THE UNIVERSITY OF HULL

The State of Terrestrial Biodiversity in Ghana:

A GLOBIO-3 Perspective

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Abstract

Conservation of biodiversity – the richness and evenness of species in an area – is a global concern. This is because the rate at which biodiversity is being lost worldwide is alarming. In order to bring the situation under control, policy makers have been urged to ensure that biodiversity is considered whenever policies are made. This notwithstanding, the situation seems to be worsening. Indeed, this is understandable to some extent because in most countries there is very little biodiversity information available and where there are some pieces of information, they are so limited in terms of spatial coverage. The situation ia worse in Ghana. In an attempt to address this problem, this research focused on a quantitative biodiversity assessment of Ghana. This was done using GLOBIO-3, a powerful tool for modelling human impacts on biodiversity. The research made some important findings. Firstly, it was found that Ghana had lost almost half of its biodiversity. Apart from this, estimates of remaining biodiversity for every location in the country were obtained which could enhance biodiversity conservation planning at all levels of administration. The regional analyses revealed that four out of the ten regions had lost more than 60% of their original biodiversity. Moreover, some areas, though not yet protected, were found to have high species richness. In addition to this, some protected areas were found to have roads constructed through them which were causing losses to their biodiversity. By way of conclusion, policy makers in Ghana are urged not only to use the information that has been made available through this research but to ensure that future infrastructural projects are biodiversity friendly. They are also informed of the need to protect those areas with high species richness which are not yet protected in order to conserve the remaining biodiversity of the country. This research recommends that more detailed data be used to improve the results.

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List of Abbreviations

EoE	Encyclopedia of Earth
ESA	European Space Agency
FAO	Food and Agriculture Organization *of the United Nations*
GBN	Ghana Business News
GHS	Ghana Health Service
GIS	Geographic Information System
GMES	Ghana Ministry of Environment and Science
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LPI	Living Planet Index
MEA	Millennium Ecosystem Assessment
MSA	Mean Species Abundance
NCI	Natural Capital Index
PA	Protected Area
PBL	Netherlands Environmental Assessment Agency
SCBD	Secretariat of the Convention on Biological Diversity
UK	United Kingdom
UNEP	United Nations Environment Programme
USA	United States of America
WWF	World Wide Fund for Nature

Chapter 1: Introduction

Biodiversity is of critical value to the world. Whereas plants and animals provide food and medicine for the survival of humans, ecosystems such as forests provide protection against strong winds and landslides. Unfortunately, biodiversity worldwide is suffering from an unprecedented rate of decline which is affecting the goods and services that depend on these vital ecosystems (MEA, 2005). According to the IUCN (2010), more than one in six mangrove species in the world are in danger of extinction due to climate change and anthropogenic activities. Though extinction is a natural phenomenon, an unnatural increase in its rate presents the danger of losing several economically important species before evidences of their existence are discovered. Currently, there are a lot of discussions in regional and global levels about high losses in biodiversity and the threats this trend poses to human survival.

The tropical region, which is the most diverse in terms of terrestrial plant and animal species (Mayaux et al., 2005; Lane, 2010), is the focal point of most of these discussions because of the rate at which biodiversity is being depleted in the region. The situation in Ghana, being part of the tropical West African zone, is not different. Over the last decade, especially, the country has put in significant efforts to reconcile biodiversity conservation with the production of timber and non-timber forest products, to protect its forest reserves, and to gather relevant information about them. However, like in many other countries, it has suffered greatly from the pressures involved in accommodating the needs of ever-expanding human population to which the terrestrial ecosystems are exposed and this is progressively extinguishing a broad array of the organisms and the habitats they inhabit. Although Ghana is home to over 4600 recorded plant and animal species (Convention on Biological Diversity – Ghana, 2010), natural forests have been extremely reduced mainly through deforestation and agriculture and the remaining patches continue to be degraded at a rate that could best be described as unprecedented. These and many other factors, including wildlife hunting, mining and general lack of appreciation for the worth of biodiversity conservation, present serious threats to biodiversity in the country. The situation, to some extent, is understandable because there is very little biodiversity information available and apart from it being limited in spatial coverage, it is believed to be diffuse, incomplete and inaccurate (GMES, 2002). Indeed, without adequate information it is difficult for policy makers to know the effectiveness of their policies. In light of these problems, this research has the objective of carrying out biodiversity assessment of Ghana in order to

1. determine the remaining biodiversity of the country as at 2006,
2. identify the areas with high biodiversity losses and those with high remaining biodiversity,
3. determine how much each biodiversity driver has contributed to the losses, and
4. suggest possible ways of conserving the remaining biodiversity.

Globally, many researchers have conducted studies on biodiversity from different angles including direct measurement of species' population (Stuart et al., 2010), biodiversity's response to some policies (Benhin & Barbier, 2004), data integration (Webb et al., 2010), trends and developments (Lane, 2010; Sodhi, 2008), economics dimensions of biodiversity (Perrings et al., 1992) and drivers of biodiversity change (Benhin, 2006; Alkemade et al., 2009; Jiang et al., 2003). Technically, direct measurements are best in terms of accuracy but are very expensive. For example, Stuart et al. (2010) estimate that the Barometer of Life, a project that would unite taxonomists, bio-geographers, ecologists, conservationists, and amateur naturalists in a coordinated exploration of global biodiversity, with an emphasis on identifying threatened species, will cost about US$ 60 million.

A relatively cheap option is the manipulation of high resolution aerial photographs and satellite images using GIS-based models. This approach was used by Hansen & DeFries (2004) for global forest change assessment. In line with this, this research uses the GLOBIO-3 modelling approach because it is powerful, cheap, fast and does not require any species data. Already, this model has been used for various national (Trisurat et al., 2010; van Rooij, 2008) and global (Alkemade et al., 2009) assessments of biodiversity.

The rest of this dissertation is structured as follows. Chapter 2 reviews the concept of biodiversity and its importance. It provides relevant statistics about global biodiversity losses as well as biodiversity losses in Ghana. It also defines the location of the country (study area) and discusses the country's biodiversity. Finally, it discusses the ecosystem zones in the country which provides background information, especially for the land cover reclassification in Chapter 4. Chapter 3 is devoted to the GLOBIO-3 modelling framework. It provides comprehensive information about GLOBIO-3, including its historical development and its detailed description. The last section of the chapter discusses the drivers of biodiversity change considered in GLOBIO-3. The entire chapter is the foundation of the practical work in Chapter 4. In Chapter 4, a summary of how GLOBIO-3 was applied to the biodiversity problem of this dissertation is given. Chapter 5 is devoted to presentation of results and discussions. Finally, Chapter 6 which is also the last chapter gives the conclusions.

Chapter 2: Terrestrial Biodiversity

2.1 The concept of Biodiversity and its Importance

Biodiversity (or biological diversity) refers to the variation of life forms, their internal genetic diversity and the assemblages they form (USA National Research Council, 1992). In Maclaurin and Sterelny (2008), biodiversity is regarded as a natural magnitude of biological systems. It is generated and maintained in natural ecosystems, where organisms encounter different varieties of living conditions and chance events that uniquely shape their evolution (Ecological Society of America, 1997). Apart from its intrinsic value (MEA, 2005), biodiversity is also recognized for its goods and services to humankind (Schmeller, 2008; Hansen & DeFries, 2004; European Communities, 2008; Perrings et al., 1992; Ecological Society of America, 1997; UNEP, 1995; Benhin, 2006). For that reason, it considered the foundation upon which human life depends (European Communities, 2008). Prehistoric biodiversity is the source of energy and oil that underpins the unprecedented technological developments the world has experienced over the last 50 years (Caserta, 2010). Primarily, food is the source of energy and 90% of foodstuffs worldwide, including fruits, nuts, mushrooms, honey, spices and aromatic herbs is provided by only about 100 species (UNEP, 1995). The World Health Organization's estimates show that more than 80% of the world's population rely on traditional medicines which are mainly plant extracts for their primary healthcare needs (FAO, 2005). It is important to note that a significant part of this percentage comes from the developed world. This is illustrated by the fact that a survey conducted in the United States of America revealed that of the top 150 prescribed drugs used, 118 were based on natural sources; 74% on plants, 18% on fungi, 5% on bacteria, and 3% on one snake species (Ecological Society of America, 1997). Humans derive a lot of pleasure and happiness from nature's beauty, the possibility of which is made only through biodiversity. The decorative images people normally choose for their homes constitute just a small sample of the beauty that nature, in this case biodiversity, provides. These should, as well, remind humanity that beauty is fragile (Caserta, 2010). In spite of the numerous benefits outlined above, there are other economic (European Communities, 2008; Perrings et al., 1992), cultural, religious, spiritual, recreational and research values that form part of the complex equation which represents biodiversity (UNEP; 1995; MEA, 2005).

2.2 Biodiversity Losses

Globally, biodiversity is in trouble. The rate at which anthropogenic activities are altering the environment; the extent of these alterations and their consequences on the distribution and abundance of species, ecological systems, and genetic variability are unprecedented in human history, and pose significant threats to sustainable economic development and the quality of life (UNEP, 1995). Since the year 1600, 484 animals and 654 plants are recorded to have gone extinct although these figures are almost certainly underestimated, especially for the tropical regions (UNEP, 1995). For some groups of vertebrates and plants, between 5 and 20% of the species already identified are recorded as being threatened with extinction in the foreseeable future (UNEP, 1995). Between 1970 and 2005 alone the Living Planet Index (LPI), a means of assessing the state of global biodiversity, declined by 27% (WWF, 2008). By 1990, more than two thirds of the area of two of the world's fourteen major terrestrial biomes; temperate grasslands and Mediterranean forests, and more than half of the area of four other biomes; tropical dry forests, temperate broadleaf forests, tropical grasslands, and flooded grasslands, had been converted primarily to agriculture within the terrestrial ecosystems (MEA, 2005). In the United States of America, more than 30 ecosystems have been identified to be critically endangered, 58 endangered and more than 30 threatened (Noss et al., 1995).

The tropical forests represent the largest terrestrial reservoir of worldwide biodiversity in all its forms; from the genes through species to the habitats level, even though they cover less than 10% of the total land area (Mayaux et al., 2005; Sodhi, 2008; Benhin, 2006; Lane, 2010). Unfortunately, huge increases in human population and the corresponding increase in anthropogenic activities in the tropical region where these forests are found have depleted most of them. This increase in forest losses in the tropics is currently perceived to be a major threat to the rich biodiversity heritage of the countries and islands in the region (Lane, 2010). In addition to the well-known contribution of Asia to the world's population, the United Nations (2004) projects that, by 2050, population growth will be much faster in Africa than any other part of the world, which will add a further one billion to the tally, resulting in population increase from 13 to 20%. This presents a further threat to biodiversity in the tropical region because there will be an increase in the pressure already on agriculture which undoubtedly remains the main factor of land conversion in the tropical region (Achard, 2002). Despite the already 50% decrease in tropical LPI (WWF, 2008), more than 65% of the area in the regional biodiversity hotspots – areas with a high reservoir of biodiversity that are under threat from humans activities – is within the tropics (Conservation International, 2010a; Myers et al., 2000). These biodiversity hotspots, which cover 6 out of a total of 10 regions in Ghana, are areas which have lost at least 88% of their primary vegetation, their endemic species are restricted to just 1.4% of the terrestrial part of the globe and in the absence of greatly increased conservation efforts are likely to lose much if not most of their remaining primary vegetation within the foreseeable future (Sodhi, 2008; Myers et al., 2000).

2.3 Biodiversity in Ghana

Ghana, the study area, is located in West Africa on latitude 8° N and longitude 2° W. The country extends over five main ecosystem zones also known as eco-regions; Eastern Guinean Forests, Guinean Mangroves, Central African Mangroves, West Sudanian Savanna and Guinean Forest-Savanna Mosaic, which are discussed extensively in Section 2.4. Figure 2.1 shows the location of Ghana in Africa.

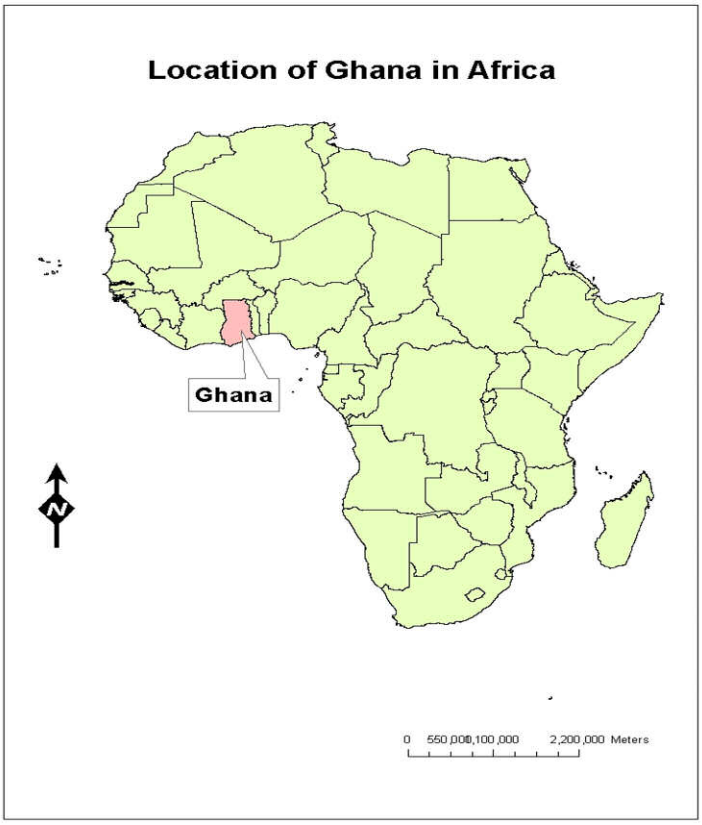


Figure 2.1 Location of Ghana in Africa.

This unique position is the reason for the country's richness in terms of biodiversity stock. It is believed that knowledge and information on genetics, species and ecosystem diversities existing in the country are diffuse, incomplete and inaccurate (GMES, 2002). The amount of information available on terrestrial ecosystems is even far better in terms of coverage than the aquatic ecosystems. To date, the entire microbial diversity of all types of ecosystems in the country remains almost unknown (GMES, 2002). So far, 2974 indigenous plant species, 728 birds, 225 mammals, 221 species of amphibians and reptiles have been recorded. Of these numbers, there are at least 3 frog species, 1 lizard and 23 butterfly species which are endemic (Convention on Biological Diversity – Ghana, 2010; GMES, 2002). Furthermore, 3 species of crocodiles and 7 species of birds are recorded as threatened (GMES, 2002).

A number of phenomena have been identified as threats to biodiversity in Ghana, some of which are deforestation, mining and quarrying, bushfires, wildlife hunting, forest conversion mainly for agricultural purposes, overexploitation and urbanisation (Benhin & Barbier, 2004; Benhin, 2006; GMES, 2002). The country was once renowned because of its extensive forests and wooded savannah, but that has changed drastically; the tropical moist forests which originally extended over 145000 km^2 of land are almost completely depleted, leaving only few fragmented, protected forests (GMES, 2002). Between 1938 and 1981 alone, the area of closed forest was reduced by 63% from 47000 km^2 to 17200 km^2, area of open woodlands was reduced by 37% from 111000 km^2 to 69800km^2 and by 1975 more than 90% of the country's high forests had been logged (GMES, 2002). As at 2002 the area of intact forest was estimated at between 15800 km^2 and 17200 km^2 which represents approximately 11% of the original cover, equivalently 6.9% of the country's total land area (GMES, 2002).

2.4 The Eco-Regions of Ghana

As mentioned in Section 2.3, Ghana extends over six eco-regions. Figure 2.2 is the map of the eco-regions of Ghana.

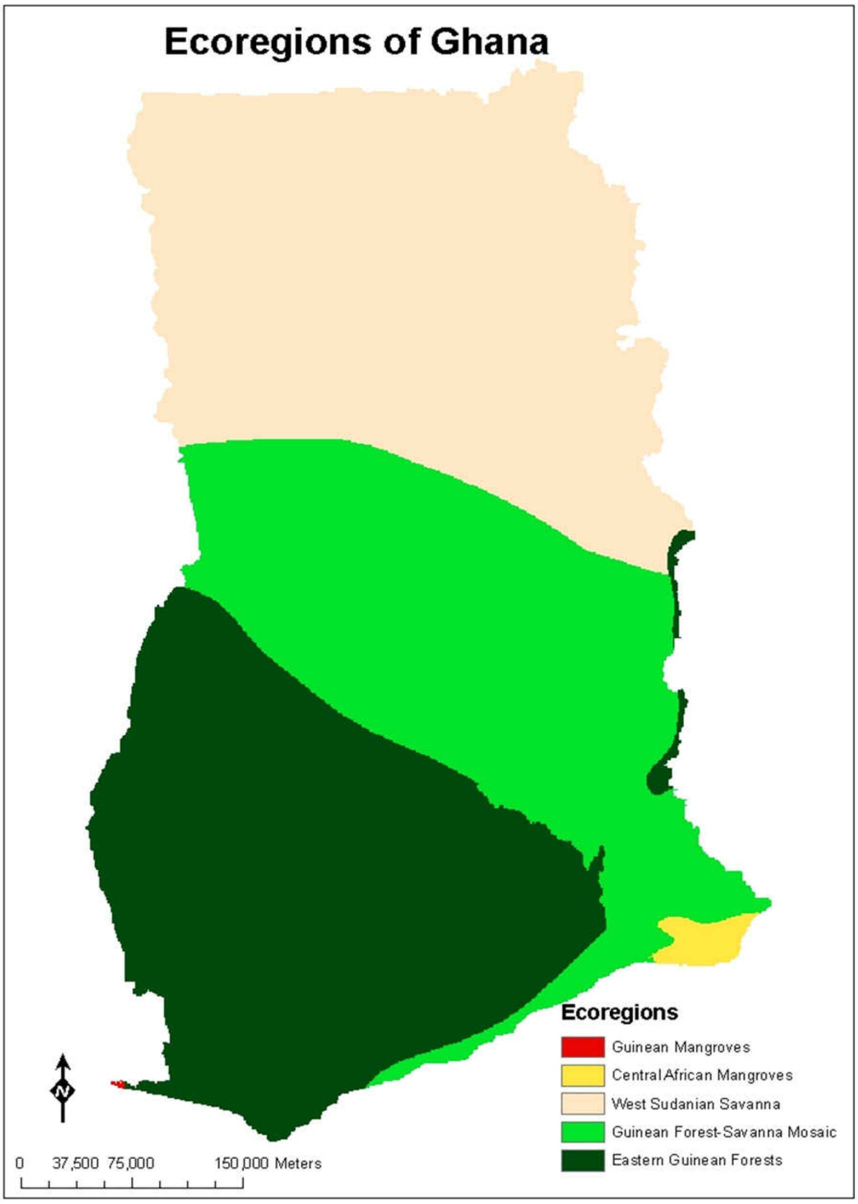


Figure 2.2 Map showing the eco-regions of Ghana.

2.4.1 The West Sudanian Savanna

The West Sudanian Savanna stretches from Senegal and Gambia across West Africa (including Ghana) to the eastern border of Nigeria. The eco-region is bounded at the south and the north by the Guinean Forest-Savanna Mosaic and the Sahelian Acacia Savanna respectively and has a total area of 1,638,500 km^2 (EoE, 2010a). It is a hot, dry and mainly flat and its vegetation is mapped as undifferentiated woodland which comprises woody trees (which are mainly deciduous in the dry season) with long grasses (which are mainly "elephant grasses"), shrubs and herbs under them. Towards the south, it is composed of shorter vegetation, having a different and impoverished floristic composition and a more scattered distribution. Small, grassy floodplains are found throughout this eco-region, with woodland and wooded grassland around its perimeter (EoE, 2010a).

The mean monthly maximum temperature in this region varies between 30°C and 33°C and the mean minimum temperature ranges between 18°C and 21°C (EoE, 2010a). Annual rainfall is as high as 1000 *mm* in the southern portion. However, this figure declines towards the north, with only 600 *mm* at the border with the Sahelian Acacia Savanna eco-region (Poorter et al., 2004; EoE, 2010a). Moreover, rainfall is highly seasonal in this region with the dry season capable of lasting for several months, usually from December to March (Poorter et al., 2004), during which time most trees lose their leaves and the long "elephant grasses" dry up which mostly results in frequent bushfires. The following figure shows a section of this eco-region.

Figure 2.3 Picture of a section of the West Sudanian Savanna eco-region downloaded from http://www.eoearth.org/article/West_Sudanian_savanna.

