USING SATELLITE REMOTE SENSING IN DETECTING ANTHROPOGENIC THREATS TO FRESHWATER WETLANDS IN TRANSFORMING LANDSCAPES; THE CASE OF NGIRI-TUMBA-MAINDOMBE LANDSCAPE OF THE CUVETTE CENTRALE IN THE CONGO RIVER BASIN.

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DEDICCATION

This work is dedicated to my family especially my wife Tanyi Martha Enow, my little daughter Lidora Besem Eninghan and my junior sister Akum-Ojong Patience Pelle Ngoh for their moral and financial support through the extreme demanding moments in Venice.

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List of abbreviations

Above Ground Biomass	AGB
Advanced Land Observation Satellite	ALOS
Advanced Visible and Near Infrared Radiometer type 2	AVNIR-2
Advanced Synthetic Aperture Radar	ASAR
Central Africa Regional Program for the Environment	CARPE
Congo Basin Forest Partnership	CBFP
Central Intelligence Agency	CIA
Democratic Republic of Congo	DRC
Digital Elevation Model	DEM
Enhanced Thematic Mapper plus	EMT+
European Environmental Agency	EEA
Environmental Protection Agency	EPA
Emission Reduction Program Idea Note	ERPIN
European Remote Sensing Satellite	ERS
European Union 7th Framework Program	EU FP7
Geoscience Laser Altimeter System	GLAS
Generic Synthetic Aperture Radar	GSAR
Monitoring the Forest of Central Africa	FACET
Food and Agricultural Organization	FAO
Forest Carbon Partnership Facility	FCPF
Ice Cloud Land Elevation Satellite	ICESat

International Union for the Conservation of Nature ..... IUCN

Lake Télé-Lake Tumba ..... LTLT

Land Use Land Cover ..... LULC

Ministry of Environment, Conservation of Nature and Tourism ..... MECNT

Maximum Likelihood ..... MLH

Multi-Spectral Scanner ..... MMS

Normalized Difference Vegetation Index ..... NDVI

Observatoire Satellital des forêts d'Afrique Centrale ..... OSFAC

Synthetic Aperture Radar ..... SAR

Shuttle Radar Topography Mission ..... SRTM

Support Vector Machine ..... SVM

United States Agency for International Development ..... USAID

United Nations ..... UN

Abstract

In the last decades efforts to curb wetland net-loss from anthropogenic factors in Congo basin has satisfied only zero wetland loss in acreage but may have not successfully mitigate the net-loss in wetland function. The ecological and environmental potentials of any wetland are a function of its configuration. Anthropogenic landscapes as new urban areas, transport systems, agricultural extension are on the increase in the Cuvette Central of the Democratic Republic of Congo as a result of an exponential growth in human population. This object of this research is to quantify the human footprint in the Cuvette Central of the Democratic Republic of Congo.

Research ability to detect, characterize and monitor wetlands dynamics are often constrained by the limited in-situ data, the risk of perturbation susceptible species, fine-scale variation in landscape, hydrology, and vegetation cover. Technologies for analysing and monitoring wetland dynamics is shifting towards the usefulness of satellite remote sensing. This research put to test the feasibility of optical remote sensing in detecting the patterns in wetland landscape transformation in the Central Congo basin. The methodology will integrate radar imagery with topographic datasets and other complementary data in an object orientation framework. Through which it will assess the magnitude of the anthropogenic footprints in relation to terrestrial ecosystem, aquatic systems, conservation policies and the physical environment.

CHAPTER ONE

1. Introduction:

1. 1. General overview

Freshwater wetlands form unique landscapes to several landforms either as segment or its entirety. Their extend covers coastal and freshwater environment and most often a function of the surrounding catchment area (EPA 2011). In this research, wetland will refer to the flooded marshes, mudflats and shallow water forest vegetation of the Ngiri-Tumba-Maindombe rainforest in the Central Congo basin of the Sub-Sahara Africa. The extensive Central Congolese wetlands is fundamental segment in the global wetlands ecosystem, highly dependent on the vegetation cover and paramount in sustaining life at regional and global level from its characteristic transitional hydrogeological surrounding, where the water table is near the surface partial or year round. It's vegetation regimes serve as erosion and flood checks, nurture groundwater aquifer and provides unique habitat for biodiversity thus safeguarding the ecosystem (Kokaly et al, 2003; Wright and Gallant, 2007; Zhang et al, 2011) and a major carbon sink, mitigating climate change (Brummett et al 2009; UN 2010; Ellison et al 2011; Tompkins et al 2015). The Science of landscape transformation is based on the constructions of the underlying knowledge of physical environmental dynamics as well as human interactions with the landscape (Gardner et al 2009). Land cover loss has for decades been a significant issue for the future preservation of ecosystems and reducing carbon emissions. Many scientific researches have stressed the significant correlations of and climate change through impacting albedo and surface flux dynamics. Understanding the significance of anthropogenic impact on landscape is crucial if dynamics in human induced climate change and ecosystem health is to be assessed (Tompkins et al 2015). Within the Congo basin, more than 90% of the population is depended on natural resources comprising: land for cultivation and non-timber products for livelihood from an ever increasing population (Evans and Costa 2013) with wetlands being converted to agriculture, and infrastructure from timber and non-timber product harvest and shifting cultivation (Bwangoy et al 2010; Hansen et al 2010).. Satellite imagery from the early 1990s maintains the rate of land Cover loss with recent data projecting a dominant fragmented and degraded environment by 2030 (Clarks and Sunderland 2004; Gardner et al 2009; Ellis 2011; Cartwright et al 2014). The decade covering the study period of this research work (1990-

