fees (3%) (III, Fig, 2). Overall, these tenancy arrangements mostly negatively affected the farmland holders (p = 0.04, p= 0.02 and p=0.08 for the respondents in the Central, Western and Brong Ahafo region study sites, respectively) (III, Fig 3).

4.2.3 Perception of the deforestation extent, the direct and the underlying causes in protected areas (Article IV)

From the proportional odd model (POM) analysis in Article IV, the people who lived in the 'buffer zone' to the Ankasa Conservation Area (ACA) were 3.35 times less likely (p = 0.001) to perceive the area as more degraded in reference to those living at the edge of the PA. Those who lived further away from the ACA were 1.25 times more likely to perceive the ACA as more degraded compared to the people living at the edge of the ACA (IV, Table 1, appendix A). Regarding the intensity of the impact of the direct causes of DFD in the ACA, there was a significant difference among the respondents in the different locations in how they ranked these direct causes in terms of severity (Table 4). In regards to agriculture being the most important direct cause of DFD, the subsistence agricultural activity was the most important driving force explaining it (IV, Fig 3a). Illegal logging and fuel wood harvesting for domestic purposes were the most important driving forces that explained wood extraction as the second most important direct cause of DFD in the ACA (Table 4). Illegal logging was prevalent among the communities in the southern part of the ACA (NA and SA, Mean = 115, 136, U = 6503, p=0.008), while fuel wood harvesting was prevalent among the communities in the northern parts of this area (NA and SA, Mean = 156, 110, U = 4975, p<0.01).

For the underlying causes, the economic factors (poverty and off-farm employment) were the most important (Table 4). Poverty was more prevalent among the communities in the northern and western parts of the ACA, and the shortage of off-farm employment (IV, Fig 4a) was prevalent among those in the western and northern parts of the conservation area. The large in-migration of people into these communities, particularly into the communities in the northern part, was the main driving force of the demographic factors as the second most important underlying cause of DFD in the ACA (Table 4) (IV, Fig 4b). Regarding the shared responsibilities among the stakeholders to curb DFD in the ACA, the first priority for the park management was the implementation of activities to alleviate poverty among the communities living around the ACA (IV, Fig 5a). There was also an urgent need for the park management to increase law enforcement, particularly among the communities in the northern part of the ACA (NA and SA, Mean = 139, 119, U = 6438, P= 0.004; NA and WA, Mean =75, 56, U = 1356, p< 0.01).

Table **4**: Ranking of the perceived direct and underlying causes of DFD on a 1-3 and 1-5 severity scale, respectively, among the respondents in the ACA, Ghana

Direct causes of DFD in the ACA	Number of respondents	Minimum	Maximum	Mean	H Test statistics (mean rank, p-values) in the north (NA), south (SA) & west (WA) of the ACA
Agricultural expansion	291	1	3	1.21	NA, SA,WA: 122 160 154 H(2) =27 74, p<0.01
Wood extraction	276	1	3	1.96	NA, SA, WA: 175 121 121 H(2) =40 28, p<0.01
Infrastructure development	273	1	3	2.82	NA, SA, WA: 117 145 150 H(2)=17 56, p<0.01
Underlying causes of DFD	*Number of respondent*	*Minimum*	*Maximum*	*Mean*	*H Test statistics (mean rank, p-values) in north (NA), south (SA) & west (WA) of the ACA*
Economic factors	280	1	5	1.6	NA, SA, WA:167 129 122 H(2) =19 32, p=0.03
Demographic factors	281	1	5	2.48	NA, SA, WA: 126 145 164, H(2)=7 30, p<0.01
Technological change	256	1	5	3.48	NA, SA, WA: 132 131 114, H(2) =1 86, p=0.39
Cultural factors	271	1	5	3.61	NA, SA,WA: 121 143 147, H(2) = 5 74, p=0.06
Policy/institutional changes	256	1	5	3.62	NA, SA, WA: 121 132 130, H(2) =1 21, p=0.55

5. DISCUSSION

5.1 Overall relevance

The deforestation and wildfire cost estimates and the identification and analyses of the deforestation drivers in this study (Articles I, II, III and IV) have important implications for forest conservation and climate change mitigation. Their current relevance is in supporting the national processes for avoiding deforestation and forest degradation. With regard to the cost estimates, they are important in raising awareness and encouraging commitment to deforestation control. It is believed that these specific cost estimates will also be an important component to the broader cost estimates that are required to pay people to pursue alternative land and forest uses that are low carbon emitting. In this way, these estimates could be a source of information in policy deliberation on how to slow greenhouse gas emissions form DFD (Olsen and Helles, 2000; Hatcher, 2009). As performed in the present study (Article I), most studies (Greig-Gran, 2006) that estimate these types of costs use the opportunity cost approach. However, it is important to note that these cost estimates are generally lower bound estimates (Article I) because of the complexities and the uncertainties involved in their calculation (Canadell and Raupach, 2008; Hatcher, 2009).