2.4.2 The Eastern Guinean Forests

The Eastern Guinean Forests is composed of a broad swath of land which extends from the western part of Ivory Coast through the eastern part of Ghana into the Togo Hills. Approximately 96% of the eco-region lies in between the east banks of the Sassandra River in west Ivory Coast and the west of Lake Volta in Ghana. The remaining portion of the eco-region is a small extension from the east of Lake Volta into the Togo Hills which lies mostly in Togo but extend across the border to easternmost Ghana, with one outlier in Benin. The portion of the eco-region near the border between Ghana and Ivory Coast extends northward and gradually fades into a mosaic of forest patches and tall grasslands of the Guinea Forest-Savanna Mosaic, which bounds the eco-region on the north. The south of the eco-region is the Gulf of Guinea.

In the south, the temperature ranges between 22 ^{0}C and 34 ^{0}C; however, temperatures are more extreme and can reach a maximum of 43 ^{0}C and fall to 10 ^{0}C on cold nights in the north (WWF, 2010a). The rainfall pattern in this eco-region is complex even though it can generally be divided into distinct wet and dry seasons (Poorter et al., 2004; WWF, 2010a). In Benin and Togo, the average annual rainfall seldom exceeds 1500 *mm*. In the south western zone of Ghana, the average annual rainfall ranges between 1000 *mm* and 2100 *mm*. Moreover, it is the portion in Ivory Coast which records the highest average annual rainfall, ranging between 1400 *mm* and 2500 *mm* (WWF, 2010a). Because rainfall in this eco-region declines inland, forest composition also changes along this gradient from the coastal zone to the inland areas.

The vegetation in the extreme south is moist and wet evergreen forest which turns into moist semi-evergreen forest inland, and which in turn becomes dry semi-evergreen forest in the northern parts of the eco-region (Poorter et al., 2004). This dry semi-evergreen forest represents the fringe of the forest belt. The high forest in the dry portion of the eco-region shares some characteristics with the lowland forests to the west of the eco-region, including a canopy at least 30 m tall (Poorter et al., 2004). Some individual trees in the mixed moist semi-evergreen rain forest in Ghana have heights ranging between 55 *m* and 60 *m* (WWF, 2010a). The semi-evergreen forest is relatively rich floristically. The Togo Hills unusually support forest vegetation in an area that should otherwise be covered by vegetation that is similar to that of savanna-woodland (Poorter et al., 2004). In Togo and Benin, the extent of forests is now greatly reduced compared with what existed at the turn of the century leaving small fragments made up of semi-evergreen or deciduous forest (Poorter et al., 2004; WWF, 2010a). A section of the vegetative cover in this eco-region is presented in the Figure 2.4 below.

Figure 2.4 Picture of a section of the Eastern Guinean Forests eco-region downloaded from http://www.worldwildlife.org/wildworld/profiles/terrestrial/at/at0111_full.html (Accessed 10 August 2010)

2.4.3 The Central African Mangroves

The Central African Mangroves eco-region is located mainly in West Africa. It is composed of mangrove areas along the coastlines of Ghana, Nigeria, Cameroon, Equatorial Guinea, Gabon, Democratic Republic of Congo and Angola (Wikipedia, 2010a; UNEP, 2007). Structurally, the mangrove areas of the eco-region vary significantly, from the lagoon systems found in the west to systems modified by complex patterns of sediment deposition at river mouths in the central and southern parts (EoE, 2010b; UNEP, 2007). The portion of this eco-region in Ghana is extremely small with an area of 1745 m^2 (less than 0.01 km^2) in south east Ghana enclosed between the Gulf of Guinea and the Guinean Forest-Savanna Mosaic eco-region.

The climate is mainly humid and tropical; however, it changes to more temperate conditions towards Angola. The average annual rainfall ranges between 750 *mm* and 6000 *mm* (EoE, 2010b). In Ghana and the western part of Nigeria, mangroves in this eco-region are primarily associated with extensive lagoons. These are enclosed parts of the year by sediments, when rainfall is lower making the freshwater outflow insufficient to counteract ocean swells. In the remainder of the eco-region, mangroves are mainly associated with river mouths, the largest of which is the Niger River Delta (EoE, 2010b).

There are different vegetation types in the eco-region, each of which is associated with a different soil type ranging from recently deposited unconsolidated, soft dark mud containing silt, clay and peaty clay, to transitional swamps. Vegetation here also varies depending on whether the soils consist of sandy troughs or muddy hollows. Five species of mangroves are found in this eco-region, including the red mangroves, the white mangroves, the black mangroves, as well as introduced species (EoE, 2010b; Wikipedia, 2010a). Below is a picture of a section of this this eco-region.

Figure 2.5 Picture of a section of the Central African Mangroves eco-region downloaded from http://www.eoearth.org/article/Central_African_mangroves (Accessed 11 August 2010)

2.4.4 The Guinean Forest-Savanna Mosaic

The Guinean Forest-Savanna Mosaic is an eco-region of West Africa which is a strip of interlaced forest, savanna, and grassland running east to west and dividing the tropical moist forests of the Eastern Guinean Forests eco-region near the coast from the West Sudanian Savanna eco-region of the interior. It occupies a total land area of 673600 km^2 (Wikipedia, 2010b) extending from the west of Senegal to eastern Nigeria, as well as portions of Gambia, Guinea Bissau, Guinea, Sierra Leone, Côte d'Ivoire, Ghana, Togo and Benin.

The eco-region has a dry and tropical climate which makes it vulnerable to bushfires. Bushfires are frequent especially during the dry season. They usually occur in small patches and are often caused by anthropogenic activities such as flush game hunting and bush burning for agricultural purposes.

Vegetation in this eco-region is made up of a combination of forests, savanna and grasslands, and is highly dynamic. The proportion of forest cover relative to other vegetation types varies greatly over time. The eco-region is a convergence zone for savanna and forest species. The forest areas are mainly patches that run along the rivers and streams and occasionally occur on hilltops, mountains, and ridges (WWF, 2010b). The driest parts of the region favour the growth of grass and inhibit the growth of trees especially those that are fire non-resistant. The southern boundary is characterised by a transition to a more continuous forest cover. There are wetlands in this eco-region host a diversity of water fowls and wading birds (WWF, 2010b). Figure 2.6 below is a picture of a portion of this eco-region.

Figure 2.6 Picture of a section of the Guinean Forest-Savanna Mosaic eco-region downloaded from http://www.nationalgeographic.com/wildworld/profiles/terrestrial/at/at0707.html (Accessed 12 August 2010).

2.4.5 The Guinean Mangroves

The Guinean Mangroves are a coastal eco-region of mangrove swamps along the rivers and estuaries near the ocean of West Africa from Senegal to Sierra Leone with very small, single patches in Liberia, Ivory Coast and Ghana. These mangroves extend from the coastlines far inland, up to 160 *km* from the coastline but tidal waters are able to penetrate deeply into the interior, carry salty water and make the mangroves thrive (WWF, 2010c; UNEP, 2007). There are seven mangrove species found in this eco-region and they have been found to be more similar to those found along the coast of the Western Atlantic than to those of Eastern Africa, giving evidence that the African and South American continents were once joined (WWF, 2010c). Like the Central African mangroves, these mangroves can grow as trees up to a height of 40 *m* or as shrubs below the high-water level of spring tides (UNEP, 2007). Figure 2.7 is a picture of a section of the Guinean mangrove eco-region.

Figure 2.7 Picture of a section of the Guinean Mangroves eco-region downloaded from http://www.nationalgeographic.com/wildworld/profiles/terrestrial/at/at1403.html (Accessed 12 August 2010).

Chapter 3: The GLOBIO-3 Model

3.1 Introduction and Background Information

For millennia, the world's terrestrial ecosystems have been altered by changes in climate, and humans to meet the growing demands for food, water, roads, building cities and towns, and other infrastructure. Although many of these changes have been of great benefit to humanity, they have also resulted in the transformation of primary ecosystems. Many government projects have created more poverty than development and the expansion of agriculture in most countries and regions has yielded increased frequency of floods without any substantial gains in food production. Presently, the challenge of meeting human demands for ecosystem goods and services is growing dramatically because of the magnitude of the human impact on terrestrial ecosystems, combined with growing human populations and the resulting high levels of consumption. These human impacts on these vital ecosystems pose serious threats not only health and food production but the economy as well.

The overreliance on trial and error approaches to managing terrestrial ecosystems has failed. There is, therefore, the need to look for better management approaches which are backed by scientific results (UNEP, 2002b). Even though the current scientific and technological advancements in ecosystem monitoring and data gathering provide a sound scientific basis for exploring the future consequences of policy choices made today, there have been very few efforts to apply science in this regard.

Conventional assessments of factors which affect ecosystems have usually been made through studies focused on specific ecosystems or species. Consequently, they fail provide a full assessment of the overall cumulative impacts of smaller, consecutive developments on a sub-national, national, continental or global scale. Because of the complexity of the world's ecosystems and the ecology of the 10-30 million plant and animal species on the Earth, the conventional approach has led to the undertaking of a considerably high number of case studies at various spatial and temporal scales (UNEP, 2001). Such a large number of studies, however, render long-term planning and decision-making very difficult, since the latter requires the appraisal of all relevant studies at once in order to assess cumulative impacts (UNEP, 2001). The different scales at which these studies are conducted compound this difficulty and the costs involved, in many cases are very expensive. Furthermore, most conventional models require unrealistically large amounts of input-data in order to be effective, and are not practical in national, industrial, or social planning (UNEP, 2001). In order to ensure that the objectives of sustainable development are realised, there is a critical need for tools that help assess the likelihood of environmental impacts of different developmental proposals. It is in light of this that the GLOBIO (Global methodology for mapping human impacts on the biosphere) was developed. It is therefore a pioneering attempt to meet the scientifically-based information needs of decision-makers and the public with the aim of providing a good idea about the consequences of their choices today for the future of biodiversity, sustainable development, and local cultures (UNEP, 2001).

GLOBIO examines the potential consequences of different scenarios of land use, infrastructural development, climate change, fragmentation and nitrogen deposition in the coming decades. Although there are many other factors which affect terrestrial ecosystems, the GLOBIO has elegance and strength which lie precisely in its focus on a simple and straightforward relationships between the six aforementioned factors and terrestrial ecosystems (UNEP 2001; Alkemade et al., 2009). It provides the opportunity to explore the consequences of human actions in the future (UNEP, 2001) as well as the opportunity to assess the current state of biodiversity. The GLOBIO project was initiated to provide an inexpensive, simple, scientifically-based communication tool for mapping, at global and national scales, the likelihood of human impacts on the biosphere resulting from increasing growth in resource utilization (UNEP, 2001). It is thus intended to bring scientific evidence on human impacts into a format suitable for policymaking.

3.2 Historical Stages of the GLOBIO Model

The GLOBIO is a global methodology for mapping human impacts on the biosphere (Prydatko et al., 2008; UNEP, 2001, Alkemade et al., 2009). The methodology was first published in 2001 as GLOBIO-2 with the objective of providing a quantitative assessment of human influence on biodiversity through the relationships between species diversity and the distance to roads and other infrastructure (Alkemade et al., 2001, UNEP, 2001). It was a distance-related, multivariable, buffer-based model for estimating the extent of land area with reduced abundance and biological diversity of living organisms, as a result of infrastructural development (UNEP, 2002a). According to UNEP (2001), the requirements set for the methodology are: a low cost, quantitative, scientifically sound, logic and simple communication tool linking development to environmental impacts. Because the GLOBIO-2 was mainly based on the impact of roads and other infrastructural developments, it was directly suitable for

1. the assessment of the ecological, cultural and socio-economic aspects of developmental projects;
2. the provision of guidance in development planning with minimum impacts;
3. the analyses of human impacts on biodiversity at various spatial scales, including sub-national, national, regional, and global scales;
4. the provision of guidance necessary for conservation;
5. undertaking scenario assessments; and
6. the assessment of impacts with complex multiplicative effects such as fragmentation (UNEP, 2001).

Before the development of GLOBIO-2, the Natural Capital Index framework (NCI) (ten Brink, 2000) had been developed by the Netherlands Environmental Assessment Agency as a contribution to the implementation of the Convention on Biological Diversity (CBD). From 1996 when it was developed, the NCI was used a biodiversity indicator representing the relative abundance of original species, compared to a postulated baseline, set in pre-industrial times (PBL, 2010b; ten Brink, 2000). Although the NCI was originally designed to be based on monitored data, a pressure-based NCI was developed in 1997 for providing future outlooks by computing the remaining species abundance based on projections of biodiversity drivers (land use and climate change) using input data supplied by the Integrated Model to Assess the Global Environment (IMAGE) (PBL, 2010b). Between the years 1997 and 2002 the NCI-IMAGE framework was applied in various assessments (UNEP, 1997; 2002b) on sub-national, national and global levels.

In order to provide an assessment platform of evaluating the global targets on biodiversity, an international consortium, made up of the UNEP World Conservation Monitoring Centre, UNEP GRID-Arendal and the Netherlands Environmental Assessment Agency joined forces in 2003 and combined the GLOBIO-2 and the IMAGE-NCI approaches into a new Global Biodiversity Model (GLOBIO-3) and it has been used since 2005 for various sub-national, national and global biodiversity assessments (PBL, 2010a; Alkemade et al., 2009).

As an improvement over the previous version, the GLOBIO-3 (Alkemade et al., 2009; van Rooij, 2008; 2009; Prydatko et al., 2008; Trisurat et. Al., 2010) was developed to accommodate more biodiversity drivers: land use, infrastructural development, climate change, fragmentation, and atmospheric nitrogen deposition. This inclusion of several factors has given the GLOBIO-3 a wider scope of application relative to the previous version. The impact of these drivers on biodiversity is derived from a set of cause-effect equations based on a quantitative synthesis of a series of peer-reviewed literature also known as meta-analysis. Similar to the NCI, it provides a quantitative estimate of the remaining biodiversity by representing the changes in the naturalness with a proxy indicator, Mean Species Abundance (MSA). Since the year 2005, the GLOBIO-3 has been used for several assessments (Leadley et al., 2010; Trisurat et al., 2010; Prydatko et al., 2008) at different spatial scales. A major limitation of the GLOBIO-3 is that fact that it is applicable only to terrestrial ecosystems.

Presently, a global model for aquatic biodiversity (GLOBIO-aquatic) which seeks to address the application limitation of GLOBIO-3 is being developed (Janse et al., 2009). The GLOBIO-aquatic module aims to assess the combined impacts of the drivers of change in a river basin: climate change, irrigation, agriculture (eutrophication, wetland conversion), overfishing, invasive species, hydraulic infrastructure, dams and river channelization, deforestation and urban pollution on aquatic biodiversity (Janse et al., 2009). Similar to the terrestrial biodiversity model, the GLOBIO-aquatic derives the cause-effect relationships between the biodiversity drivers and biodiversity from meta-analysis of literature data. The first version of GLOBIO-aquatic module became ready in 2009 and the environmental pressures included in this model are land use and eutrophication in catchments, and damming of rivers for hydropower or water extraction (PBL, 2010c). The other environmental pressures will be included in a later stage. In this model also the impacts of these pressures on biodiversity are captured in terms of the mean abundance of original species relative to their abundance in undisturbed ecosystems (Janse et al., 2009; PBL, 2010c). The current version of GLOBIO-aquatic is limited to freshwater ecosystem types: rivers, lakes and wetlands.

3.3 GLOBIO-3 in Detail

The GLOBIO-3 model is a tool used for the assessment of past, present and future human impact on biodiversity. It describes biodiversity as the remaining Mean Species Abundance (MSA) of original species (plants and animals), relative to their abundance in primary vegetation, which are assumed to be undisturbed by human activities for a prolonged period (Alkemade et al., 2009; Prydatko et al., 2008; Trisurat et al., 2010). The MSA, a proxy indicator of biodiversity, considers biodiversity as a stock entity containing all original species and their corresponding abundance. Therefore, it is the average abundance of the original species compared to their abundance in the natural state represented as a value belonging to the set $\{x| \ 0 \leq x \leq 1\}$. The methodology is designed to quantitatively compare MSA patterns and changes in them at different spatial scales, ranging from sub-national to global. The GLOBIO-3 is currently restricted to the terrestrial part of the globe, excluding Antarctica (Alkemade et al., 2009). The uniqueness of the model lies in its ability to provide relatively accurate national and global biodiversity assessments without considering individual species responses. However, by using the MSA, the average response of the total species belonging to the ecosystem under study is represented in the assessment. It is composed of a set of equations which represent cause-effect relationships between biodiversity drivers and their impacts on biodiversity derived from literature using meta-analyses (Alkemade et al., 2009). The driving factors that were used in the original GLOBIO-3 model (Alkemade et al., 2009) are the following.

1. Land use
2. Infrastructural development
3. Fragmentation
4. Climate change
5. Atmospheric nitrogen deposition

So far, no cause-effect relationships for the biodiversity drivers; biotic exchange and atmospheric CO_2 concentration, exist so they are excluded from GLOBIO-3 (Alkemade et al., 2009). The module on infrastructural development is obtained from GLOBIO-2 (UNEP, 2001). Moreover, the biodiversity drivers; land use change and harvesting (mainly forestry), atmospheric nitrogen deposition, fragmentation, and climate change are obtained from the IMAGE (Alkemade et al., 2009).

The GLOBIO-3 is applicable for the assessment of

1. the impacts of biodiversity drivers on MSA and their relative importance;
2. the expected trends under various future scenarios; and
3. the possible impacts of various responses or policy options (Alkemade et al., 2009).

3.3.1 Calculation of MSA and Relative Contribution of Each Environmental Driver

For each driver, x, an impact map, MSA_x, having the mean species abundance value for each cell over the entire study area is computed in ArcGIS by applying the cause-effect relationships to the appropriate input map(s). So far, there exists very little quantitative information on the interaction between drivers (Alkemade et al., 2009). For cases where there exist no interactions between the drivers, the overall means species abundance (MSA_x) for each cell, i, is obtained by multiplying the MSA value derived from the cause-effect relationship between each driving factor and biodiversity for the cell, i, according to the following equation:

$$MSA_{x_i} = MSA_{LU_i} * MSA_{I_i} * MSA_{F_i} * MSA_{CC_i} * MSA_{N_i} \qquad (3.1)$$

where, MSA_{x_i} is defined as a function of LU, I, F, CC and N being land use, infrastructural development and fragmentation, climate change and atmospheric nitrogen deposition respectively. For cases where there exit complete interaction, only the worst impact is allocated to each grid cell (Alkemade et al., 2009). Full details on how MSA_{LU}, MSA_I, MSA_F, MSA_{CC} and MSA_N are obtained are given in van Rooij (2006; 2008; 2009).

Because the area of land within the IMAGE (where drivers like land use is obtained) grid cells are not equal, the overall MSA of the area is the area weighted mean of MSA_i values of all relevant grid cells (Alkemade et al., 2001; van Rooij, 2008). This is obtained according to the following equation:

$$MSA_A = \frac{\sum_i MSA_i * A_i}{\sum_i A_i} \qquad (3.2)$$

where A_i is the land area of grid cell i. From equations (3.1) and (3.2), the relative contribution of each driver to a loss in MSA may be computed.

The following is a simple illustration of how the MSA relative to land use is calculated.