2010), almost 0.49% of Land cover was lost in the Congo basin with significant proportions (54%) in the Democratic Republic of Congo (Bwangoy et al 2010; Hansen et al 2010; Mayaux et al 2014). The Provinces of Bandundu and Equateur of the Democratic Republic of Congo between 2000 and 2010 statistical data presents 2.2% and 2.4% of land cover loss respectively (OSFAC 2010).

Estimates of land cove loss from human aspect are largely uncertain and vary substantially despite substantial improvements in remote sensing technology. A recent FAO data on the rainforest gives the annual rate of land cover loss from 2000–2010 at 0.23% in the Congo Basin, about 0.43% in the Amazon Basin and about 0.41% in the Southeast Asia. Nevertheless, despite these varying estimates the consensus is that tropical wetland systems are at risk from human impacts (Tompkins et al 2015). Estimating drivers of landscape transformation is demanding, as drivers depend on a series of factors and their multipliers all acting and interacting in a network (Geist and Lambin 2001). To comprehend how this composite network of drivers impacts current landscape and possible future scenarios worthwhile for designing models. A host of landscape transformation models are derived from regressions between detected rates and local computed values insinuating the significance of regional factors on the spatial extend of landscape transformation (Tompkins et al 2015). Therefore, quantitative data on the spatial distribution of land use and land cover change within and the adjacent riparian areas to freshwater wetland is vital in assessing the state of the ecosystem (Cartwright et al 2014).

The Limited scientific work in most of tropical Africa is further complicated by the extensive size and inaccessibility to these environment making in-situ data collection more complex (De Roeck et al 2009). Time series imagery from digital spatial technologies have been accessible for almost half a decade, and have been handy for several scientific research ranging from, mapping of landscape dynamics to hydrology and geological analysis (Tompkins et al 2015). These datasets are becoming increasingly important due to the sensitivity of global environmental change owing to their applicability in change detection (Chavez 1996; Ramanathan Sugumaran 2004; De Roeck et al 2009). Previous researches on freshwater wetlands were based on the traditional methods of ground measurement and aerial photography, which was not only time consuming but very expensive and limited to a smaller scale thus truncating realistic scientific research (Mitsch and Goselink 2007; 2015).

This digital technology is not only cost effective, but effectually and adaptively handy for the mapping of wetland landscape variability (Forman et al 1997; Wrbka et al 2004), owing to its multi-temporal and multi-spectral qualities. Its optical imagery has played a significant role in the early global wetland management. The early Landsat Multi-Spectral Scanner (MSS) technology discriminated of wetland and salt marshes in the United State; swamps in Australia (Evans and Costa 2013). Non-the-less, its effectiveness in the tropical freshwater wetland mapping was significantly constraint by the dense nature of the associated forest lands and continuous cloud and smoke cover. The introduced SAR (Synthetic Aperture Radar) operatives, has potentialities of detecting the spatial and temporal patterns of flooded water levels and soil moisture in tropical wetlands (Lang 2008) presenting innovations in tropical wetland mapping. This, propelled institutional efforts in protected areas designation as a procedural strategy for sustainable natural resources management (Perfecto and Vandermeer 2008; Wittemyer et al 2008; Gardner et al 2009). Even at this, technical underdevelopment, compound with high poverty in the tropical Sub-Sahara Africa has significantly reduced the possibilities of wetlands at the rims of anthropogenic threats to be fully investigated (FAO 2006; Gardner et al 2009); making these environments the present point of interest for conservators, scholars and policy managers (Bradshaw et al. 2009), raising debate to the degree of resistance of their ecosystem to the persistent human impacts (Gardner et al 2009), in a globalized natural resources intensive world.