The identification and the analyses of the drivers of deforestation at the micro level (Articles II, III, and IV) appear to provide important scientific information regarding the climate mitigation processes. As Kanninen et al. (2007) note, understanding the causes of these drivers is critical to identifying the appropriate incentives for deforestation control. In particular, wildfire and its cost-effective control measures (Article II) are vital for deforestation control and climate change mitigation and even more so in a developing country such as Ghana, where the financial resources and the modern equipment for fighting wildfires are limited. Despite the fact that these indigenous wildfire control measures and knowledge only suffice for surface forest fire management (Article II), they could be cost effective in the case of Ghana and they need to be improved upon while waiting for the required investment in modern firefighting equipment and training in the distant future.

A clearer understanding of the causes of DFD is identified as a prerequisite to an effective REDD regime design (Kanninen et al., 2007; Angelsen et al., 2009; Davis et al., 2009). For instance, a key factor in deforestation and forest degradation is land and tree tenure in Africa and a thorough understanding of tenure is needed for redress (Hatcher, 2009). Unclear tenure has already been identified as a challenge in a review of 25 countries, including Ghana’s RP-INs (Readiness Plan Idea Notes) (Davis et al., 2009). Owing to this challenge of unclear land tenure, there are renewed calls for securing tenure rights with a bit more urgency and speed to support the climate change mitigation and REDD+ processes (Hatcher, 2009). Although tenure reform is not envisaged to be easily performed in a shorter time (Larson, 2010), the scientific information provided in this study (Article III) in the case of Ghana could be useful. This information could, at least, inform the policy makers about the issues at stake to assist in the initiation of a possible tenure reform process, regardless of the time that may take.

5.2 The economic cost of deforestation and the estimates of food and tree crop loss due to wildfires (Articles I, II).

The results show that US$133,650,000 gross revenue, equivalent to 2.6% of the 2008 agricultural Gross Domestic Product of Ghana, is lost annually due to deforestation (Article I). This loss consists of the following value losses for the four ecosystem services studied: stumpage revenue value loss of US$20,238,000; non timber forest product—fruits, US$50,018,000; carbon storage, US$63, 302,000; and soil fertility, US$91,000. While these estimates could call for broader cost estimates for climate change mitigation and adaptation in Ghana, they could also create awareness regarding the nation's economic losses through deforestation and could draw attention to the need to address these losses (Olsen and Helles, 2000).

For Ghana to adapt to climate change, the Economics of Adaptation to Climate Change (EACC) study estimates a cost of US$300-400 million per year (Cameron, 2011). The cost items for these estimates were from various economic sectors, including agriculture and forest ecosystem goods and services (World Bank, 2010). These estimates are aimed at assisting policy makers to better cost, prioritize and incorporate adaptation strategies into their development plans. The value estimates obtained in the present study (Article I) could be useful in supporting these cost estimates, particularly in the forest sector. These value losses have important implications for sustainable forest management, although the carbon storage values are potential losses of carbon credits earnings (Olsen and Helles, 2000). In particular, the losses in stumpage revenue affect the development of the forest communities because these funds are used to supplement district level developments as well as sustainable forest management activities. Already, forest land owners and the communities complain of inadequate benefits from their forest resources (Bamfo, 2008b), while the official resource managers complain of the lack of adequate funds to police the forest against illegal activities. These factors together lower the level of commitment to the management of these resources. These losses mean that the plight of the forest communities is further worsened and their interest in these forests further dampened possibly heightening the deforestation rate as a consequence (FAO, 2010a).

The food and tree crops loss estimates provide an indication of the socio-economic impact of wildfires on the livelihood of the forest dwelling communities in Ghana and call for urgent and innovative ways to control wildfires. Already, merchantable timber loss due to wildfires is high in Ghana (ITTO, 2003); adding the losses of the farmers implies a significant loss to the nation from wildfires alone. What is more significant about the results (Article II) is the higher value loss in maize, a principal food crop supporting a larger segment of Ghana's population (World Bank, 2010). The loss of maize to wildfires implies a significant impact on the livelihood of many people in the country. The low value losses for cocoa (Article II), the main cash crop in Ghana, also shows the negative effect of wildfire on people, particularly in the study area. This effect is the probable reason for the drift of people to the southwestern parts of Ghana where the wildfire effect is relatively minimal for the cultivation of this crop (Article IV) (Knudsen, 2007). While climate change is envisaged to lower the crop yields in Ghana (World Bank, 2010), these additional losses due to wildfires (Article II) imply that much greater losses in the yields of these crops are likely if significant effort is not put into controlling these forest fires. Lastly, in terms of the cost estimates for the adaptation to climate change, these food and tree crop value losses of farmers (Article II) could also assist in improving these estimates for adaptation strategy designs in the local communities.