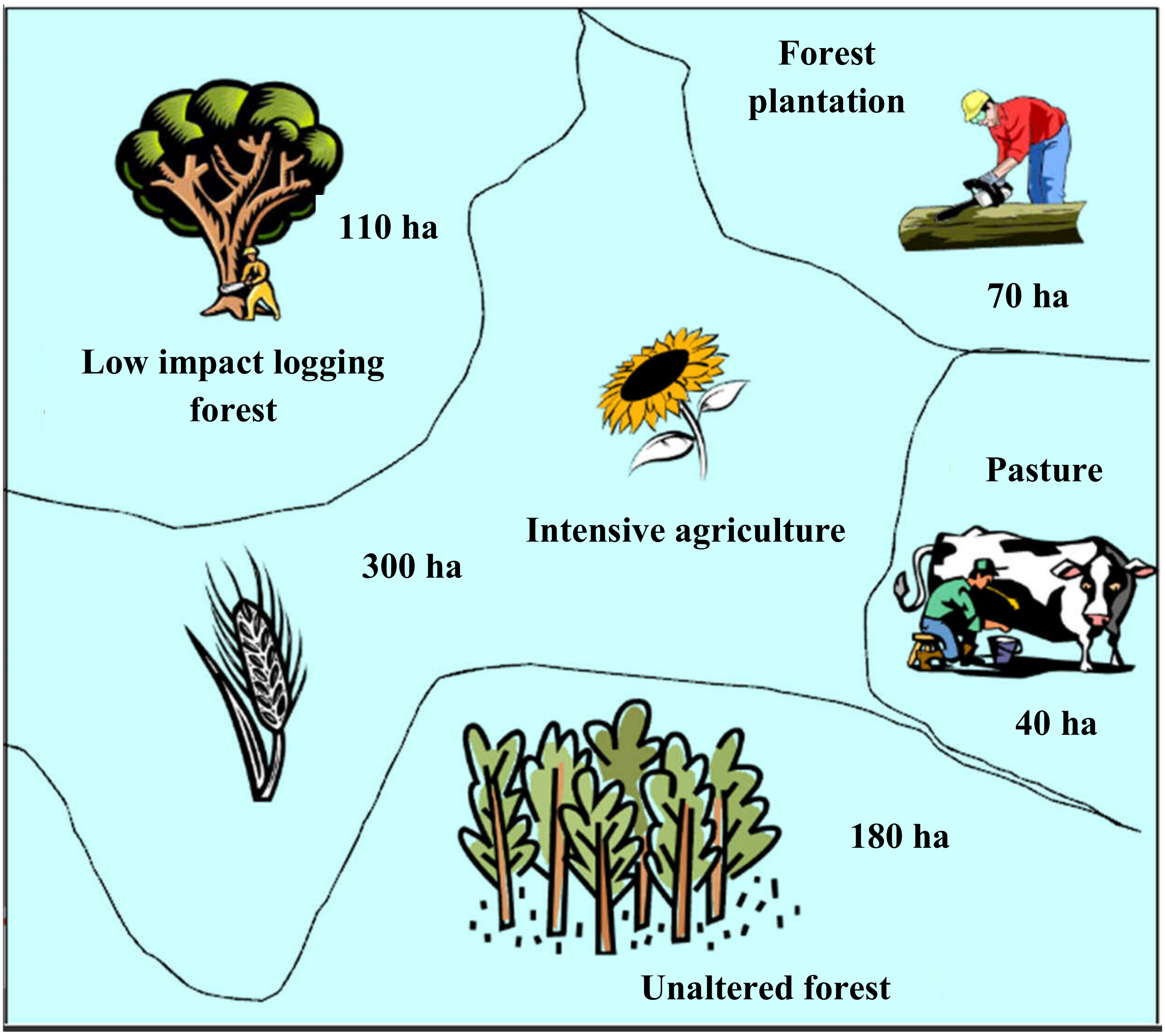


Figure 3.1 Land use map of a hypothetical GLOBIO-3 study area (modified from van Rooij (2009)).

The MSA values for the above types of land use intensities obtained from (Alkemade et al., 2009) are the following.

1. Low impact logging forest (lightly used natural forest) = 0.7
2. Primary forest (unaltered forest) = 1
3. Intensive agriculture = 0.1
4. Man-made pasture = 0.1
5. Forest plantation = 0.2

From Figure 3.1, the MSA of the hypothetical GLOBIO-3 study area relative to land use is calculated according to the following equation.

$$MSA_{LU} = \frac{(110 * 0.7) + (70 * 0.2) + (300 * 0.1) + (180 * 1) + (40 * 0.1)}{110 + 70 + 300 + 180 + 40} = 0.4357$$

$$= 43.57\%$$

From the above calculation, the remaining biodiversity due to land use is obtained as 43.57%, which implies that the biodiversity loss due to land use is 53.43%.

3.4 The Drivers of Biodiversity

3.4.1 Land Use Changes

Land use refers to the human modification of the natural environment into built environment such as fields, pastures, and settlements. These modifications also known as land use changes have great consequences on biodiversity (IPCC, 2002; Alkemade et al., 2009; Jiang et al., 2003; Gaston et al., 2003; Slingenberg et al., 2009). It is important to note that different types of land use have different impacts on biodiversity.

In Jiang et al. (2003), for example, among the three $1km$ sites chosen to study the relationship between land use type and biodiversity, the site dominated by farmland was found to have the least value in terms of species richness compared with the other two sites, one of which had mostly natural vegetation and the other, forest plantation. In the same study, moreover, afforestation and grass planting were found to have made changes in the floristic features of plants compared with the natural vegetation in several aspects even though they had a small positive impact on biodiversity at the local ecosystem level. In their study, in which land use was categorised into 16 classes, Gaston et al. (2003) reported that between a fifth and a quarter of the world's bird population in the pre-agriculture era had been lost. In addition, their result strongly suggested that bird population increases which resulted from habitat conversion only went a short way towards balancing the associated loses. Tropical deforestation and transformation to cropland and pasture were also found to result in continued biodiversity loss.

Other studies (Brenda, 1999; Alkemade et al., 2009; Milchunas et al., 1998; Slingenberg et al., 2009) have also addressed the relationship between biodiversity and other classes of land use such as livestock grazing and human settlements.

For the purpose of GLOBIO, a meta-analysis was done by Alkemade et al. (2009) on the cause-effect relationship between land use modification and biodiversity. In the publication, they associated the relationship between 15 different classes of land use and biodiversity with appropriate MSA values. Table 3.1 is a summary of their results together with similar information from van Rooij (2008).

Global Land Cover Class	Sub-Class	MSA
Forests	Natural forests	1.0
	Lightly used natural forests	0.7
	Secondary forests	0.5
	Forest plantations	0.2
Agriculture	Low-input (extensive) agriculture	0.3
	Intensive agriculture	0.1
	Irrigated intensive agriculture	0.05
	Perennials and woody bio fuels	0.2
Mosaic cropland/forest	Agroforestry	0.5
Scrublands and grasslands	Natural grasslands and scrublands	1.0
	Man-made pastures	0.1
	Livestock grazing area	0.7
Natural bare & rock and snow & ice	Primary vegetation	1.0
Artificial surfaces	Build up area	0.05

Table 3.1. Relationship between land use classes used in GLOBIO-3 and biodiversity.

3.4.2 Infrastructural Development

From the beginning of the 21st century, many economies worldwide have achieved budget surpluses and countries are investing, now more than ever, in improving infrastructure to meet the challenges of the century. In the World Development Report 1994, the World Bank (1994) stated that for several past decades the availability of infrastructure had increased significantly in the developing countries. For many governments, increasing country access through the construction of better roads and rail network, building ports for global trade, expanding telecommunication networks, generating adequate electric power for constant supply of electricity and exploring lands and waters in search of oil and gas and other natural resources are activities essential for the continued expansion of their economies and to meet the challenges of the ever-expanding population. This is true and, indeed, the World

Bank (1994) acknowledges it in a statement which refers to infrastructure as ‘wheels’ of the economy, if not the engine, however, there is the need to take biodiversity conservation concerns into account whenever an infrastructural project requires changes in land use.

The environment is greatly affected by the presence of infrastructure, such as roads, airports, pipelines, power lines, and dams, even with low levels of transportation traffic (UNEP, 2001; van Rooij, 2008). It follows then that, roads and other infrastructure impact wildlife and biodiversity (Benítez-López et al., 2010) in general through the modification of animal behaviour and species distribution (UNEP, 2001). The construction of roads and railways give humans access to previously inaccessible areas and this is where the most important impact of infrastructure on biodiversity is seen (van Rooij, 2008). Even though roads take up less than 0.1% of land even in densely populated areas (van Rooij, 2008), their impacts on biodiversity in some areas, especially densely forested areas, are much high. Light and wind penetrate the forest through the edges of the road causing forest dryness and humans are able to enter and subject the forest to all sort of activities including hunting, agriculture and extraction of other forest products.

Animals, the most vulnerable of which are insects and smaller reptiles, are directly impacted by infrastructure through collisions with vehicles. Apart from this, roads form physical barriers and sometimes tend to be too hot or dry for animals when trying to cross from one side to the other (van Rooij, 2008). In some cases where there is a valley on one or both sides of a road, guardrails may be constructed along the road to prevent vehicles from leaving the roadway, not to mention barriers that are raised in the middle of dual carriageways to keep vehicles in their lanes. Whereas these restrictions on roads are good for human safety, they prevent certain animals from crossing and even cause discomforts to those that can safely run across. Other animals are so vulnerable that a slight alteration in their natural habitats, introduction of exotic species (UNEP, 2001) or even substantial noise could cause a sharp decline in their population densities. In fact, many studies (Barber et al., 2009; Schaub et al., 2008; Parris et al., 2009; Forman and Alexander, 1998) have established that noise is becoming so ubiquitous to the extent that it may threaten biodiversity. According to Barber et al. (2009), noise pollution worsens the problems associated with habitat fragmentation and wildlife responses to human presence. With their experiment, Schaub et al. (2008) tested and confirmed the hypothesis that bats avoid foraging areas with large background noise. Notwithstanding the fact that vegetation potentially reduces noise (Chih-Fang and Der-Lin, 2003; Watts et al., 1999; Anderson et al., 1984) and that the effect noise on biodiversity may be minimal at far distances from roads, areas within shorter distance ranges become degraded in their suitability not only as foraging areas (Schaub et al., 2008) but as habitats for other species.

It is quite clear at this point to note that the degree of impact of infrastructure, the dominant of which are roads, on the biodiversity of an area depends on the kind of species which make up the surrounding ecosystem. Benítez-López et al. (2010) gives a comprehensive account of the impact of infrastructure on bird and mammal populations. From the meta-analysis of data they gathered from 49 studies on 234 mammal and bird species, they found that mammal and bird population densities declined with their proximity to infrastructure even though the distances for which infrastructure had no influence on their population densities were different; $1km$ and $5km$ for birds and mammals respectively. The following is the result of their analyses.

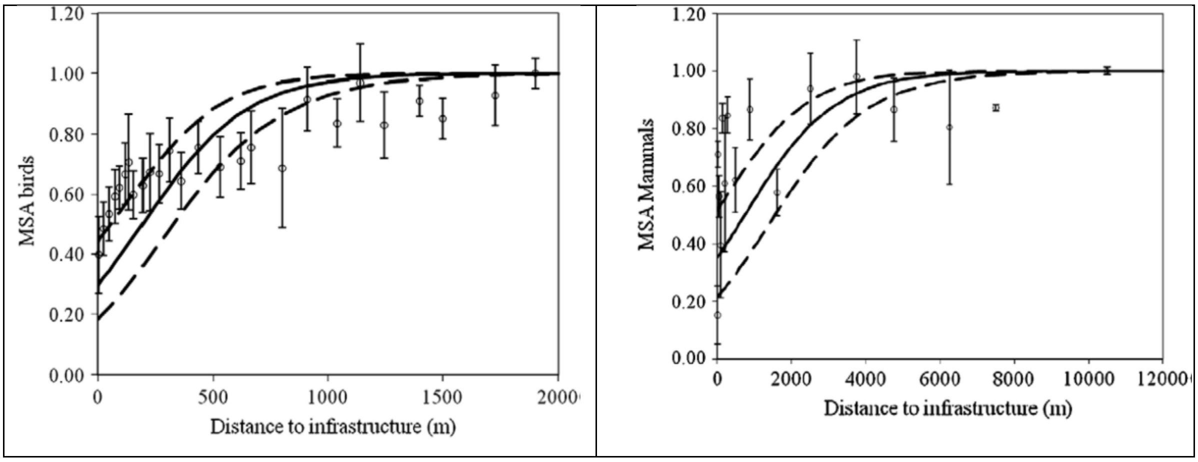


Figure 3.2. The relationship between distance to infrastructure and mean species abundance for birds and mammals copied from Benítez-López et al. (2010).

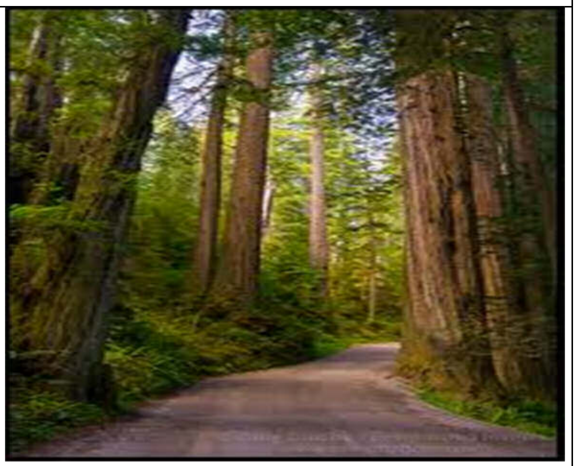
Infrastructural development has impacts on vegetation as well. In UNEP (2001), it is noted that the impacts of roads on vegetation are greater at distances less than $1km$ not only because of road dust but increases in plant water discharge and changes in albedo. In fact, the probability of impact of infrastructure on vegetation varies with type of disturbance involved. In the Artic, for example, the impact of infrastructure on the vegetation and hydrology of the tundra is relatively small from power lines and pipelines; however, greater impacts are generally related to changes in snow distribution, ablation patterns, and minor disturbances of soils within $5km$ distance range (UNEP, 2001).

Apart from roads and railways it is important to note that other forms of infrastructure have impact on biodiversity as well. For example, groundwater extraction has been identified to pose threats to groundwater-dependent ecosystems (Brown et al., 2007) including savanna ecosystems which depend on exceptionally deep rooted trees. In addition to this, phone masts constructed for communication purposes have been found to have profound impacts on various terrestrial species including birds, mammals, amphibians, insects and vegetation. A detailed account of the impacts of microwaves from these masts is given in Balmori (2009). Figure 3.3 is an illustration of some impacts of roads on biodiversity.

a. Construction of road through the bush (downloaded from http://nationalzoo.si.edu/scbi/MAB/conservation/centralafrica/gabon/roads.cfm)

b. A black-tailed deer killed on a highway (downloaded from http://www.vancouversun.com/technology/More+than+wild+animals+killed+drivers+highways+last+year/2200137/story.html)

c. A bear crossing the road (downloaded from http://nmcintyre.kua.press.kua.org/2009/12/17/road-kill/)



d. A road through the forest (downloaded from http://www.enlightphoto.com/webpages/NewImages/new01-03.html)

Figure 3.3. Some impacts of roads on biodiversity.

In GLOBIO-3, the module on the cause-effect relationship between infrastructure and biodiversity is based on the module developed for GLOBIO-2 in UNEP (2001).

3.4.3 Climate Change

It is a well-established fact that changes in climate (major components being temperature and precipitation) have significant impacts on biodiversity (IPCC, 2002; Leemans and Eickhou, 2004; Gregory et al., 2009; Bakkenes et al., 2006; Hanski, 2005; Warren et al., 2001). As climate changes, many local species shift from their current habitats to areas better suited to them. As global average temperature rises, the implication is that many species, not only animals but plants, may experience a range shift towards the poles and, potentially, cause problems for the existing species in those areas or vice versa. These movements of species between different climatic zones are undoubtedly detrimental to biodiversity. In their studies, because the distribution and production of ecosystems and the species they contain are directly controlled by climate, and that each climate zone is characterised by a typical ecosystems, Leemans and Erickhou (2004) used the shifting processes of ecosystems (based on four different indicators) to estimate the rate of change in ecosystems on the basis of global mean temperature. From the result of their analyses, they observed that that even small changes in climate could have substantial consequences on terrestrial ecosystems, most of which involve reduction in biodiversity, especially those that are temperature-limited like tundra. A summary of their results is given in the Figure 3.4 below.

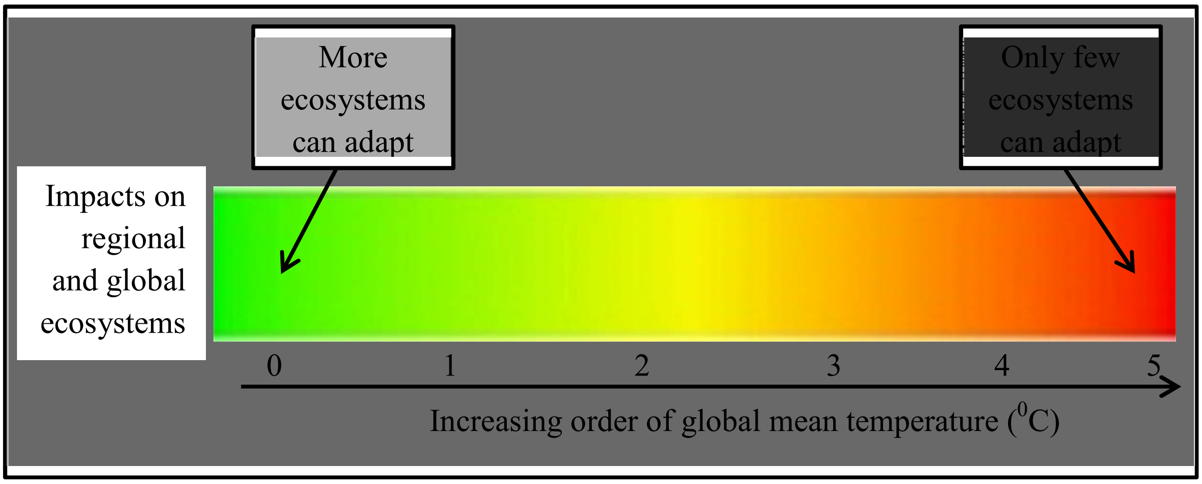


Figure 3.4 Diagram showing the relationship between global mean temperature and the corresponding impact on regional and global ecosystems.

A methodology similar to this was used by Gregory et al. (2009) with which they found that there is a significant relationship between population variation trend and the change in potential shift range extent. This indicates that, indeed, shifts in climate zones resulting from changes in climatic variables affect biodiversity by changing the distribution of animal and plant species. Moreover, climate change is particularly detrimental in regions where natural habitats are highly fragmented, and which hinder the movement of species over geographical ranges when shifts in climate zones occur (Warren et al., 2001).

In IPCC (2002), some information regarding temperature and precipitation changes over the last 100 years are given. The paper reports that over the 20th century, there was consistent, large-scale warming of both land and ocean surfaces, with the most observed warming likely to have occurred during the last 50 years of the century due to increases in greenhouse gas concentration. From Bakkenes et al. (2006), it is read that global greenhouse gas emission in the absence of climate change policies (the baseline scenario) leads to a global mean temperature increase of more than 3^0C over pre-industrial levels by the year 2100. Again, in IPCC (2002), it is reported that whereas increase in precipitation ranged between 5 to 10% during the same period over most mid and high latitudes of the Northern Hemisphere continents, approximately 3% decrease in rainfall was recorded on average over most parts of the subtropical land areas. In the same report, global average surface temperature is projected to increase by a value between 1.4 and 5.8^0C over the period of the period between 1990 and 2100 with nearly all land areas warming more rapidly that the global average, and global average annual precipitation is projected to increase during the next 100 years with both increases and decreases in precipitation between 5 and 20% at the regional scale.

It is reasonable, at this point, to ask how these changes translate into changes in biodiversity. In the same report, IPCC (2002), indicated that for the same period, there were discernible impacts of regional climate change, especially increases in temperature, on biological systems. According to the report, many species showed changes in morphology, physiology, and behaviour in response to changes in these climatic variables, not to mention changes in the timing of biological events. Apart from the above mentioned changes in biodiversity, the following, all of which are linked to changes in climatic variables, were also observed in the terrestrial ecosystems.

1. Changes in species distribution.
2. Increased frequency and intensity of outbreaks of pest and diseases.
3. Changes in streamflow, floods, droughts, water temperature and water quality.

In GLOBIO-3, the cause-effect relationships between climate change and biodiversity are obtained from models including the species-based logistic regression model, EUROMOVE (Bekkenes et al., 2006) and IMAGE (PBL, 2010b) with support from the results obtained by Leemans and Erickhou (2004) are implemented. This cause-effect relationship expressed with a simple linear regression that relates predicted temperature rise to impacts on MSA for different biomes is the following,

$$MSA_{CC} = 1 - S \times \Delta T \qquad (3.3),$$

where CC is climate change, S represent sensitivity values also called *Slopes* in mathematical regression equations and ΔT is the change in temperature based on the Organisation for Economic Co-operation and Development (OECD) baseline scenario (van Rooij, 2006). S and ΔT are obtained from Tables 3.2 and 3.3 below.

Biome	**Slope, S ($°C^{-1}$)**	
	IMAGE	**EUROMOVE**
Ice	0.023*	0.050
Tundra	0.154	0.070*
Wooded tundra	0.284	0.051*
Boreal forest	0.043*	0.079
Cool conifer forest	0.168	0.080*
Temperate mixed forest	0.045*	0.101
Temperate deciduous forest	0.100*	0.109
Warm mixed forest	0.052*	0.139
Grassland and steppe	0.098*	0.193
Hot desert	0.036*	-
Scrubland	0.129*	0.174
Savanna	0.093*	-
Tropical forest	0..034*	-
Tropical woodland	0.039*	-

Table 3.2 Slope values computed from IMAGE and EUROMOVE for different biomes (developed from a *Climate.xls* file obtained from Netherlands Environmental Assessment Agency). The slope values with * against them are those used in GLOBIO-3.