Comparatively, the Congo Basin in general possesses, limited quantitative and qualitative data in terms of critical environments of international standings (Melack and Hess 2004; De Roeck et al 2008) when compared to other significant river basins like the Amazon in the American continent. The Ngiri-Tumba-Maindombe freshwater wetland is a rare landscape which has been relatively intact through history (Céline et al, 2012; Zhuravleva et al, 2013). It forms part of the world's freshwater wetlands which occupy just 6% of the terrestrial land surface and 60-65% of surface water, controlling hydrologic quantity and quantity sustaining biological diversities in this ecosystem (Richey et al 2015; Sanchez et al 2015; Töyra and Pietroniro 2005; Kokaly et al, 2003). Unfortunately, Scientific research in the last decades reveal an significant trends in these wetlands fragmentation and degradation (Hung et al, 2010; Polasky et al 2011; Congalton et al 2014), attracting the interest of conservation as an ignition to their survival (Batzer and Sharitz, 2014). These trends have been blamed on

increase in the demand for natural resources partly to meet the resource needs of the exponential human population growth (Brooks et al 2011; Yanggen et al, 2010). The swamp forest resources of the Congo basin form a significant portion livelihood for more than 80% the population of the Cuvette Centrale (Brooks et al, 2011). Its natural vegetation serve as a major source of timber and non-timber products; and its soils the only sources for land for subsistence activity and urbanization which controversially impacts the giving end of the ecosystem from fragmenting and degradation producing considerably altered landscapes (EEA 2015).

Anthropogenic drivers, however, are commonly accepted as the agent of rates and patterns in landscape transformation. Their trajectories present segments with ecological significance and feedback mechanisms of the interaction between man and the environment (EU 2000; Wrbka et al 2004; Schaich et al 2010; Plit and Myga-Piatek 2014). About a third of the earth's largest wetlands are rapidly depleted by anthropogenic stressors (River-Moore and Cowden 2012; Alain Buis 2015). Europe for example has lost almost two thirds of its freshwater wetlands. With a consequential decreased in the number of biological life and natural habitats in large marshes and shallow lakes producing modified environmental functions and landscapes (Töyra and Pietroniro 2005; EPA 2011). When undisturbed, the horizontal configuration of landscape evolves towards homogeneity. Sensible entropy on landscape rapidly increases heterogeneity. Severe entropy increases or decrease system heterogeneity. Empirical research demonstrates that disturbance on the natural freshwater wetlands attained the highest significance in the Paleolithic age when man improved from hunter-gatherer to the cultivator-herder way of life which consequentially alterations in landscape producing new climate climax, and impacting biodiversity (Forman and Godron, 1986; Szabó 2009).

1. 2. General Scope

1. 2. 1. Research aim and Objectives

The general goal of this research is to frame a detailed synthesis of the scientific picture that routes our knowledge and possible future scenarios in freshwater wetlands in the face of anthropogenic induce turbulence in the Ngiri-Tumba-Maindombe landscape. Using the core analytical, historical mapping and quantitative datasets to investigate the significance of

direct and indirect human factors operating in-situ, such as cropland extension, that commence from intended land use and underlying driver forces of fundamental social and biophysical processes, for instance human population growth or agricultural policies, that strengthens the proximate causes, either operating locally or region wide, the research aims to answer the following main question:

1) To what extent is landscape transformation happening in the study area?

2) What are the main drivers and pressures of landscape transformation in the case study are?

3) How is landscape transformation impacting the ecosystem services and functions in the study area? (in changing livelihoods).

In responding to the above research question the research will:

- Analyse the significance of the proximate factors and underlying driver factors of wetland landscape transformation and their causal effects.
- Demonstrate the role of wetland fragmentation and degradation in producing new landscape from the localized anthropogenic impacts to causal synergy at underlying and proximate levels.

Specific objective of this study is;

To test:

- Hypothesis: Freshwater wetland Landscape is transformed from human impact in the study area between 2000 and 2010.
- Policy decision management significant in natural resource fragmentation and degradation in the study area between 2000 and 2010.

1. 2. 2. Research problem

The Central Congolese freshwater wetlands support a critical biological life rendering a host ecosystem services and functions at local and global levels. Its significance in global climate change mitigation through the enormous quantity of carbon it stores and its rich biodiversity gave large portion of its land surface the international recognition as the largest

Ramsar wetland in the tropical African continent (de Wasseige et al 2014). Regionally, food security for forest communities is reliant on the possible agriculture and animal protein, both of which are at the expense of this fragile ecosystem. Nationally, policy decision stakes ecosystem health to economic development mostly notable in logging concessions and other commercial ventures such as mining (de Wasseige et al 2014), limiting ecological significance of these wetlands in their climate change mitigation (Mitsch et al 2012). However, the sustainability of the wetland communities is highly dependent on the integrity of these environments, as alterations in any facet of the landscape impact the fauna and flora ecosystem health (Carlisle et al 2012). During pre- colonial and colonial era, the Democratic Republic of Congo was flustered with natural resources ordeals resulting in a reluctant ecological viability (Potapov et al 2012; Hansen 2013). Processes of wetland fragmentation and degradation produces not only modified landscape but undermine the energies in wetland to provide valuable ecosystem services and functions to humanity. Freshwater wetlands are critical resources which play a multiplicity of functionalities which their alteration poses a significant threat to both endogenous and exogenous systems associated to them. Tropical freshwater wetlands harbour a bulk of the total terrestrial biodiversity of international significance enhancing perfect functionality of our economic systems. Nevertheless, the future these freshwater wetlands have never been more uncertain, as only an insignificant proportion has evaded anthropogenic transformations (Dixon and wood 2003; Fungai 2006; Gardner et al 2009; Smith 2013). For some reasonable period, the wetlands of Ngiri-Tumba-Maindombe have been under considerable pressure from human activities. With population numbers increases at the rate of rate of 2–3% per year in the region, significant portion of the forested swamps are being transformed from commercial and artisanal logging, agricultural extensions, extractions of non-timber products and urbanization (Bwangoy et al 2010). Scenarios of climate change depict characteristic dominant seasonal hazards in these areas, with projected significant future increase in flood risk (Ludwig et al, 2013). The wetlands stores some 23Gts of Carbon which is a significant 8% of the carbon content of Earth's living forest; an equivalent to the total global greenhouse gas release in two years. This is some 50 times those from burning fossil fuel (WWF 2009; Mitsch et al 2012). Though recognized in 2008 as the world's largest RAMSAR wetland ecosystem for priority landscape conservation and sustainable natural resource management, its adjacent landscapes are compounded with the problems of rapid