5.3 Wildfire mitigation and adaptation strategies, tenure effects on deforestation, and causes in Protected Areas (Articles II, III and IV)

Wildfire can be a significant threat to sustainable forest management. Wildfire leads to carbon loss from the forest into the atmosphere through the burning of biomass (Forner et al., 2006; Herawati and Santoso, 2011). As a result, controlling wildfire could play an important role in climate change mitigation. In Ghana, wildfire management in the fire prone areas to reduce the occurrences of wildfire is among the strategies taken to address forest-related climate change (Bamfo, 2008b). The findings on the mitigation and adaptation strategies to wildfires (Article II) could be useful in the design of strategies for wildfire control and in addressing forest-related climate change. As the results show, the indigenous communities have important knowledge regarding wildfire occurrences and have developed strategies to manage them, although they only apply to surface wildfire control. Amissah et al. (2011) record similar findings in their study of the transition zone of Ghana. The knowledge of wildfire and the strategies for its control need to be improved through sensitization and education.

Regarding the tenure effects in deforestation, the results indicate that many of the land and tree tenure arrangements in the HFZ of Ghana affect the farmers, particularly the leasehold and share crop farmland holders. In most cases, these farmers do not have the freedom to use the acquired farmlands as desired. In Asiedu’s (2010) study, similar findings have been recorded that affect the cocoa carbon REDD + scheme in diverse ways in Ghana. These effects are challenging to counter and make it difficult for these farmers to engage in sustainable forest management (Article III). The effects have a negative implication for sustainable forest management in the HFZ and, more importantly, for any REDD+ scheme in Ghana. Because the landowners are currently the only beneficiaries of the formal timber revenues, the share crop and leasehold farmers may have to be included in any future forest resources benefit-sharing scheme to encourage sustainable forest management practices among them as well (Article III).

The Protected Areas have the potential to avoid carbon emission into the atmosphere (Soares-Filho et al. 2010), and they could play an important role in climate change mitigation. Therefore, the direct and underlying causes of deforestation and the control measures identified in the present study (Article, IV) could be useful in sustaining these areas. As the results show, the areas surrounding the Ankasa Conservation Area (ACA) appear to be quickly degrading and would require much attention. Issues that also require attention are subsistence agricultural activities, poverty, lack of off-farm employment, and the large in-migration of people into the communities surrounding the ACA. These correspond with the findings of other studies (Knudsen, 2007) and call attention to the need for priority to be given to livelihood improvement and the provision of ecosystem services in the management of this area, rather than focusing solely on its core function of biodiversity conservation, as is the case at present (Article, IV).

6. CONCLUSION

This study elucidates the cost estimates of deforestation and wildfire at the forest/farm level in the high forest zone of Ghana (Articles I, II). This study also provides information on the drivers of deforestation and wildfires and the remedial measures taken to address them (Articles II, III, and IV). Altogether, this information could make a useful contribution to sustainable forest management and climate change mitigation strategies in Ghana. While the cost estimates of deforestation and wildfires could contribute to the broader cost estimates for climate change mitigation and the adaptation strategies of Ghana, they could also be useful in raising awareness of what the local communities and the nation are losing through these events (deforestation and wildfire). In this way, these estimates could draw attention to the need for increased commitment in controlling the impact of deforestation and wildfire.

The findings in the present study on the mitigation and adaptation strategies for deforestation and wildfire could also be relevant by contributing to the deforestation control and climate change mitigation strategies and the REDD+ processes in Ghana. The policy implications for all of these findings are as follows.

i) The knowledge of indigenous communities on mitigating and adapting to wildfires, although only effective for surface forest fire control, could be cost effective. They provide a base on which to build an improved wildfire control strategy.
ii) Although land and tree tenure reforms cannot be quickly or easily completed, there is a need for reforms that pay particular attention to the share crop and leasehold farmland holdings system as it currently pertains to the HFZ of Ghana. The holders of farmlands under this system do not significantly benefit from formal timber revenues, yet are faced with challenging tenancy arrangements for their holdings. The arrangements for forest revenue sharing, including potential payments from REDD+, need to include these holders to encourage sustainable forest management practices among them as well.
iii) With regard to the Ankasa Conservation Area (ACA), there is a need to give priority to livelihood improvement and ecosystem services provisions in the management of these conservation areas. In this way, the macroeconomic problems of a large in-migration, poverty and the lack of off-farm employment, among other issues identified, could be addressed effectively to enable these areas to contribute more to biodiversity conservation and climate change mitigation.

The way forward is to perform further research employing a multi-criteria decision analysis technique to identify a cost-effective option to support the management of the ACA as suggested in point (iii) above. Other important aims would be to expand the cost estimates of deforestation by applying systematic cost benefit techniques, applying scenario analysis for carbon storage values, and increasing the number of ecosystem goods and services beyond the original four. Aside from these, the wildfire cost estimates need to be replicated in other fire-prone areas in the high forest zone of Ghana and, indeed, in other parts of the country. In performing these cost estimates it would be important to add other ecosystem goods and services (e.g., immediate carbon losses from fires and further losses from the deaths of injured economic trees) and increase the sample size of the farmers and the number of communities to be surveyed. In addition to the surveys, sample plots could be set up in the fire prone areas to perform the cost estimation and monitoring. Furthermore, theoretical models such as those of Chayanov and von Thunen need to be applied in the fields of further research, varying the methods of analysis (e.g., using laboratory experiments from the field of Experimental Economics) to better understand the land and tree tenure issues and the problems for redress.

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