Year	Temperature change (ΔT)
1970	0.187
1975	0.179
1980	0.217
1985	0.302
1990	0.382
1995	0.496
2000	0.569
2005	0.647
2010	0.759
2015	0.882
2020	1.007
2025	1.149
2030	1.298
2035	1.432
2040	1.573
2045	1.714
2050	1.847

Table 3.3 Predicted temperature values for different years based on OECD baseline scenario (developed from a *Climate.xls* file obtained from Netherlands Environmental Assessment Agency).

3.4.4 Fragmentation

When primary vegetation is subjected to intense exploitation such as intensive agriculture or continuous extraction of natural products, it becomes divided into separate fragments. This division process is called fragmentation. Franklin et al. (2002) defines the process of fragmentation more technically as the set of mechanisms which lead to the discontinuity in the spatial distribution of resources and conditions present in a habitat (or ecosystem) at a given scale that affects occupancy, reproduction, and survival in particular species. These mechanisms of discontinuity may be anthropogenic or natural. A major anthropogenic activity which causes fragmentation is road construction and ecosystems suffer more when road networks are expanded. A similar situation arises when water channels are created for irrigation purposes. On the other hand, habitat fragmentation can also be caused by geological processes that slowly alter the layout of the physical environment or formation of new river courses.

It is quite obvious at this point that there exists an important relationship between infrastructure and fragmentation. In Bekker and Iuell (2004), transportation infrastructure is regarded as a principal cause of fragmentation. Fragmentation results in changes in ecosystem processes, the result of which is a further habitat decline and species loss (Hobbs, 1993; Bekker and Iuell, 2004). According to Solé et al. (2004), fragmentation and loss of habitat are regarded as the greatest existing threats to biodiversity. Generally, species with large area requirements and those with strong dependence on a specific type of habitat are the ones which are most vulnerable to habitat fragmentation (Bekker and Iuell, 2004).

The result of the meta-analyses done by Alkemade et al. (2009) revealed that the impact of fragmentation on biodiversity depends on the total area occupied by the fragmented patch. Their result, which is also implemented in GLOBIO-3 is summarised in the Table 3.4 below.

Area of fragmented patch (km^2)	MSA
Less than 1	0.3
Less than 10	0.6
Less than 100	0.7
Less than 1000	0.9
Less than 10000	0.95
Greater than 10000	1

Table 3.4 The relationship between patch area and biodiversity (measured in mean species abundance).

3.4.5 Atmospheric Nitrogen Deposition

The term, nitrogen deposition, is used to describe the input of reactive nitrogen species which are mainly from nitrogen oxides (NO_x) and ammonia (NH_y) in the atmosphere to the biosphere. The emission of these gases into the atmosphere has been linked primarily to agricultural and industrial activities such as combustion of fossil fuel, production and application of nitrogenous fertilizer, widespread cultivation of legumes, rice and other nitrogen-fixing crops and intensive stockbreeding (Galloway et al., 2003; Vitousek et al., 1997)

Naturally, among the life-needed chemical elements, nitrogen (N) has the greatest total abundance in the Earth's atmosphere, hydrosphere, and biosphere even though it is the element least readily available to sustain life (Galloway et al., 2003). Of this huge abundance, less than 1% is available to more than 99% of living organisms, the reason being that N is almost entirely in the form of molecular nitrogen; a chemical form that is not usable by most living organisms, and whose inter-atomic bond could be broken primarily through high-temperature processes such as lightning or biological nitrogen fixation in the pre-human world (Galloway et al., 2003).

Presently, the situation is different. Anthropogenic activities of different forms are promoting the transfer from the vast and unreactive atmospheric pool of N to biologically available forms on land through biological nitrogen fixation (Vitousek et al., 1997). For example, between 1940 and 1997, industrial nitrogen fixation increased exponentially from near zero and today a total of greater than 20 teragrams of fixed N is emitted to the atmosphere annually through fossil-fuel combustion (Vitousek et al., 1997).

These developments have direct and indirect impacts on ecosystem health at different spatial scales (Xiankai et al., 2008; Vitousek et al., 1997; Galloway et al., 2003, Alkemade et al., 2009). In the terrestrial ecosystem species respond differently to N deposition. In Xiankai et al. (2008), it is noted that understory vascular plants and cryptogam plants are more sensitive to N deposition than arborous plants. It is quite straightforward to conclude from this that anytime N deposition exceeds the critical load, the level above which N deposition is detrimental to ecosystem health, species that respond slowly are likely to dominate the fast-responsive ones which would affect the biodiversity of the area. Apart from plants, excess amounts of N deposition have impacts on the diversity of other species including fungus, bacteria and animals (Xiankai et al., 2008). Excess N availability also causes nutrient imbalances in plants and reduction in the diversity of species at the landscape level and species richness within communities which consequently affect other aspects of ecosystem function (Vitousek et al., 1997).

In Alkemade et al. (2009), the cause–effect relationships between the amount of N added annually which exceeds the empirical critical-load level and the relative local species richness in terms of mean species abundance were established. A summary of their result which is also implemented in GLOBIO-3 is given in Table 3.5 below.

Ecosystem	**Equation**	**Applicable land cover class**
Artic alpine ecosystem	$MSA_N = 1 - 0.15\ln(NE + 1)$	Snow and ice
Boreal & temperate forests	$MSA_N = 1 - 0.22\ln(NE + 1)$	Forests
Grasslands	$MSA_N = 1 - 0.19\ln(NE + 1)$	Grassland and scrubland

where $\boldsymbol{NE}$ is the calculated amount of $\boldsymbol{N}$ added in excess to the critical $\boldsymbol{N}$-load.

Table 3.5. Regression equations expressing the relationship between excess N and MSA for three ecosystems.

Chapter 4: Application of GLOBIO-3 for the Assessment of Biodiversity in Ghana

4.1 Production of Impact Maps for Each Environmental Driver

GLOBIO-3 is implemented as a process. This is because in the production of impact maps for some biodiversity drivers, outputs from calculations carried for the production of impact maps for other drivers are required as inputs. The first step in the process is always land use, followed by infrastructure. Once the impact maps of these drivers have been produced, the others can follow in any order. The following is a flow chart of the order in which the impact maps for the biodiversity drivers were produced. Atmospheric nitrogen deposition data for Ghana is not available so it was excluded.

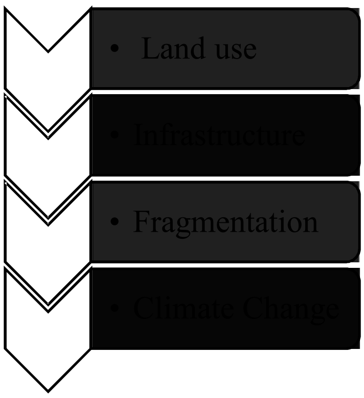


Figure 4.1 Impact calculation flow chart.

In order to get grid sizes of similar size, GLOBIO-3 uses map projections which preserve area. For this reason the Africa Albers Equal Area Conic projected coordinate system is used. Moreover, all maps need to be in grid (raster) form with cell size $1000m \times 1000m$.

It should be noted that the steps outlined in this chapter have been heavily compressed even though they capture all the relevant aspects of the implementation process. The detailed sets of steps are contained in van Rooij (2006; 2008; 2009) and Jeuken (2008).

The dataset for this practical work and their sources are as follows:

1. Land cover map of Africa downloaded from the European Space Agency GLOBCOVER Project Group led by MEDIAS France.

2. Biodiversity value table, biome regression slope table, temperature change per year table and disaggregation query in Microsoft Access from the Netherlands Environmental Assessment Agency.
3. Ghana outline and regions maps from the Map Library (http://www.maplibrary.org/stacks/Africa/Ghana/index.php).
4. Global eco-regions map from World Wide Fund for Nature.
5. Ghana road network map from Penn State University Library.

The software used for the practical work is ArcGIS 9.3.

4.1.1 Land Use Impact Calculation

Land use impact calculation involves the reclassification of land cover map based on the GLOBIO-3 land use classes so that appropriate MSA values belonging to the class can be assigned. Because biodiversity loss due to land use depends on the original vegetation, the reclassification of a cell to a GLOBIO-3 land use class is done with reference to the eco-region in which the cell falls. For that reason, the same land cover type which appears in different eco-regions may be reclassified differently. Therefore, whereas a low density forest land cover type belonging to the Guinean Forest-Savanna Mosaic eco-region may be reclassified as primary forest with a MSA value of 1, it may be reclassified as secondary forest with a lower MSA value of 0.5 when it belongs to the Eastern Guinean Forests eco-region.

Here, the reclassification of the land cover map was done with reference to the eco-regions discussed under Section 2.4. The dataset used are the following.

1. Land cover raster map of Africa.
2. Eco-region shapefile (polygon) map of the world.
3. Biodiversity value table.
4. Outline shapfile (polygon) map of Ghana.

4.1.1.1 Preparation of Land Use Impact Map

Following the GLOBIO implementation manuals prepared for similar biodiversity assessments carried out in Vietnam and Zambia (van Rooij, 2006; 2008), the following steps were carried out.

1. The three maps were all projected to Africa Albers Equal Area Conic projected coordinate system.
2. Land use and eco-region maps of Ghana were extracted respectively from the Africa land use map and the eco-region map using the outline map of Ghana as clip feature.
3. The eco-region map of Ghana was converted to raster map with cell size $1000m \times 1000m$. Also, the land use map was resampled to $1000m \times 1000m$ cell size using the nearest resampling technique. In fact, resampling was done for each of the four resampling techniques in ArcGIS 9.3; nearest, bilinear, cubic and majority, nearest resampling technique which is also the default was chosen. The reason is that whereas the outputs of the spatial interpolation-based ones; cubic and bilinear nodata values which made them inappropriate for the methodology, the output from the majority resampling was poor, visually.
4. The land use classes from the land use map were exported, opened in excel and sorted into unique classes.
5. Reclassification to biodiversity classes were done in excel with the help of the biodiversity value table, the ESA GLOBCOVER products description manual and the eco-regions descriptions under Section 2.4, and their corresponding MSA values were assigned. An additional column for $MSA \times 100$ was added to excel table.
6. The land use and the eco-region raster maps were combined using raster calculator and obtained a new land use eco-region map having unique value classes (to make the final reclassification possible). The equation which used is the following.
   $LandUseEcoRegion = 1000 \times [LandUseRaster] + [EcoRegionRaster]$ …..(3)
7. A new column was added to the result obtained from step 5 and completed based on equation (3).
8. A lookup table was created for $LandUseEcoRegion$ and $MSA \times 100$which was used for the reclassification of the land use eco-region map obtained from step 6. Finally, since MSA ranges between 0 and 1, the reclassified map was divided by 100 to the land use impact map.

The land use impact map obtained from the above steps is the following.

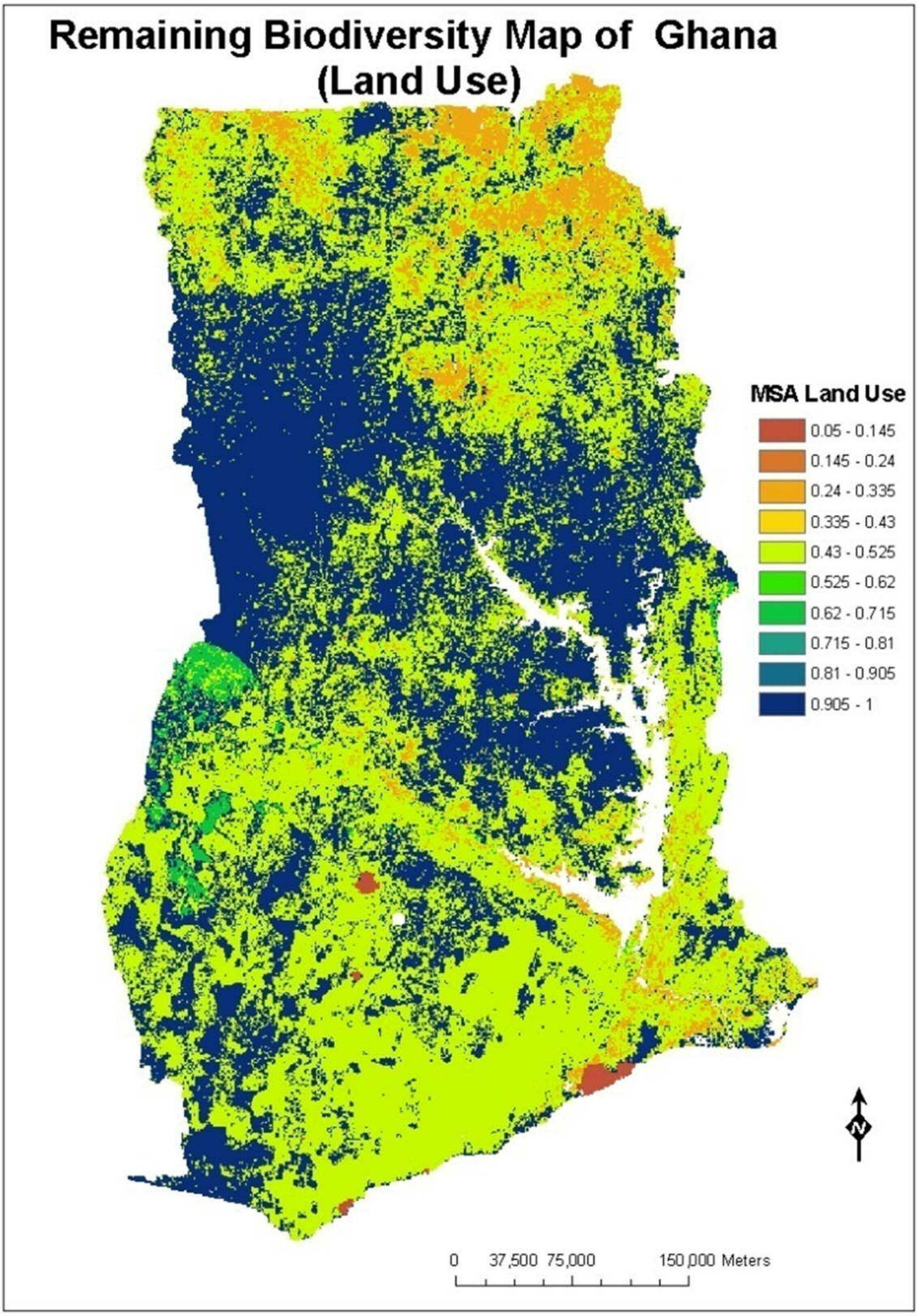


Figure 4.2 GLOBIO-3 biodiversity impact map of Ghana (2006) due to land use. River Volta and the other inland water bodies are shown in white (null values) because GLOBIO-3 is limited to terrestrial ecosystems.

4.1.2 Infrastructure Impact Map Calculation

In GLOBIO-3, the impact of infrastructure on biodiversity is calculated mainly based on the road network map of the study area, even though there are other forms of infrastructure. This is because the mean species abundance of an area is as a function of distance to the nearest road as well as the land use type (van Rooij 2006).

Impacts of infrastructure on biodiversity are high with low MSA values when the ecosystem is close to roads but are lower with high MSA values when they are far away from roads. Roads, therefore, have diminishing impacts on biodiversity and at certain distances, they have no impacts anymore. Moreover, species belonging to different type of vegetation respond differently to the influence of roads. For land use types which have no biodiversity impact values associated with them, the MSA value is set to 1 in order not to affect the calculations.

The fundamental distance-impact relationships obtained from van Rooij (2006) are presented in the following table for three different land use types.

I Class	Land Use Type	High Impact $MSA_I = 0.5$	Medium Impact $MSA_I = 0.75$	Low Impact $MSA_I = 0.9$	No Impact $MSA_I = 1$
1	Crops, grass, desert, wetlands, snow and ice	$0.0 - 0.5\ km$	$0.5 - 1.5\ km$	$1.5 - 5.0\ km$	$\geq 5.0\ km$
2	Boreal and temperate forests	$0.0 - 0.3\ km$	$0.3 - 0.9\ km$	$0.9 - 3.0\ km$	$\geq 3\ km$
3	Tropical forest, tundra	$0.0 - 1.0\ km$	$1.0 - 3.0\ km$	$3.0 - 10.0\ km$	$\geq 10.0\ km$
4	Towns, lakes, rivers	$-$	$-$	$-$	$\geq 0.0\ km$

Table 4.1 Relationship between distance to roads and MSA for different land use types. I, on the table, represents infrastructure.

In this module, the distance impact relationships presented in Table 4.1 above are incorporated to produce a map of the impact of infrastructure on biodiversity. In general road buffers are created according to the specifications in Table 4.1 and the pixels that fall into each specification are selected and combined to obtain the final infrastructure impact map. Because the calculations in this module require more detailed maps, a finer spatial resolution of $100\ m$ is used instead of the $1\ km$ spatial resolution requirement of almost all processes in the GLOBIO-3.

The dataset used for this module are the following.

1. Land use raster map of Ghana (obtained from the land use module above).
2. Road network shapefile (polyline) map of Ghana.
3. Infrastructure MSA table.

4.1.2.1 Preparation of Infrastructure Impact Map

Following the GLOBIO implementation manuals prepared for similar biodiversity assessments carried out in Vietnam and Zambia (van Rooij, 2006; 2008), the following steps were carried out.

1. The cell size under the Spatial Analyst Options menu was set to $100\ m$.
2. The land use map was reclassified according to natural/non-natural land cover types. This was done so that the impact of roads on biodiversity could be calculated only for the natural classes since the impact of roads is already included in the biodiversity values for non-natural classes. Here, natural classes include forests, grasslands, scrublands, ice and deserts while non-natural classes include cropland, artificial pastures and urban areas. Natural classes were assigned 1 and non-natural, 0.
3. Buffer zones were created for the road network map for each of the four specifications under the infrastructure classes 1 and 3. Those under the infrastructure class 2 were ignored because its land cover type does not correspond to the land cover in Ghana. To obtain the MSA maps for the two infrastructure classes the following equations were executed using the raster calculator.

a. MSA_I_1 = Con([infra_class] = = 1, ([buf_500] * 0.5) + ([buf_1500] * 0.75) + ([buf_5000] * 0.9) + buf_max_1, 0),

b. MSA_I_3 = Con([infra_class] = = 3, ([buf_1000] * 0.5) + ([buf_3000] * 0.75) + ([buf_10000] * 0.9) + buf_max_3, 0),

where infra_class is the infrastructure class, buf_500, buf_1500, buf_5000 and buf_max_1 represent respectively the distance specifications for infrastructure class 1, and buf_1000, buf_3000, buf_10000 and buf_max_3 represent respectively the distance specifications for infrastructure class 3, in Table 4.1. The Con function ensures that the value of every pixel which does not fall into the distance specification is set to zero.

4. A raster overlay operation was performed on the two maps obtained from step 2, ensuring that the value 1 is assigned to any pixel which falls under infrastructure class 4 according to the following raster calculator equation.
   MSA_I_all = Con([Infra_class] = = 4, 1, [MSA_I_1] + [MSA_I_3]).
5. The natural/non-natural raster map obtained from step 1 was used to assign the MSA values to all natural classes. All non-natural classes were assigned the value 1 to ensure that there are no zeros on the final map. It is important to note that assigning 1 to the non-natural classes would not affect the overall MSA even though it is obtained by multiplying all the driver impact maps because 1 is the multiplication identity. The raster calculator equation executed to get the final impact map for infrastructure is the following.
   Impact_infra_100m = Con([NN] = = 1, [MSA_I_all], 1),
   where NN is the natural/non-natural raster map. Below is the infrastructure impact map.
6. Finally, the Aggregate function in Spatial Analyst Tools was used to reduce the spatial resolution of the raster obtained from step 5 to 1 km using a Cell Factor of 10 and the MEAN Aggregation Technique.

The infrastructure impact map obtained from the above set of steps is the following.