population growth thus inducing increasing demand for agricultural land for subsistence farming and other forest resources. It primary forest is presently 37 percent of the total exploitable forest in the Democratic Republic of Congo, with mounting pressures on the ecosystem and limited quantitative when compared to other important river basins like the Amazon. The few available are with limited statistical baseline data; recording of features has been basically on estimations based on the traditional methods which in some instances unrealistic in terms of scale data coverage (Evans and Costa 2013). Satellite remote sensing and other digital technologies in recording of geographical happenings which have been very handy in pioneer data recording on wetland dynamic in the United States of America, Australia and India have been very limited in the Congo Basin in terms of recording of the freshwater wetland dynamics partly due to technological under development and extensive poverty. The few initial trial nevertheless, proved problematic owing to the intense canopy, cloud and smoke cover, constant inundated forest and soil moisture (Mayaux et al 2000; Evans and Costa 2013).

1. 2. 3. Structure of the research

This research is structured in an inclusive conceptual context that integrates a range of human and ecological dynamics to identify and contextualize the perceptions and the possible future scenarios of the tropical freshwater wetland in the Congo Basin. The work based on five major sections of individual chapters:

The first part of this research scrutinizes the perceptions and constrains which determine a bulk present scenarios and empirical research on tropical wetlands in relation to anthropogenic activities. It equally investigates the correlation between ecology and dynamic anthropogenic circumstances influences practical patterns in space and time in an almost homogenous intact ecological setup. The second part of this research is based on empirical works on synergies between humans and wetland landscape. It illustrates the loops in relationships possible future scenarios in freshwater wetlands from a spectrum of threats to fragmentation and degradation in the natural system by using reference books and Open access online materials. The third section basically deals with the general research method. Basically, this is based on datasets acquisition from major past and ongoing projects including other empirical research works specialized on the subject matter in this

research. In the final section, is basically of the two last chapters of the study. This interpretation and presentation of the results to demonstrate impacts from anthropogenic threats on wetland in changing the ecosystem landscape of the study area.

CHAPTER TWO

2. Literature Review

2. 1. Wetland Perception and Ecosystem Concepts

Wetlands are a multiplicity of natural and man-made environments in floodplain, peatland, rivers, lakes and the coast; of extremely complex nature constantly filled with water attaining a maximum height of some six meters minimum surges (Ramsar Convention 2013). These typical environments occupy an insignificant portion of the total land surface of the earth; some 6% (Mitsch and Gosselink 2000), and is highly depended on the local hydrology, soil and vegetation cover. In this research, wetland will refer to the flooded marshes, mudflats and shallow water forest vegetation of the Ngiri-Tumba-Maindombe rainforest in the Central Congo basin of the Sub-Sahara Africa. The ecological significance makes them a unique ecosystem on earth (Dahl 2000; Mitsch and Gosselink 2000; Mitsch and Gosselink 2007) in sustaining an equilibrated functioning of our natural environment (wright and Gallant, 2007; Stedman and Dahl 2008). This principally from the energies associated with sustaining human life on the planet. This in the last century attracted the interest of conservation (Barbier 1994; Mitsch and Gosselink 2000; 2007; Ogato 2013). Not only are in-situ anthropogenic activities like dredging, ditch filling, draining are a point of concern, but equally activities on adjacent landscape like deforestation, slash and burn agriculture equally increases sediment load and conduit of invasive species conduits into these critical natural environment (Vance 2009; Tiner et al 2015). Through history, natural resources have been trigger for human settlement expansion (Foley et al 2005; Tuner et al 2007). The unidirectional relationship between human and wetlands at the dawn of enlightenment has triggered the transformation of more than 50% of wetland landscape (Foley et al 2005); affected biosphere CO_2 stocks, inducing anthropogenic induced climate change (Jensen 2005).