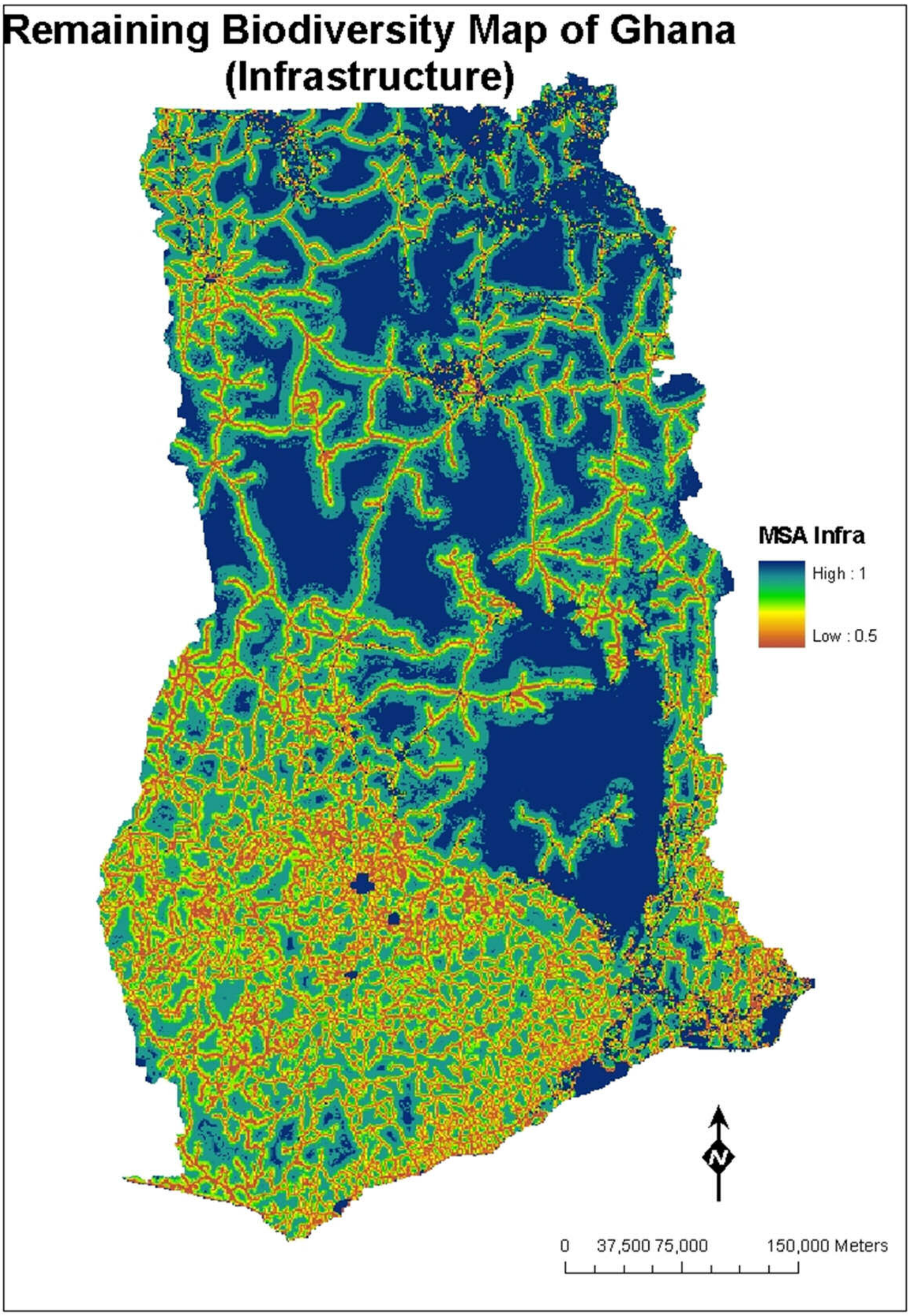


Figure 4.3 GLOBIO-3 biodiversity impact map of Ghana (2006) due to infrastructure.

4.1.3 Fragmentation

Under this module the result of Alkemade et al. (2009) on the on the minimum patch area required by the species in it to support their minimum viable population which was summarised in Table 3.4 is implemented. For the same reason given under the infrastructure module the impact of fragmentation is calculated only for natural land cover classes. The module considers natural areas dissected by large roads as separate fragmented natural areas for which their individual areas are calculated. Again, for the same reason given under the infrastructure module a fine spatial resolution of $100\ m$ is used all calculations here.

The dataset used are the following.

1. Natural/non-natural raster map obtained from step 1 under the infrastructure module.
2. Road network shapefile (polyline) map of Ghana.
3. Fragmentation table (Table 3.4)

4.1.3.1 Preparation of Fragmentation Impact Map

Following the GLOBIO-3 implementation manuals prepared for similar biodiversity assessments carried out in Vietnam and Zambia (van Rooij, 2006; 2008), the following steps were carried out.

1. A road raster map was made from the road network shapefile map.
2. A raster overlay operation was done using the road network map and the natural/non-natural raster map ensuring that, on the output raster map, the value 1 is given to all natural land cover pixels without roads and 0 is given to pixels with roads or non-natural land cover types, according to the following raster calculator equation.

   Roads_NN = Con(Isnull([Roads]), 1, 0) * [NN],

   where Roads is the road network raster map obtained from step 1 and NN is the natural/non-natural raster map.
3. Using the Region Group function in the Spatial Analyst Tools, a fragmented natural area map in which connectivity between a pixel and its neighbours is permitted within the entire Moore neighbourhood was made using the output of step 2, Road_NN, as input with the following parameters.

   Number of Neighbours: Eight

   Zone Grouping Method: Within

Excluded Value: 0

4. In order to create a new raster in which every pixel contains the area of the cluster that it belonged to in km^2, the .count function was used to reclassify the natural area cluster values according to the following raster calculator equation.
   Ghana_Area = [Reg_Road_NN].count / 100,
   where Reg_Road_NN is the output of step 3.
5. The fragmented natural area cluster values in the raster obtained from step 4, Reg_Road_NN, were reclassified into their corresponding fragmentation impact classes and their respective MSA values obtained from the fragmentation table were assigned.
6. Finally, the Aggregate function in Spatial Analyst Tools was used to reduce the spatial resolution of the raster obtained from step 5 to 1 km using a Cell Factor of 10 and the MEAN Aggregation Technique. Also the cell size which was set to $100\ m$ in step 1 under infrastructure was set back to 1 km ($1000\ m$).

The fragmentation impact map obtained from the above set of steps is the following.

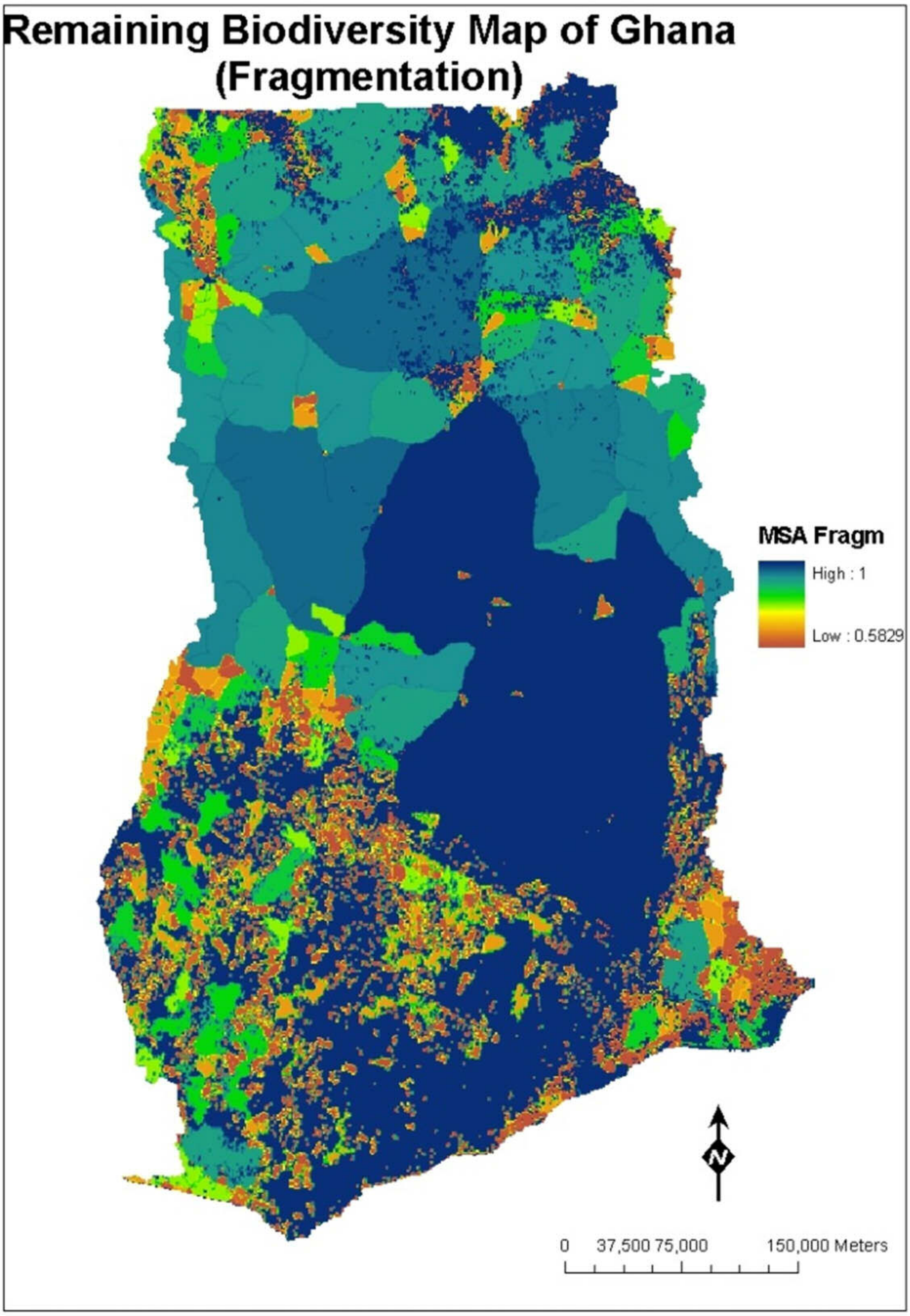


Figure 4.4 GLOBIO-3 biodiversity impact map of Ghana (2006) due to fragmentation.

4.1.4 Climate Change

This module implements the cause-effect relationship expressed as a linear regression (equation (3.3)) between predicted temperature rise and MSA for different biomes.

The dataset used are the following.

1. Eco-region map of Ghana (obtained from step 2 under the land use module).
2. Biome regression slope table (Climate.xls).
3. Temperature change per year table (Climate.xls).

4.1.4.1 Preparation of Climate Change Impact Map

Following the GLOBIO implementation manuals prepared for similar biodiversity assessments carried out in Vietnam and Zambia (van Rooij, 2006; 2008), the following steps were carried out.

1. The eco-region map was rasterised using biome as the raster field and obtained a biome raster map of Ghana.
2. MSA values were computed for each biome on the biome raster map obtained from step 1 based on equation 3.3 using the Slope (S) and temperature change (ΔT) values from Climate.xls.
3. The biome map was finally reclassified using MSA values obtained from step 2 and obtained the climate change impact map.

Below is the climate change impact map obtained.

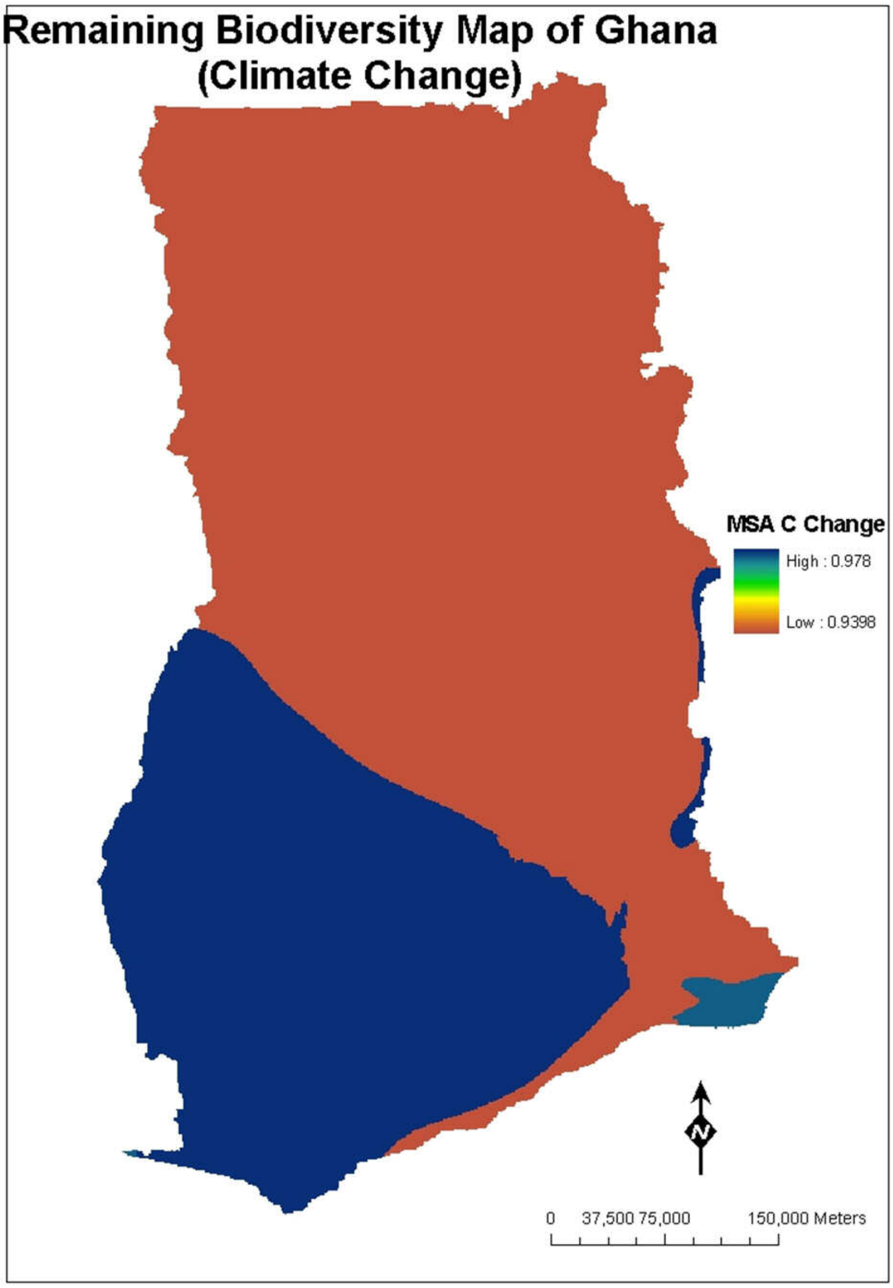


Figure 4.5 GLOBIO-3 biodiversity impact map of Ghana (2006) due to climate change.

4.2 Production of Total Impact Map

In line with GLOBIO-3, the final impact map also known as the remaining biodiversity map was obtained by multiplying the four impact maps; land use, infrastructure, fragmentation and climate change, using the raster calculator. The impact of atmospheric nitrogen deposition was not calculated because the nitrogen deposition map could not be obtained. The remaining biodiversity map obtained is the following.

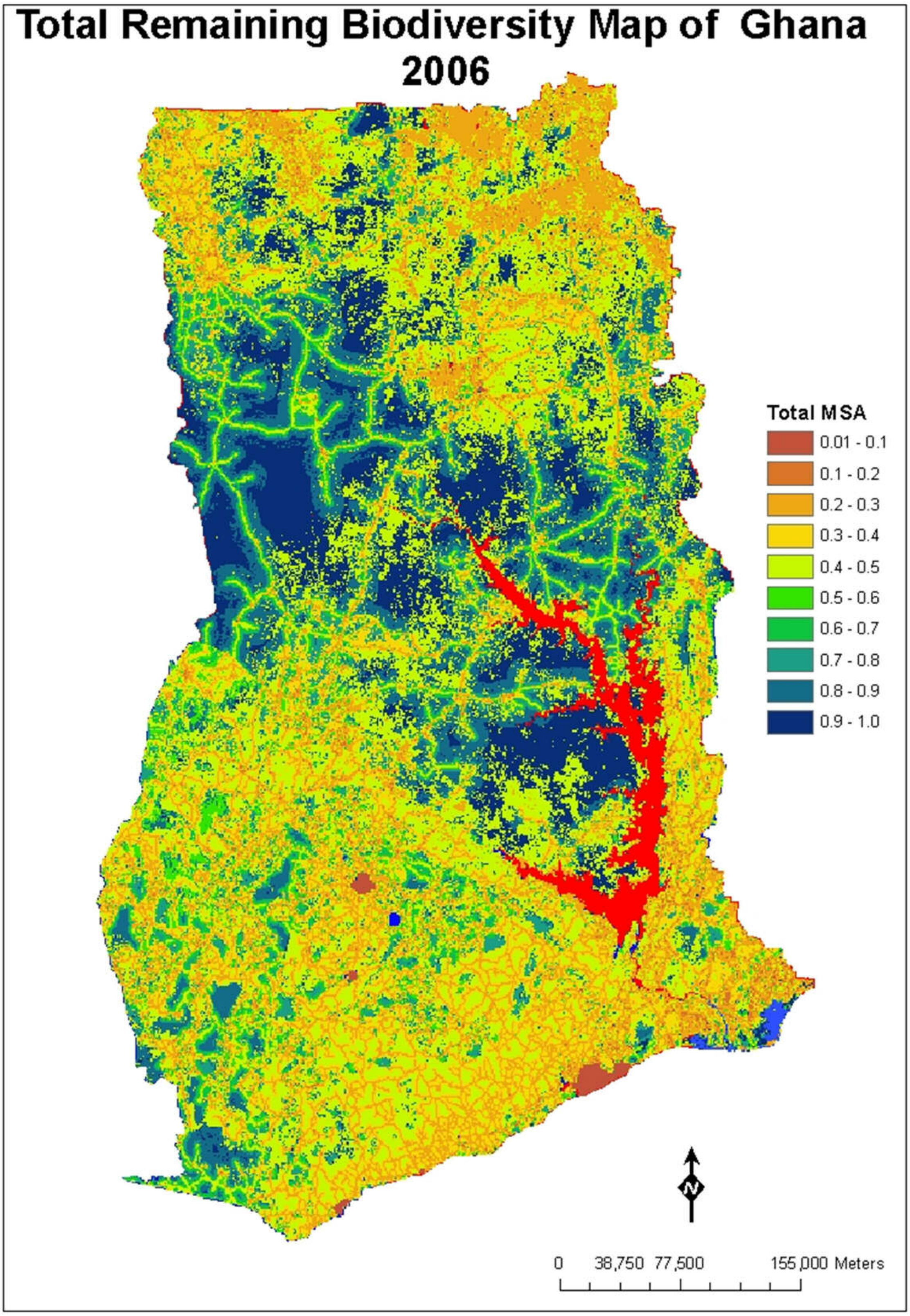


Figure 4.6 GLOBIO-3 remaining biodiversity map of Ghana (2006).

4.3 Disaggregation of Result

In order to obtain the contribution of the individual drivers (also known as pressures) to the loss of biodiversity in the country as well as the MSA values for the ten subnational regions, the information contained in the final map had to be subjected to disaggregation. To make the disaggregation simple and quick, Jeuken (2008) created a Microsoft Access database (MSA_per_province_and_LU.mdb) containing a set of queries which produces all the relevant disaggregation tables based on a single table input. Generally speaking, the disaggregation input table is obtained by exporting all the information contained in the raster obtained by combining the impact maps for the different biodiversity drivers with the map of the subnational areas of interest and the land use map.

The dataset used for the disaggregation analyses are the following.

1. Biodiversity impact raster maps for land use, infrastructure, fragmentation and climate change obtained from the sets of steps above.
2. Land use raster map of Ghana.
3. Shapefile (polygon) map of subnational areas of interest like regions, administrative districts or protected areas.

4.3.1 Disaggregation Procedure

Based on the information in Jeuken (2008), the following set of steps was carried out for each disaggregation analyses made.

1. The shapefile map of the subnational area of interest was converted to raster with a cell size of $1000\ m$.
2. A raster map with a uniform pixel value of 1 was created for atmospheric nitrogen deposition. This was done because the disaggregation input table needed to have a column for nitrogen deposition. Moreover, to avoid the situation where some biodiversity losses could be attributed to nitrogen deposition the highest MSA value of 1 had to be chosen as the pixel value.
3. In order to make the combine operation possible each of the four impact maps needed to have integer pixel values so they were each multiplied by 10000 and converted to integer pixel type raster maps. Accordingly, since nitrogen deposition is also an environmental driver, it was multiplied by 10000.

4. Using the Combine tool in the Spatial Analyst Tools the five maps obtained from step 3, the land use raster map and the raster map of the subnational area of interest obtained from step 1 were combined to produce a single raster map.
5. Finally, all the records in the attribute table of the combined map obtained from step 4 were exported.

Before the execution of the Microsoft Access queries the three tables in the database; land use, land use classes and the subnational table, were updated appropriately. In order to update the land use and the land use class tables, the 23 land use classes were grouped into 4 bigger classes (Agriculture = 1, Forest = 2, Grass, shrubs and others = 3, and Built up and bare areas = 4) according to the following table.

GLC Class	**LU Name**	**LU Group**
11	Post-flooding or irrigated croplands (or aquatic)	1
14	Rain-fed croplands	1
20	Mosaic cropland (50-70%) / vegetation (grassland/scrubland/ forest) (20-50%)	1
30	Mosaic vegetation (grassland/scrubland/forest) (50-70%) / cropland (20-50%)	1
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	2
50	Closed (>40%) broadleaved deciduous forest (>5m)	2
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	2
70	Closed (>40%) needle-leaved evergreen forest (>5m)	2
90	Open (15-40%) needle-leaved deciduous or evergreen forest (>5m)	2
100	Closed to open (>15%) mixed broadleaved and needle-leaved forest (>5m)	2
110	Mosaic forest or scrubland (50-70%) / grassland (20-50%)	3
120	Mosaic grassland (50-70%) / forest or scrubland (20-50%)	3
130	Closed to open (>15%) (broadleaved or needle-leaved, evergreen or deciduous) scrubland (<5m)	3
140	Closed to open (>15%) herbaceous vegetation (grassland, savanna or lichens/mosses)	3
150	Sparse (<15%) vegetation	3
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	2
170	Closed (>40%) broadleaved forest or scrubland permanently flooded - Saline or brackish water	2
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	3
190	Artificial surfaces and associated areas (Urban areas >50%)	4
200	Bare areas	4
210	Water bodies	n/a
220	Permanent snow and ice	n/a
230	No data (burnt areas, clouds,…)	n/a

Table 4.2 Global land cover (GLC) classes and their assigned land use (LU) groups. The last three GLC classes; 210, 220 and 230, were excluded from the groupings because the scope of GLOBIO-3 is limited to terrestrial ecosystems.

Chapter 5: Results and Discussions

The MSA information in the total impact map was subjected to disaggregation in order to obtain information not only about how the loss in biodiversity is shared among the drivers but to know more about the state of each of the ten regions in terms of biodiversity. Another major concern was about the accuracy of the assessment results. For that reason, a map of 17 protected areas, including those that have met the criteria set by the International Union for Conservation of Nature (IUCN) regarding protected areas management and have subsequently been put into any of their six categories as well as those that have not yet met any of those criteria but are well recognised nationally, was produced and analysed. Remaining MSA values were calculated for each of these protected areas and the drivers which contributed to the biodiversity losses and the magnitude of their contributions in each of the areas were obtained. The results obtained from the above analyses are given in the following sections. It is important to note, for the purpose of clarity, that the terms *loss* and *impact* are used interchangeably in different contexts because they are oriented along the same direction of biodiversity quantification. This means that greater impacts on biodiversity cause greater losses to biodiversity whereas lower impacts yield lower losses to biodiversity.

5.1 National MSA and Biodiversity Loss per Pressure

The MSA value obtained for the whole country is 51.34% which means that, by the year 2006, 48.66% of biodiversity had been lost to the biodiversity drivers. The share of this loss according to these drivers are the following; 26.98% due to land use, 14.39% due to infrastructural development, 3.32% due to fragmentation and the remaining 3.98% due to climate change. These figures are represented graphically in Figure 5.1.

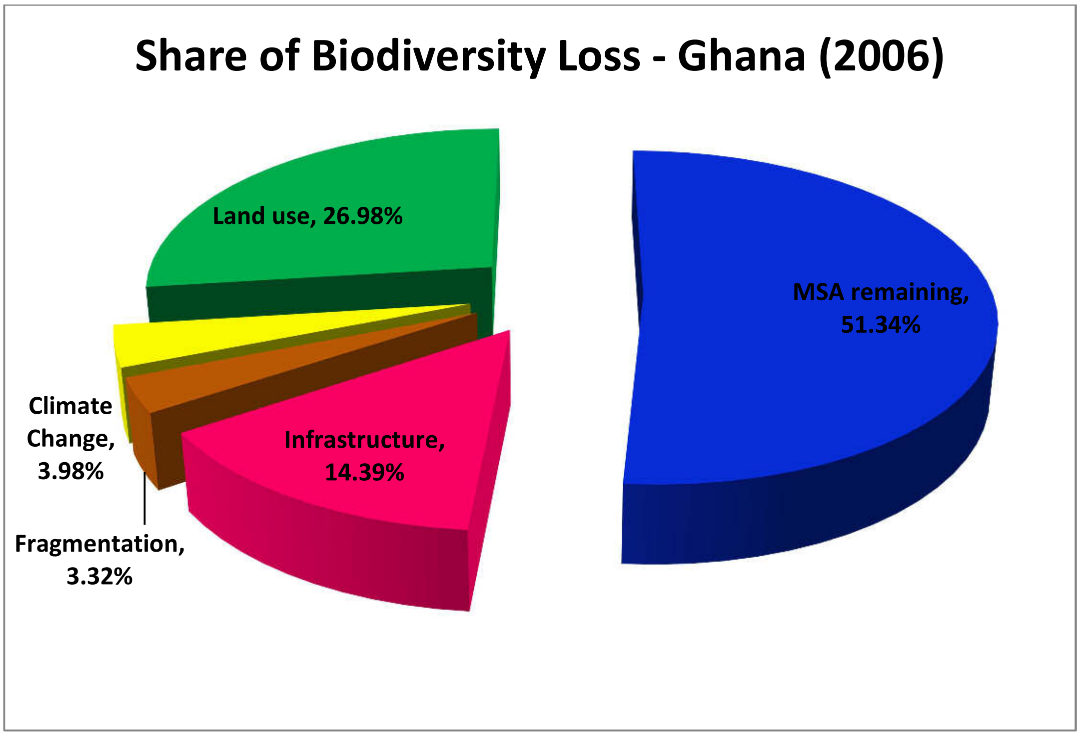


Figure 5.1 Pie chart showing the remaining MSA and the relative contribution of each biodiversity driver towards biodiversity loss in Ghana (2006).

Further disaggregation based on the land use groups in Table 4.2 revealed that of the 26.98% loss due to land use, 13.66%, 0.87%, 0.93% and 11.05% are due to agriculture, built-up and bare areas, forest, and grass, shrubs and others respectively. This suggests that the decline in biodiversity at areas where agricultural activities are carried out outweigh the decline at areas covered by grass, shrubs and other forms of vegetation. A graphical representation is the following.

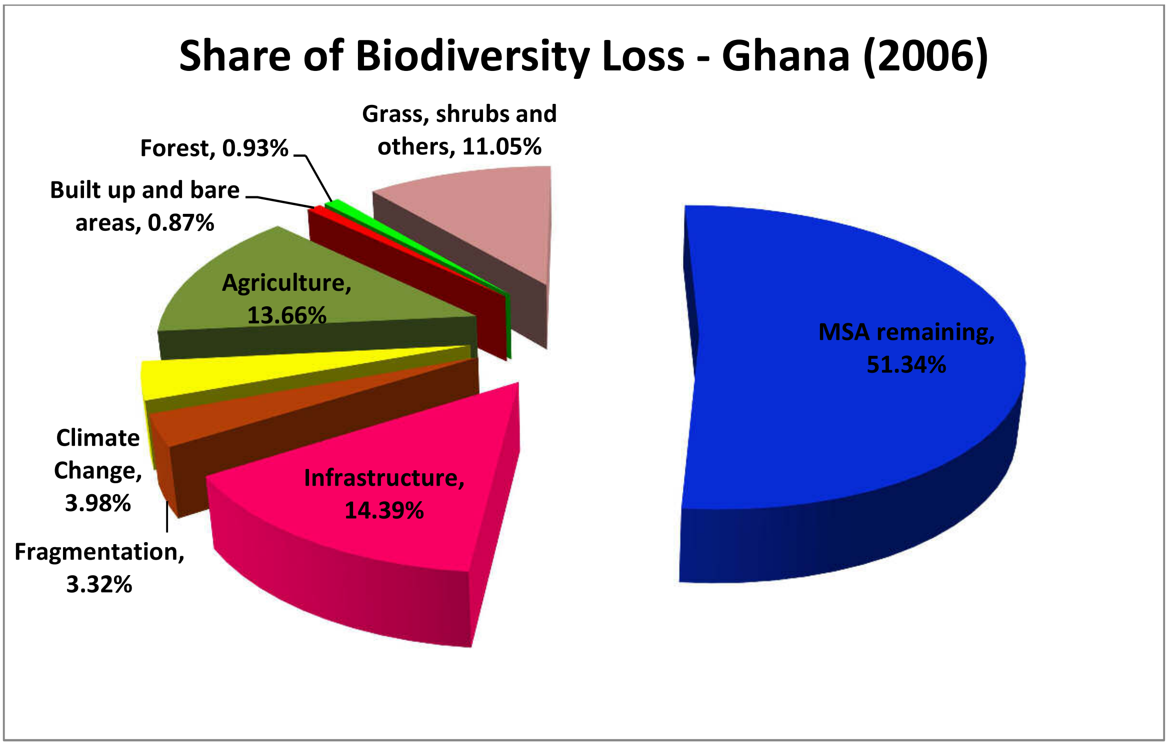


Figure 5.2 Pie chart showing the remaining MSA and the relative contribution of each land use group as well as the other biodiversity drivers.

The figures given above, about the remaining biodiversity and the corresponding loss, become clear by looking at the remaining biodiversity map (Figure 4.6) which gives details about the spatial distribution of biodiversity over the entire country. From the remaining biodiversity map, it is observed that a significantly high percentage of the remaining biodiversity is located west of River Volta in the Guinean forest-savanna mosaic and the West Sudanian savanna eco-regions. Apart from this area, the other areas in the country having relatively high MSA values are patches of forest most of which are conserved. This observation becomes clear when the remaining biodiversity map is overlain with the eco-regions and the protected areas maps. Figure 5.3 below is an illustration.

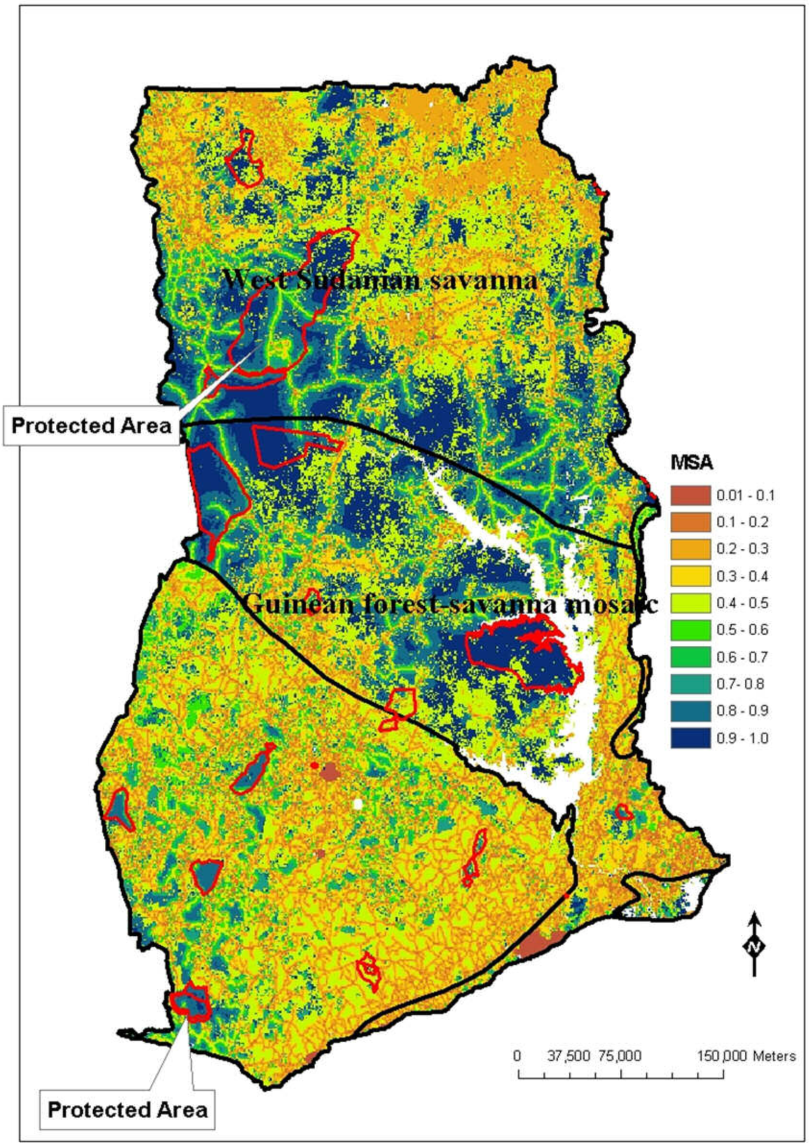


Figure 5.3 Protected areas and the eco-region maps of Ghana overlain on the remaining MSA map. Areas with red outlines are protected.

This result is consistent with information in the country's profile at the Secretariat of the Convention on Biological Diversity (SCBD). Records about the country from the secretariat indicate most of the existing forests only exist in statutory forest reserves with very little patches of traditionally protected forest occurring as sacred groves outside the reserves (SCBD, 2010a). In 2001, the estimated biodiversity of the country using the National Biodiversity Index (BNI) recorded in the Global Biodiversity Outlook 1 (SCBD, 2010b) was 0.646, equivalently 64.6%. This figure is slightly higher than the 51.34% obtained and, even though biodiversity decline is on the rise worldwide, it is impossible to equate them unless there is substantial evidence of possible biodiversity decline in the country between the years 2001 and 2006.

Land cover statistics indicate that the area covered by forest in the country reduced significantly from a total of 6,094,000 ha in 2000 to 5,517,000 ha in 2005 (Ghana, 2006) representing a total forest cover decline of 9.46% (approximately 1.89% annually). Apart from this, other studies (Amisah et al., 2009; Agyemang, 2010; Kusimi, 2008; Dunkan et al., 2009) have reported land use changes of varying degrees between the years 2000 and 2006 in different parts of the country. Infrastructural development in the form of road construction also increased significantly during the period. According to Obeng-Odoom (2009) the total length of the country's surfaced roads increased by over 72% between the years 2000 and 2008 alone. In line with this increase in the number of roads, it is important to stress the rate of horn honking in the country. Observation made over the years indicates that most drivers in the country honk not only when they approach road curves and bridges, but as greetings to other road users. In 2008, for example, the noise complaints received by the Environmental Protection Agency outnumbered all other complaints forming 40% of the total number of complaint received (GBN, 2009). Furthermore, climate change has been of concern in the country. An assessment of the country's climate change in 2007 (Dazé, 2007) indicated that the country had experienced an increase in average temperature of approximately 1°C over a 30 year period and rainfall had decreased by 20%. Despite the sharp decline in rainfall, heavy rains are experienced at unexpected periods, essentially due to climate change, resulting in huge losses. In 2007, for instance, the three northern regions which normally experience draught and less rain experienced extremely heavy rains two months earlier than the expected period for the usual rains which resulted in heavy floods destroying lives and property. Cumulatively, these developments give obvious indications that a further decline in biodiversity is likely to have occurred after 2001.

5.2 Regional MSA and Biodiversity Loss per Pressure

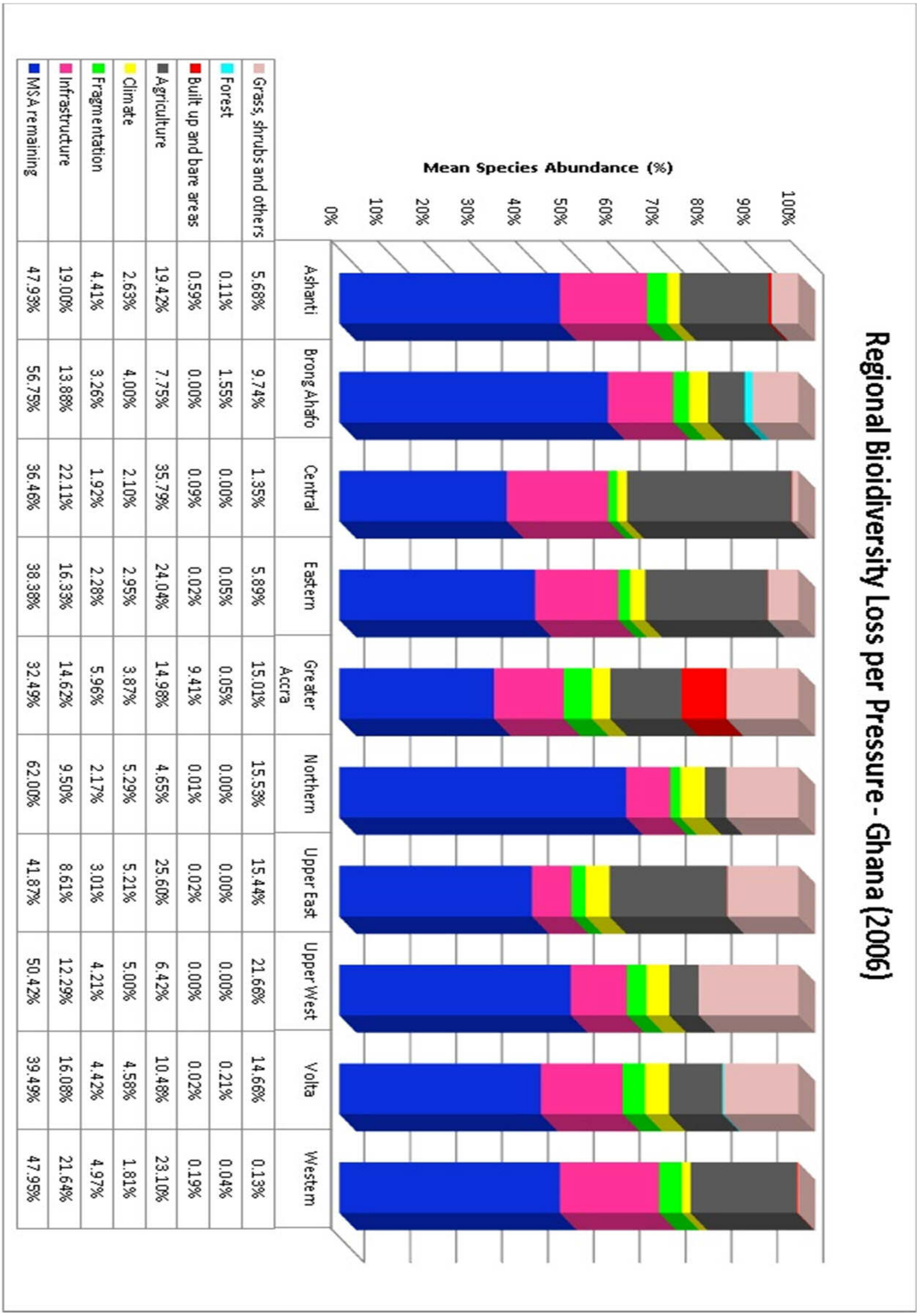
Of the 10 regions, the regional results show that Northern has the highest MSA value of 62%, followed by Brong Ahafo with 56.75% MSA. Greater Accra has the least MSA value of 32.49%. Following Brong Ahafo are Upper West, Western, Ashanti, Upper East, Volta, Eastern and Central in decreasing order of MSA. It is also observed that among the biodiversity drivers, land use causes the greatest loss to biodiversity followed by infrastructure for all the regions. Moreover, although the impact of climate change is higher than that of fragmentation in 7 out of 10 regions, its impact is less in Ashanti, Greater Accra and Western.

Land use, the dominant driver, has its greatest impact in Upper East (41.06%), followed successively by Greater Accra (39.45%) and Central (37.14%). The Brong Ahafo and Northern Regions experience the least land use impacts of 19.04% and 20.1% respectively. This means that the greatest loss to the country's primary land cover has occurred in the Upper East region, with the least loss occurring in the Northern Region. A close look at the regional land cover disaggregation result indicates that in Ashanti, Central, Eastern, Upper East and Western Regions, land cover losses due to agricultural activities are greater than those due to the other land use groups. However, land cover losses at areas covered by grass, shrubs and other vegetation types are greater in Brong Ahafo, Greater Accra, Northern, Upper West and Volta Regions. Another observation made is that whereas land cover losses in built-up and bare areas are completely low in all regions, the loss is particularly high in the Greater Accra Region.

The impact of infrastructure is greatest in the Central Region (22.11%), following which are Western and Ashanti Regions with 21.64% and 19% respectively. The Upper East and the Northern Regions are the least impacted by infrastructure having impact figures, 8.61% and 9.5% respectively.

From the results, the impacts of climate change and fragmentation are minimal. The regions which recorded the highest impact figures for climate change are Northern (5.29%), Upper East (5.21%) and Upper West (5%). The least impacted regions are Western, Central and Ashanti recording impact figures 1.81%, 2.1% and 2.63% respectively. Moreover, Greater Accra, Western and Volta respectively recorded the highest fragmentation impacts of 5.96%, 4.97% and 4.42%. Less fragmentation impacts of 1.92% and 2.17% were recorded for the Central and Northern Regions respectively.