Wetlands were perceived to be more profitable for alternative development (Millennium Ecosystem Assessment 2005). Agricultural expansions, urban sprawl and industrial expansion are present day inescapable alternatives to wetlands and significant direct drivers

to this transformation (Foley et al 2005), with consequential effects on the ecosystem (Dana Beach 2002; Godswill and Tumunabickiri 2015; Vaz et al 2014). Conservation theories in the last three decades have encouraged protected area as an alternative for preserving this critical environment (Wittemyer et al 2008). In the Cuvette Centrale, reasonable portions have been placed under Ramsar reserves. Almost 9.8% of the topical land surface area is under protected area (Ramsar 2013). The long term viability of this policy decision on adjacent landscape is very unclear as the pressure on land increases on a daily base (Gardner et al 2009).

Wetlands are ecological viable environments which when left intact yield potentially incalculable ecological benefits. With human population crisis in tropical Africa (CIA 2007), dynamics in wetland has more than doubled setting modified landscapes. By all standards, the ecosystem health of swamp forest, and water bodies bordered by reinforced watershed are less distinct, less secured and less valuable than those of the natural watershed. This is practical in societies where wetland's alternative economic activities are vividly vital for poverty alleviation and food security (McCartney 2010; IES 2009). In the United States of America, large portions of wetlands were transformed to agriculture land use. The United States swamp Land Act of 1850, encouraged wetland reclamation for agricultural (Somerville and Pruitt 2006). After the arrival of the Europeans to the United States, massive draining and filling, clearing down of forest in wetlands and excavating shallow marsh, produced transformed landscape of fragmented community structures (Dahl 2000; 2006). During this period, some 50% of wetlands were lost. In Georgia alone almost 23% of its wetland were converted into agricultural use between 1780 and 1980 (Dahl 1990). In the Congo basin though the rate forest transformation for agriculture has been relatively low for decades (Hansen et al 2008; Giree et al 2013; Megevand et al 2013) as perceived, owing to the limited quantitative data, from the era of political conflicts to the present day, the scenario has been much different.

2. 2. Detecting and Quantifying Wetland Landscape Transformation with Satellite Remote Sensing

2. 2. 1. The core concepts in landscape transformation

The physical-biological relationships that influences wide-ranging spatial unites in any given space could either operate vertically or between in the spatial units producing modified patches and trajectories (Forman and Godron 1986). As time series transformations of environment vary in character and potency, the receiving end of the spectrum equally very in accommodation; thus policy specification framework is required for compensation and mitigation of targeting driving forces.

2. 2. 1. 1. Drivers and impact on wetland landscape transformations

Comprehending the driving forces and impacts of landscape transformation is critical in present day global science (Lambin and Geist 2006; Hersperger et al 2010). Owing to its global significance, in the last few decades much research have been concentrated on issues of landscape transformation (Turner ‖ et al 2007). These driving forces, mostly exogenous to the system could either set the system to equilibrium or induces wide scale modifications in composition and structures (Klijn 2004; Nasi et al 2011; Rosenberg et al 2014). Decline in the aquifer in a typical wetland does not necessarily impact the local ecosystem health as it is an endogenous function natural water cycle. However, the quantitative loss in wetland forest qualitatively impacts the entire system's landscape (Evans and Costa, 2013; Rosenberg et al 2014). Typical, is the tropical wetlands significance in the global cycle in climate change mitigation and ecosystem regulation, guarantor water quantity/quality and food security (Bwangoy 2010).

Freshwater Wetland fragmentation and degradation has always been associated with socio-economic alternatives and demographic pressures (EEA 2002). The variability in human population in much of the Congo basin in the last thirty years is resulting to open access to forest and non-forested resources leading to habitat destruction, fragmentation in fauna and flora life and ultimately global CO_2 composition. Habitat destruction is the most persistent anthropogenic impact on other species. It is the greatest present-day threat to biodiversity and ecosystem integrity and the root cause of pushing freshwater wetland

ecosystem to the edge (Malanson 2002; UNESCO 2010). Open access to the intact forest through development endeavours transform the entire wetland landscape; as not only is the swamp forest disturbed by logging and complementary activities but influx of new populations is a major area of concerns (Mitsch and Gosselink 2000). Commercial and artisanal logging concession and its complementary activities in the central Congo basin is relatively producing dominant secondary forest landscapes (CBFP 2005; UNESCO 2010). Much is still to be ascertained on the future scenarios in this intact landscape. Ecological concerns need to strike a balance between understanding the scientific base of wetland and the policy management decisions (Mitsch and Gosselink 2000; Siry, 2007). This reality is fundamental in assessing how humans will continue to be an integral part of fragile ecological regions without irreversibly degrading the environmental functions or transforming the land services. In the Central Congo Basin limited scientific works in the wetland was carried out during the colonial era (De Grandi et al, 2011; Campbell, 2005). As the Landscape layouts are outcome of a combination of biotic and abiotic operations in space and time (Bolliger et al 2007; Turner 2005), environmental configuration over time is a function dynamics within the wetlands from natural and anthropogenic forcing. (Irish et al 2006). Based on this, conservation demands sustainable schemes crucial in detecting Land-use and Land-cover dynamics for any specific space sustainability (Gillander et al 2008; Jwan Al-doski 2013).