A quick look at the distribution of losses due to land use among the land use groups for the regions revealed the following. Biodiversity losses due to agricultural activities are highest in Ashanti, Central, Eastern, Upper East and Western regions. However, in Brong Ahafo, Greater Accra, Northern, Upper West and Volta regions, biodiversity losses are highest in areas covered by grass, shrubs and other forms of non-forest vegetation. Moreover, biodiversity losses in built-up and bare areas are significantly low in all regions except Greater Accra where the loss is up to 9.41%. Clearly observable from the results is the fact that loss in areas covered by forests is completely low for all regions. Figures 5.4, 5.5 and 5.6 are the graphical representations of the regional level results.



	Ashanti	Brong Ahafo	Central	Eastern	Greater Accra	Northern	Upper East	Upper West	Volta	Western
Grass, shrubs and others	5.68%	9.74%	1.35%	5.89%	15.01%	15.53%	15.44%	21.66%	14.66%	0.13%
Forest	0.11%	1.55%	0.00%	0.05%	0.05%	0.00%	0.00%	0.00%	0.21%	0.04%
Built up and bare areas	0.59%	0.00%	0.09%	0.02%	9.41%	0.01%	0.02%	0.00%	0.02%	0.19%
Agriculture	19.42%	7.75%	35.79%	24.04%	14.98%	4.65%	25.60%	6.42%	10.48%	23.10%
Climate	2.63%	4.00%	2.10%	2.95%	3.87%	5.29%	5.21%	5.00%	4.58%	1.81%
Fragmentation	4.41%	3.26%	1.92%	2.28%	5.96%	2.17%	3.01%	4.21%	4.42%	4.97%
Infrastructure	19.00%	13.88%	22.11%	16.33%	14.62%	9.50%	8.61%	12.29%	16.08%	21.64%
MSA remaining	47.93%	56.75%	36.46%	38.38%	32.49%	62.00%	41.87%	50.42%	39.49%	47.95%

Figure 5.4 Bar chart showing the remaining MSA and the relative contribution of each biodiversity driver for each region of Ghana.

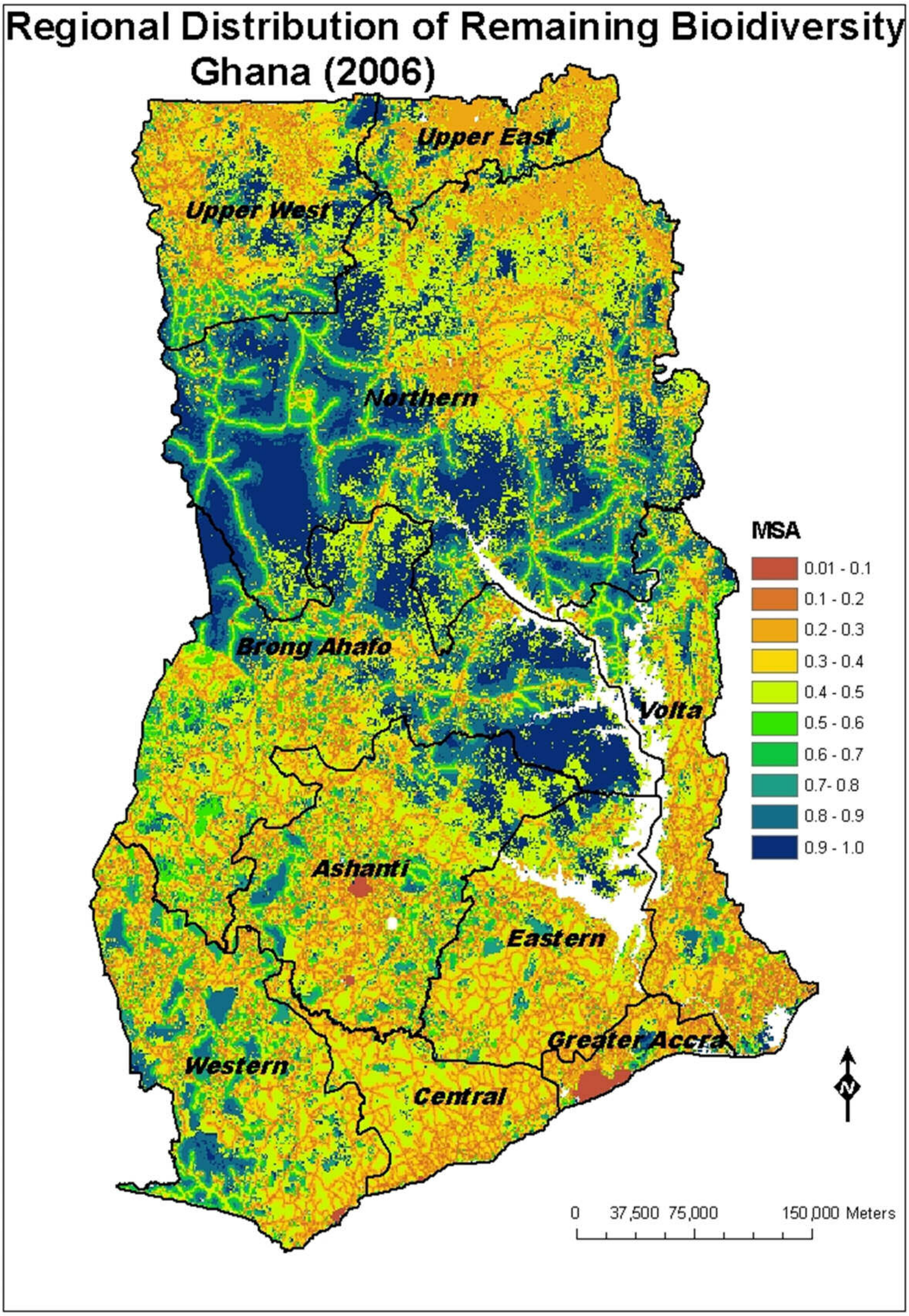


Figure 5.5 Map showing the regional distribution of the remaining biodiversity in Ghana (2006).

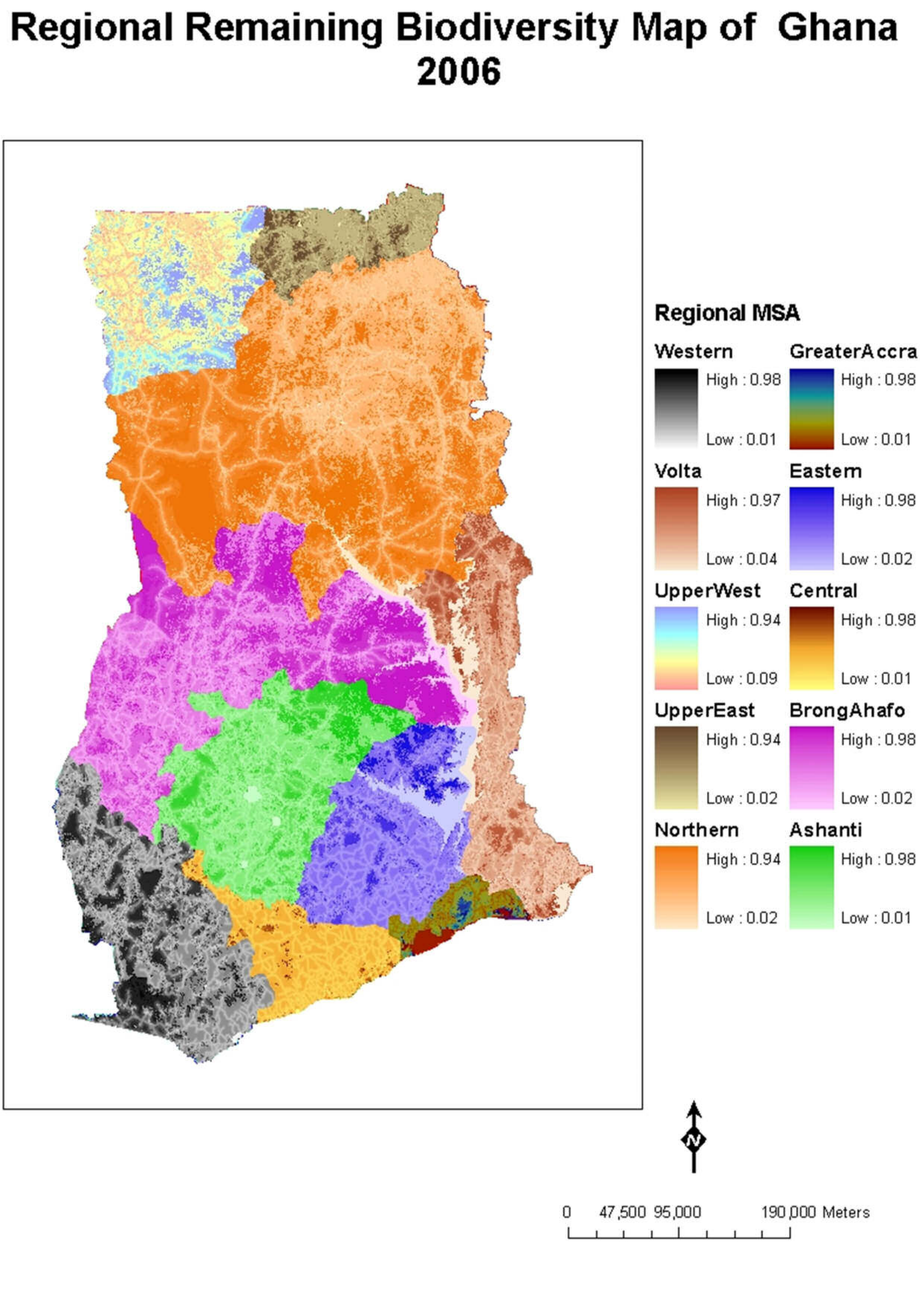


Figure 5.6 Map showing the minimum and maximum MSA values for each region of Ghana (2006).

Statistics indicate that as at 2003 agricultural activities covered approximately 65% of the country's total land area (NationsMaster.com, 2010; FAO, 2009). Cocoa, the most important agricultural commodity in the country (Breisinger et al., 2007), accounts for 40% of the country's total exports (Frimong et al., 2007), and its production occurs in the southern regions; Ashanti, Brong Ahafo, Central, Eastern, Western, and Volta Region (Clark, 1994). Between the years 2000 and 2004, the share of cocoa in Ghana's Gross Domestic Product (GDP) was 4.9% but by 2006 this figure had risen to 8.1% essentially due to huge increases in cocoa yield in the cocoa producing regions. Over the years the government has encouraged cocoa farmers mainly through bonuses and the provision of fertilizers at subsidised costs. Since 2001, the government, in addition to these incentives, has embarked on regular state sponsored mass-spraying exercise to enhance cocoa production (Vigneri and Santos, 2007). This mass-spraying exercise has a great impact on biodiversity. Apart from the many animals, especially insects, which are killed during the exercise, the vegetation of an area once sprayed takes several months to regrow. According to Frimpong et al. (2007), an increase in cocoa yield leads to a drastic loss of forest species in cocoa farms with subsequent recruitment of non-forest species. Apart from cocoa, other food crops including maize, cassava, plantain, oil-palm and rice are grown at varying proportions in different parts of the country. An illustration of this fact, which also gives a visual explanation to why biodiversity due to agriculture in the country is greater than losses due to the other land use types, is Figure 5.7 below.

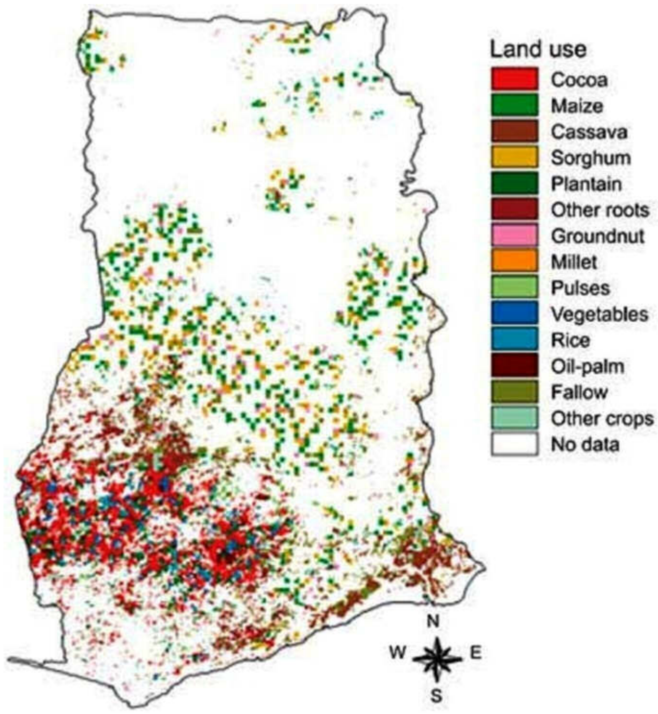


Figure 5.7 Simulated agriculture land use map of Ghana (downloaded from http://www.fao.org/docrep/008/a0013e/a0013e04.jpg (Accessed 6 September 2010)).

The regional results also show that losses in areas covered by grass, shrubs and other vegetation types are high especially in Greater Accra, Volta, and the three northern regions. Unlike farmers in the southern Ghana who cultivate tree crops which last for several years on the same piece of land, those in the northern sector cultivate mostly annual crops which are able to complete the wet-dry season cycle without irrigation including cereals and legumes. Because the savanna vegetation is less rich in nutrients compared with the tropical forest vegetation in the south, a piece of land after few years of cultivation becomes almost completely depleted of all soil nutrients and the vegetation turns into grass or bare land. The result obtained by Agemang (2010) from a study conducted in the Bolgatanga and Talensi-Nabdam districts of the Upper East region is relevant for this discussion. According to his report, the original land cover type of the area which comprised of open savanna woodland interspersed with some closed savanna woodlands had been replaced by grasses and barren environments due to human activities. His findings are summarised in Table 5.1 below.

Area	**Observed Land Cover Changes**
Bolgatanga, Zuarungu and Kombosigo in the Bolgatanga Municipality, mid-north of the study area.	Open savanna woodland replaced by grasses of dominant elephant type, settlements and infrastructural projects.
Nangodi, Kongo, Pelungu and Sekote in the Talensi-Nabdam District, north eastern part of the study area.	Reserved closed savanna woodland gradually taken over by grasses and settlements due to small-scale illegal mining.
Duusi, Accra, World Bank, Kejetia, Bantama, Tarkwa and Obuasi in the south eastern part of the study area.	Savanna woodland with grasses of various types replaced by grasses and barren areas.
Sherigu in the north western part of the study area.	Reserved savanna woodland with grasses encroached upon by small-scale illegal mining.
Pwalugu, Tongo and Winkogo in the south western part of the study area.	Savanna woodland and grasses replaced by barren land.

Table 5.1 Observed land cover changes in Bolgatanga and Talensi-Nabdam Districts of the Upper East Region of Ghana.

From the discussion above, it is likely that the losses observed in areas covered by grass, shrubs and other vegetation types in the other regions are due to practices similar to those observed in the three northern regions.

Furthermore, significant among the land use losses due to built-up and bare areas is the figure for the Greater Accra Region. Greater Accra recorded 9.41% loss due to built-up and bare areas against figures less than 1% for all other regions. Greater Accra is the smallest region but is the most populated. According to the GHS (2010), the region has a population density of 1,019 persons per square kilometre with 88% of the population living in urban localities. As at 2000, the inhabitants of Accra Metropolitan Assembly alone constituted 25% of all urban dwellers in the country, with an annual increase of 4.2% (Otoo et al., 2006). This huge increase in population has resulted in an increase in demand not only for housing facilities but all other forms of amenities.

The impact of infrastructure on biodiversity was calculated based on the country's national road network. From the road network map, the total number of individual roads is 7733 and they are distributed over the regions as given in Table 5. 2.

Region	**Number of Roads**
Ashanti	1535
Brong Ahafo	866
Central	828
Eastern	847
Greater Accra	351
Northern	478
Upper East	218
Upper West	358
Volta	953
Western	1299

Table 5.2 The distribution of roads over the ten regions of Ghana.

The impact of infrastructure observed for the Central Region is the greatest while the Upper East Region records the least impact. Because the assessment only made use of the road network map, the impacts observed for these 2 regions as well as those observed for the other 8 region could be seen as functions of the number of roads and the land cover types which lie in close proximity ($\leq 10\ km$ as given in Table 4.1) with the roads. However, a further study about these factors in the regions is required to adequately explain the results. Observed impacts for climate change and fragmentation are almost insignificant. However, climate change appears greater in the three northern regions and the Volta Region than the other southern regions.

5.3 Biodiversity Status of the Protected Areas (PAs)

Out of a total of 17 PAs considered, 11 are IUCN categorised and 6 are not. Table 5.3 gives the details.

Status	Name
IUCN Categorised	Mole
	Digya
	Bui
	Bia
	Kogyae
	Kalakpa
	Gbele
	Nini-Suhien
	Kakum
	Boabeng-Fiema
	Assin-Attandanso
No Category	Yakombo
	Tano Ofin
	Subuma
	Ankasa
	Atewa Range Range
	Kani Kani

Table 5.3 Protected areas in Ghana and their IUCN statuses.

The result of the analyses performed on these PAs revealed that 6 have MSA values >80% and 4 have MSA values ranging between 70% and 80%. Of the remaining 7, 3 have MSA values ranging between 60% and 70%, 2 have MSA values between 50% and 60% and the remaining 2 have MSA falling between 40% and 50%. The PA with the highest MSA value is Digya (86.85%) followed closely by Yakombo with MSA value 86.37%. Kakum and Kogyae have the least MSA values of 46.13% and 47.96% respectively. These results and a map which shows the location of each PA are given in Figures 5.8, 5.9 and 5.10 below.

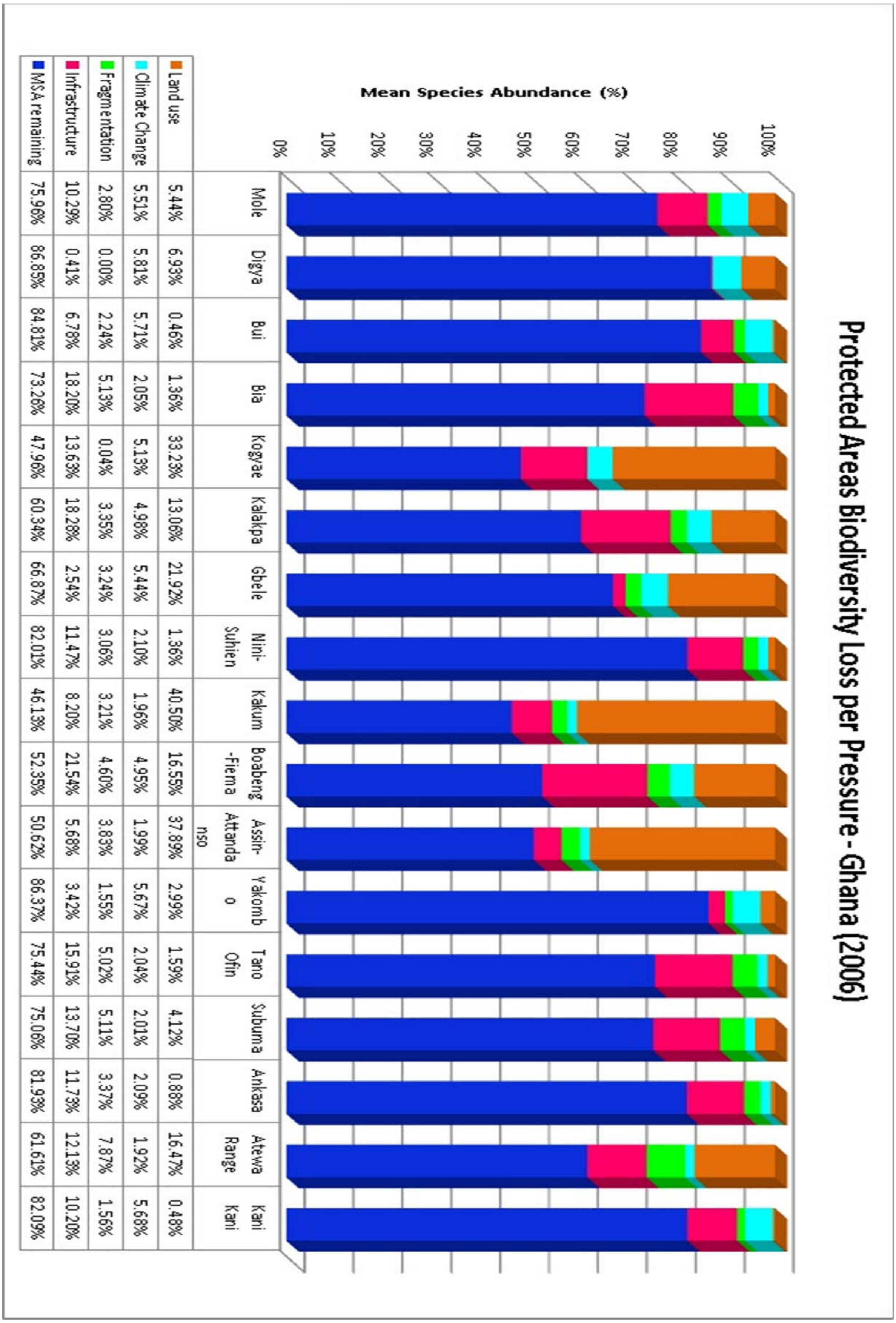
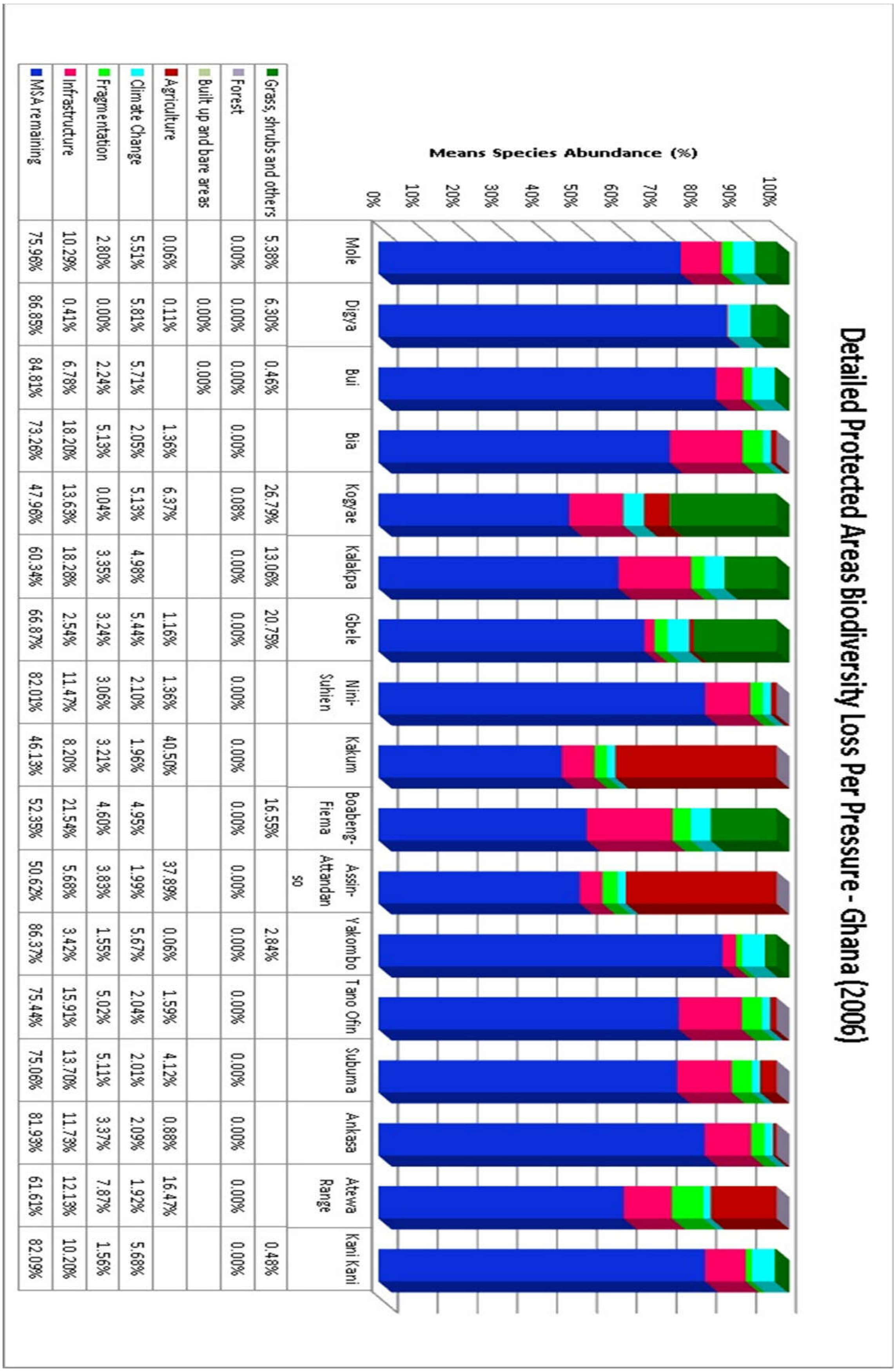


Figure 5.8 Bar chart showing MSA values for 17 protected areas of Ghana and the share of MSA loss among the biodiversity drivers.



	Mole	Digya	Bui	Bia	Kogyae	Kalakpa	Gbele	Nini-Suhien	Kakum	Boabeng-Fiema	Assin-Attandanso	Yakombo	Tano Ofin	Subuma	Ankasa	Atewa Range	Kani Kani
Grass, shrubs and others	5.38%	6.30%	0.46%		26.79%	13.06%	20.75%			16.55%		2.84%					0.48%
Forest	0.00%	0.00%	0.00%	0.00%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Built up and bare areas		0.00%	0.00%														
Agriculture	0.06%	0.11%		1.36%	6.37%		1.16%	1.36%	40.50%		37.89%	0.06%	1.59%	4.12%	0.88%	16.47%	
Climate Change	5.51%	5.81%	5.71%	2.05%	5.13%	4.98%	5.44%	2.10%	1.96%	4.95%	1.99%	5.67%	2.04%	2.01%	2.09%	1.92%	5.68%
Fragmentation	2.80%	0.00%	2.24%	5.13%	0.04%	3.35%	3.24%	3.06%	3.21%	4.60%	3.83%	1.55%	5.02%	5.11%	3.37%	7.87%	1.56%
Infrastructure	10.29%	0.41%	6.78%	18.20%	13.63%	18.28%	2.54%	11.47%	8.20%	21.54%	5.68%	3.42%	15.91%	13.70%	11.73%	12.13%	10.20%
MSA remaining	75.96%	86.85%	84.81%	73.26%	47.96%	60.34%	66.87%	82.01%	46.13%	52.35%	50.62%	86.37%	75.44%	75.06%	81.93%	61.61%	82.09%

Figure 5.9 Bar chart showing MSA values for the protected areas of Ghana and the share of MSA loss among the biodiversity drivers.

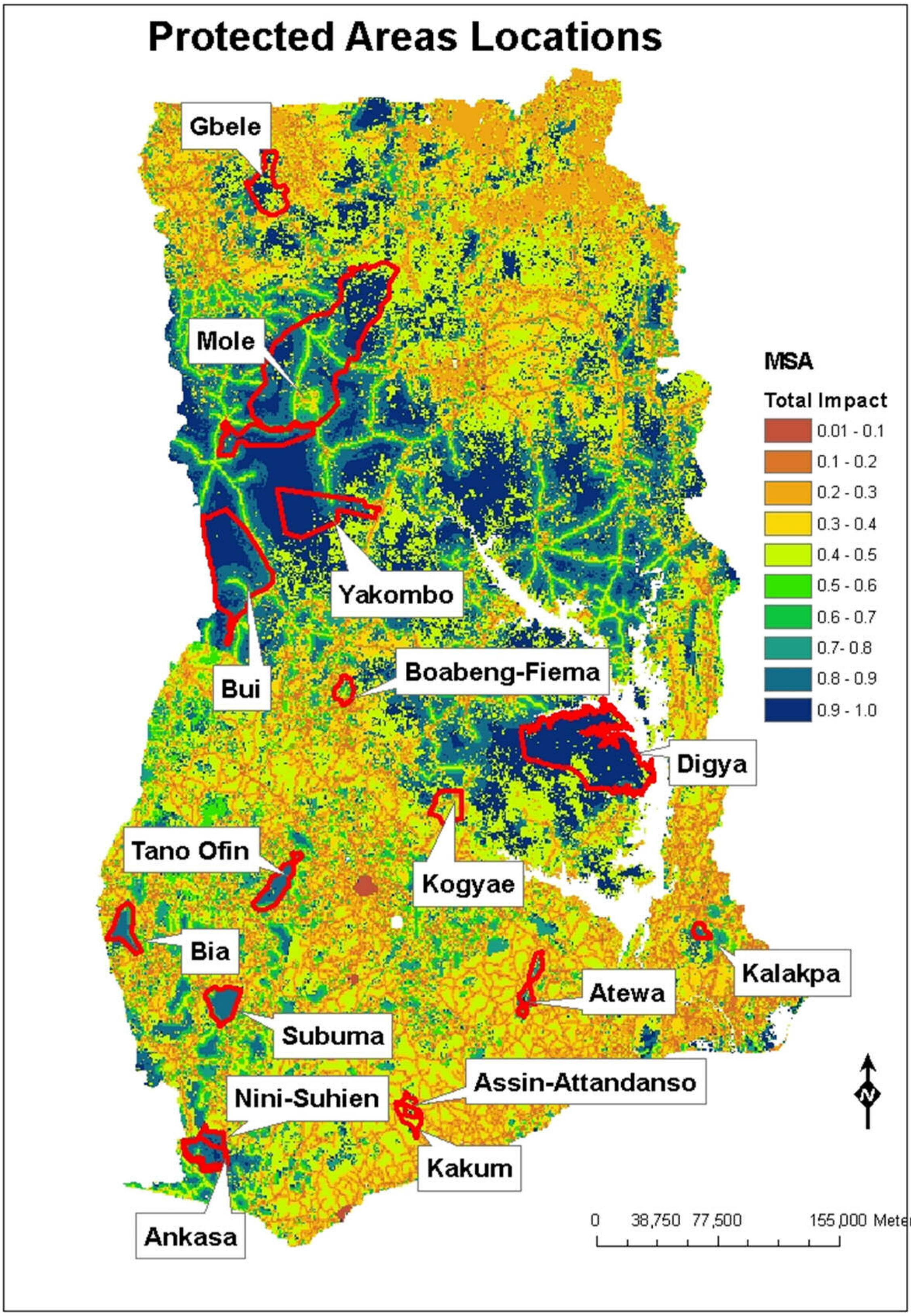


Figure 5.10 Map showing the locations of the protected areas in Ghana.

Clearly observable from the three figures above is the fact that losses, especially in the PAs having low MSA values, are largely due to land use activities going on in or around such places. Infrastructure is also seen to have similar impacts even though the magnitude of its impact is less compared with that of land use. These observations are particularly clear for Kogyae, Kakum, Boabeng-Fiema, Gbele, Atewa Range and Assin-Attandanso. Climate change is seen to have had some impacts, though less in magnitude, on Mole, Digya, Bui, Yakombo and Kani Kani, while fragmentation impact of similar magnitude is experienced by Bia, Tano Ofin, Subuma and Atewa Range.

Although the MSA values obtained for most of the PAs are high giving indications about the robustness of the model, those obtained for some PAs especially, Kakum, Assin-Attandanso, Boabeng-Fiema and Kogyae are low. The causes of this are clear from Figure 5.8 which, to some extent, is not surprising because the forest reserves in the country, especially those in the Eastern Guinean Forests eco-region lying in the southern Ghana which had lower MSA values are far from pristine condition. In a report about this eco-region, the Conservation International (2010b), indicated that even the so-called forest reserves are under increasing threat from logging, agricultural conversion and bush meat hunting. As an example, the organisation pointed out that the Bia National Park which initially had forest covering a 298 km^2 area was reduced completely to only 77 km^2 by logging within just two years of its establishment in 1974. Larsen et al. (2009), also indicates that the condition of Boabeng-Fiema is far from pristine. According to Larsen (2008), the remaining forest patch in Boabeng-Fiema stands today because of a joint effort of two nearby communities who saw the need to preserve their ancestral heritage by protecting the monkeys it sheltered. Today, even the Atewa Range, a Globally Significant Biodiversity Area (GSBA), which was kept when the government opened several forest reserves for mining in 2001 (McCullough et al., 2007) is threatened with bauxite mining (Larsen, 2008). The condition of the Kakum Conservation Area (KCA) which comprises Kakum and Assin-Attandanso is not different. In an elephant survey carried out in KCA, (Danquah et al., 2004) identified an evidence of past logging activities in the area in the form of points associated with loading of timber products. They also noted that illegal hunting for almost all species of animals except elephants still occurs in the area.

In addition to the land use impacts discussed above, infrastructure has also played a major role. Figure 5.11 below is a visual explanation of the impact of roads on the biodiversity of some of the PAs in the country.

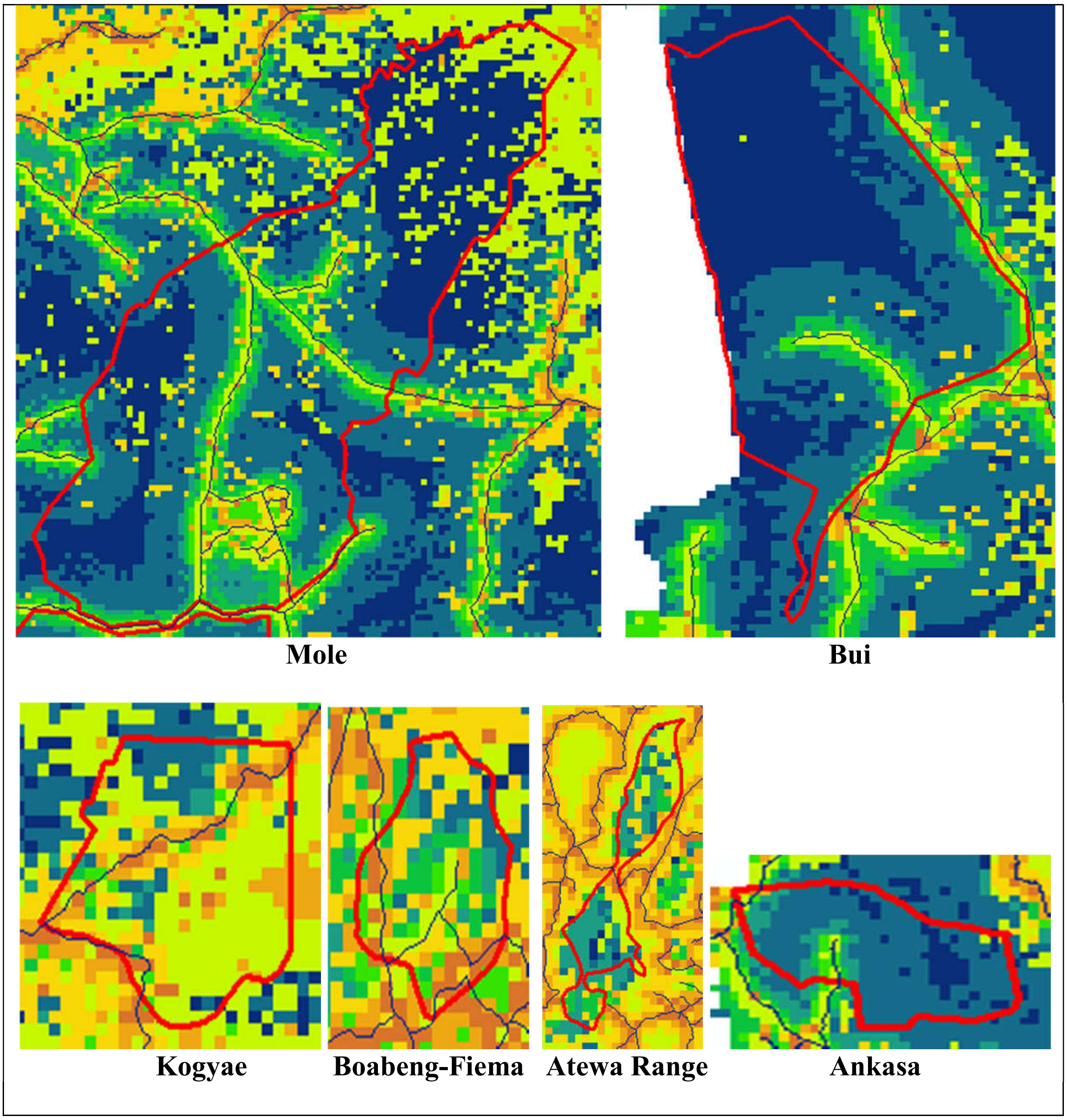


Figure 5.11 Visual explanation of the impact of roads on the biodiversity of some protected areas in Ghana.

5.4 Implications for Policy Making and Biodiversity Conservation

An obvious concern about the results of the analyses is whether the areas designated as protected are really protected when roads are constructed through them providing complete access to the public. This, as the Conservation International (2010b) expressed, makes it uncertain whether existing government actions, especially through the provision of forest guards, are sufficient to protect these important areas. The impact of these roads on some PAs is quite significant as seen from Figures 5.8 and 5.11. There is therefore the need for policy makers to look into their policies regarding the provision of infrastructure especially near PAs. The low MSA values obtained for some PAs also underline the fact that the physical presence of a PA is not the only thing that matters but the protection of the species it shelters. The results also suggest that smaller PAs are not limited in their ability to conserve biological diversity. This becomes clear when the MSA values for smaller PAs like Nini-Suhien, Ankasa, Kani Kani and Tano Ofin are compared with that of a much larger PA like Mole. A similar observation was made by Larsen (2008) on which he noted that the number of butterflies in 12 forest reserves in West Africa, 7 of which are in Ghana, is not correlated with the sizes of the reserves.

Finally, the areas with high MSA values which are not yet protected could also be turned into PAs in order to keep their biodiversity. This could be done by comparing the remaining biodiversity map (Figure 4.6) with the map of the present PAs in the country.

Chapter 6: Conclusions and Recommendations

In his foreword to the Global Biodiversity Outlook 3, the United Nations Secretary-General, Ban Ki-moon wrote that higher priority must be given to biodiversity in all areas of decision making and in all economic sectors in order to tackle the root causes of biodiversity loss. However, as Conservation International (2000) reports, conservationists and governments can make biodiversity friendly decisions, only if they know more accurately and in great detail how biodiversity is distributed, the degree to which the present biodiversity is protected and the areas where the broadest protection gaps are. In an attempt to provide conservationists and the government of Ghana the needed information to enhance their decision making this dissertation sought to carry out a biodiversity assessment of the country using GLOBIO-3. Because GLOBIO-3 is restricted to terrestrial biodiversity the assessment excluded aquatic biodiversity. At the end of the assessment a detailed biodiversity view of the country was obtained, though not fully validated.

The results obtained indicate that the country has lost almost half of its biodiversity. The remaining biodiversity obtained, measured in means species abundance, was 51.34%. Of the 48.66% loss, it was found that 26.98% is due to changes in land use, 14.39% due to infrastructural developments (specifically road construction), 3.98% due to climate change and 3.32% due to fragmentation. At the regional level, the Northern Region recorded the highest remaining biodiversity of 62% while the Greater Accra Region had the least remaining biodiversity value of 32.49%. The biodiversity figures obtained for the remaining eight regions are Brong Ahafo (56.75%), Upper West (50.42%), Western (47.95%), Ashanti (47.93%), Upper East (41.87%), Volta (39.49%), Eastern (38.38%) and Central (36.46%).

Apart from the observations made above which could enhance policy making at different administrative levels, there are others that urgently require the attention of policy makers in the country. Some areas, though not yet protected, were found to have high MSA and there is the need to have them protected in order to keep their biodiversity. In addition to this some protected areas were found to have roads constructed through them which are causing losses to their biodiversity. Policy makers are thus urged to find a suitable solution to it and to ensure that future infrastructural projects are biodiversity friendly.

For the purpose of validation, analyses were made for 17 protected areas in the country. The expectation was to obtain higher biodiversity values for all of them. Although the remaining biodiversity values obtained for 13 of them were high, the remaining 4 recorded some relatively low values. Information obtained in an attempt to explain the results was only partial.

All analyses were based on a 1 *km* spatial resolution land cover map of Africa, the national road network map and some relevant data obtained from the Netherlands Environmental Assessment Agency. Because the land cover map is global, the accuracy of the results may be affected. However, a detailed land cover map could greatly improve the results. It should be noted, in addition, that the proxy indicator (mean species abundance) used is one of the many indicators that are needed to give a full view of the biodiversity status of the country. Furthermore, as Hanski (2005) explains, there are time lags in species' response to changes in their natural ecosystems. This suggests that the actual remaining biodiversity may have been underestimated.

Although this dissertation has provided some detailed information about the status of biodiversity in Ghana, there are still gaps that could be filled in the future. Firstly, as already mentioned above, a detailed land cover map could be used to improve the results. It would also be interesting to extend this project to include future predictions in order to provide decision makers with information about future biodiversity trends based on present policy options.

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