2. 2. 2. Detecting landscape transformations with satellite remote sensing.

With the present general convergence among researchers on ongoing transformations in the Central Congo Basin, it is prudent to develop our knowledge on accurate appraisal for system dynamics within wetland of this basin, in terms of alterations. Many scholars have advanced a series methodologies frequently applied in assessing these transformations (Turner et al 2003; 2007). Prominent are: the comparative analysis of supervised classifications, synchronized analysis of multi-temporal data, image differentiation, rationing, principal component analysis and change vector analysis (EPA 1999). Even at this, the task of detecting landscape transformation from anthropogenic factors is not that simple (Dadras et al 2014). A host of national and international bodies are keenly on scenarios of landscape transformation based on classification using standardized frameworks configured to suit the present day exigencies of Ramsar classification standards

(Jones et al 2008), employing a host of techniques for a rigorous quantitatively assessment of landscape transformation (Turner et al, 2007). Wetland management in most developing nations has heavily relied in traditional field data collection techniques. This has not only proven to be limited as a resource but has equally been problematic at regional and global level because of the natural landscape attributes.

Satellite remote sensing technology is presently vivid in detecting and quantifying the state alterations in wetlands (Ramanathan Sugumaran 2004; Gillander et al 2008; De Roeck et al 2009; Zhou et al 2014). Elements of remote sensing like image analysis, has become significant in complementing and updating conventional data collection on land use and land cover change (Jones et al 2009; Esam et al 2012). The Landsat mapping programs, an innovative technology in mapping landscape transformation is innovative technology introduced in the Democratic Republic of Congo just a few decades ago (Verhegghen, 2012; Viennois et al 2013; Zhuravleva, 2013). its optical sensed multiple imagery technology enhances quantitative and quality data collection on land cover changes even in the inaccessible tropical rainforest (Hansen et al 2008; Achard et al 2007; Vancutsen et al 2009; Verhegghen et al 2012). By providing synoptic records of land cover changes it sets an authentic planform for acquiring multi-temporal quantitative data for landscape transformation in space and a time series (Wrbka et al 2004; Lunetta et al 2006; Gillander et al 2008). The presentation of Landsat in the 70s by NASA and the US Geological Survey was a major break-through. It's Multispectral Scanner (MMS) with the recent Thematic Mapper (TM), and the Enhanced Thematic Mapper Plus (ETM+) has become the critical sources for quantitative remotely sensed data (Powell et al, 2007). Their viability has been proven in principal tropical wetland mapping (Adam et al 2009; Bwangoy 2010; Lane et al 2014). Multispectral remote sensing tolerates the discrimination of the distinctive land use and land cover types. (Michishita et al 2012; Govender et al 2007; Adam et al 2009; Bwangoy, 2010). The challenging of using passive remote sensed imagery to classify tropical wetlands characterised by high spatial heterogeneity and temporal variability with constant and smoke cover cloud cover (Lane et al, 2014), bred interest in research into a more faster and sustainable automatic algorithms (Malack and Hess, 2004; Joyce et al 2009). A host of these techniques are presently operational with most of them using active remote sensing data

(Bwangoy, 2010), in the discrimination of the distinctive vegetation types, soil moisture, topography, clear and turbid water (Govender et al, 2007).

2. 2. 3. Quantifying rates and patterns in wetland landscape transformation

Landscape transformation is one of man's most distinguished evolutions. It traces back to the Palaeolithic era when man in bit to attain food security transformed his activities from hunter-gathering to cultivator-herder, resulting in vast extend of alterations in the natural ecosystem functioning (Forman and Gordon 1986; Szabó 2009). The rate and trajectories in in the transformation is central in detecting and analysing anthropogenic driver as a function of change (Turner II et al 1990). This ascertains the theory in Landscape ecology as a science largely founded on the notion of environmental patterns as a function of ecological evolutions (Mcgarigal et al 2009). Environmental frameworks are complex and can be generally characterized as biomes spatially structured to scale based on the predator-prey correlation. Using remote sensing to detect these structures, similar trajectories propelled by certain processes generates discrete landscape characteristics of sustained direct and indirect human interaction with the ecosystems. Typical are community population and structures, habitat composition patterns, vegetation patterns and (Ellis and Ramankutty 2008).

2. 2. 3. 1. Quantifying rates in wetland landscape transformation

The significant impact of anthropogenic pressures on freshwater wetlands is the rapidity of transformation of structure and functions of the ecosystem which has really be alarming in the 21st Century. The rate of this modification is really magnifying as both human population size and economic strength surges. This significantly fragment and deplete the diversity of life in in this fragile environments at an accelerated rate. The loss of plant and animal species is irreversible. So, too, is the unravelling or elimination of whole ecosystems. Quantifying the rates in landscape transformation is critical to the science of conservation as the loss of flora and fauna is irreparable. So, too, is the elimination of an entire community or the collapse of the entire system (WHO 2005; Hansen et al 2008). Datasets on rates of transformation in wetland are problematic and scanty in the entire Central Africa due to the inaccessible of portions of the rainforest coupled with limited technological capacities (Zhang et al 2005). Analysing rates of change using satellite imagery is very challenging due

to weak textural differences and nearly homogenous spectral response in the landscape (Varma et al 2013). In the world of conservation, satellite imagery is central in the specifications of changes on any geographic space and more significant in the 21st Century due to the fact that anthropogenic activities are site rate specific in terms of land use and land cover. An accurate data on the rates of evolution in the system is critical in wetland management (Zhou et al 2014).

2. 2. 3. 2. Qualifying patterns in wetland landscape transformation

Entropy is in play when allusion is made on drivers that modify the ecosystem. Sustainability of a systems vigour, organization and resilience embodies all aspects of the entire ecosystem. Interactions of this magnitude could be similar to entropy in thermodynamics in physics as it enhances knowledge of stress on a system. Most present-day complex spatial patterns in terms of natural resource distribution, reflects environmental influences on ecological process (McGarigal 2009). The trends associated with system response to any degree of anthropogenic stress are site specific. Qualification of the patterns with specific suite of manifestations provides profound system-level indicators of the ecosystem response to anthropogenic stress (Mageau et al 1998; Turner 2005; Gardner et al 2009; Mcgarigal et al 2009), and representing the main point of interest among contemporary scientist of spatial data mining (Turner 2005; Guo and Mannis 2009; Miller and Han 2009). Several quantitative evaluation techniques are handy in analysing processes and patterns of landscape transformations, with main interest in the characterization of the geometric and spatial patterns represented at a single scale (Turner ‖ et al, 2007; Hansen et al 2008; Vancutsen et al 2009; Verhegghen et al 2012). Most prevalent include the nearest neighbour algorithm (Clark and Evans 1954); cluster detection in spatially re-occurring patterns (Repley 1977; Brimicombe 2008); spatial autocorrelation analysis to verify the connection spatial extent and the spatial correlations between species (Sokal and Wartenber 1983; Volker Bahn 2005; Dormann et al 2007). Lacunarity-based texture analysis for patterns in any point dispersal after an entropy (Myint and Lam 2005; Buston and King 2006). Other methods involves the use of the graph theory for determine the connectional relationships between different point samples under converging drivers in transformation (Kindlmann and Burel 2008). Finally and most widely applied, landscape metrics, developed

from ecological empirical works to resolve the stochastic present ecological landscape patterns (McGarigal et al, 2009).

CHAPTER THREE

3. Methodology

3. 1. The Case Study:

3. 1. 1. Locational settings of Ngiri-Tumba-Maindombe Wetland Landscape.

The case is situated in the Cuvette Central in the Democratic Republic of the Congo, overlapping between the Provinces of Equateur and Bandundu.

The Ngiri-Tumba-Maindombe Wetlands Landscape

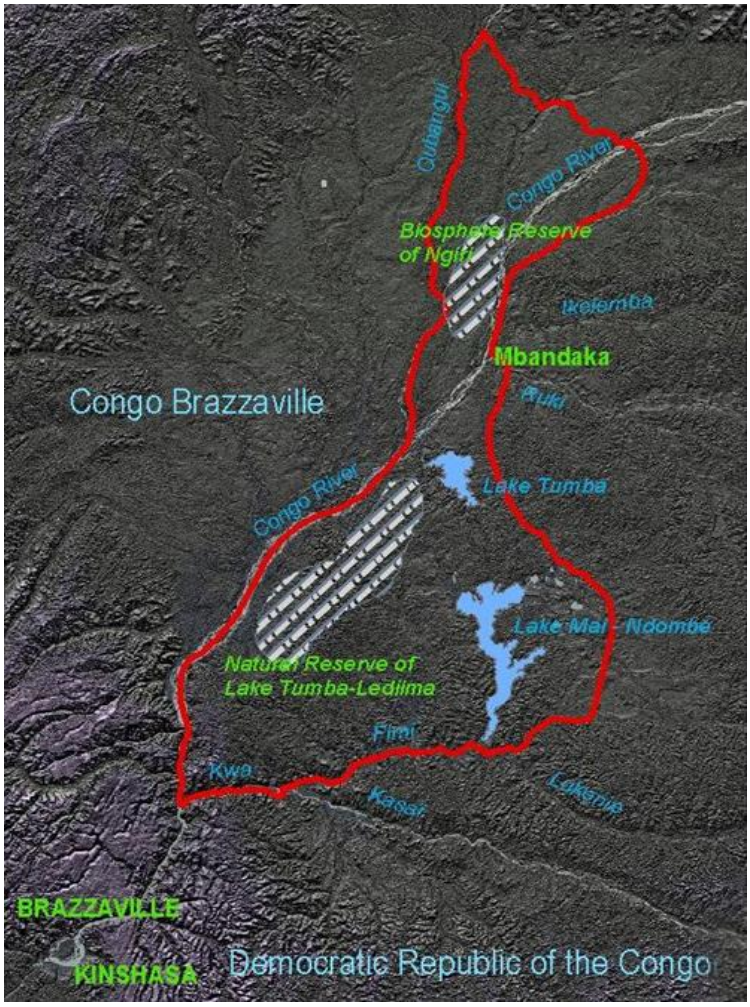
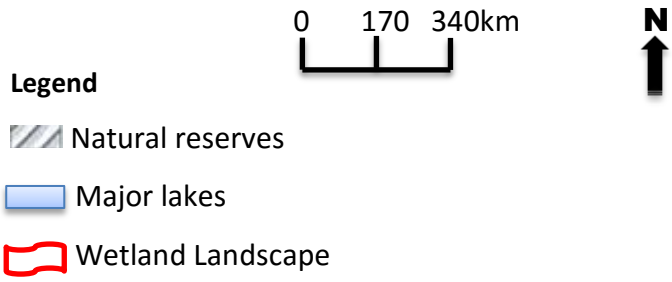


Figure 1; Ngiri-Tumba-Maindombe Wetland Landscape DRC (Source: OSFAC 2009)



It is irregularly shaped (Figure. 1) and runs through the Eastern portion of the Republic of Congo through the western segment of the Democratic Republic of Congo, stretching into the Central African Republic. Its Southern boundary is defined by the River Kasai and its tributary, the River Fimi into which drains the Lake Maindombe. Its Northern extend is bordered by the city of Mbandaka and Makanza. The entire Landscape contains the most extensive continental freshwater mass in the Sub-Saharan Africa region; containing the greatest proportion of flora and fauna, with enormous quantity of other natural resources that supports the ever growing population which solely depend on the natural resources for livelihoods (IES 2009; OSFAC 2010). These principal wetlands occupy a Pliocene-epoch lake bottom which was subsequently flooded with sediment producing a shallow basin with insignificant topographic variation which is presently an issue discriminating silent attributes of the wetlands as is criss-crossed by slowly flowing rivers which make up the entire watershed (Bwangoy et al 2010). These wetlands include flooded forests and inundated grasslands with characteristic anaerobic and saturated soils covering the Western part of the Democratic Republic of Congo and the North Eastern part of the Republic of Congo, stretching into the hydrologic networks of the Central basin (Mayaux et al 2000).

3. 1. 2. Physical setting of the case study.

The landscape of the bisected by the Equator presenting an almost homogenous topographic setup of essentially undistinguished alluvial plain attaining maximum height of 450 meters (Bwangoy et al 2010). The climatic peculiarity of this landscape is noticeable in the Northern portions, manifesting a slight seasonal variation in temperature while the southern section, a significant temperature variations with precise dry periods between the months of June and August (Haarpaintner et al 2012). Its rainfall regimes average 1800mm/yr. in certain portions with dominant wet conditions, high humidity and high temperatures of averaging 25^{oc} annually (Campbell 2005; Bwangoy et al 2010). The wetland includes permanent rivers, streams, creeks and freshwater marshes and pools, forested peatlands, peats swamps forest and permanent freshwater lakes, with an almost homogenous 'Raphia Palms' which variates with annual rainfall (Mayaux et al 2002). Its soils are anaerobic and water saturated made of basically sand and clays (Campbell 2005), with extensive shrubs and herbaceous vegetation, at the convergence of the Giri, Oubangui

and the Congo Rivers (Verhegghen et al 2012). This area is principally washed by the Rivers Congo and the Oubangui exhibiting a uni-modal discharge a direct contrast of its tributaries, the Rivers Femi, Kasai, Kwo and the Ruki which display a bi-modal discharge. Major lakes include the Lake Tumba and the Lake maindombe both located south of the Equateur Province. The greatest extent of the wetlands area with permanent inundation is on the banks of the River Congo south of the River Ruki surrounding the lake Tumba. In the elevated areas also are characteristic open wetlands rivers and dry forested zones hosting a heterogeneous forest strand (Bwangoy et al 2010), a significant determinant for the determining the distribution of biological life

3. 2. Anthropogenic hotspots in the case study areas

The emphasis on anthropogenic hotspots stems from its significance in the dynamics of structure and function of the wetland ecosystem. In order to comprehend the correlation between anthropogenic pressures and ecosystem performance, this research elaborated the trigger-pressure footprints in terms of alteration in the natural functioning in the ecosystem, facilitated by the innovative digital technologies datasets. In the Cuvette Central, main hotspots are along the water ways, and the two major lakes. The area forms a stretch west of the River Congo between the Eastern Swamp Forest and the Central wetland, covering a great proportion of the Equateur and Bandundu Provinces. Early biological inventories biodiversity in this area reveals significant botanical and zoological abundance with some twenty three fauna species short listed in the IUCN “Red List”. These are typical of the diversified herpetofaunal taxa and ichtyofaunal with multiple other endemic iconic mammal species like okapi and white rhinoceros (IUCN 3013). Others includes the endangered Great Apes, bonobo and common chimpanzee, the two endangered subspecies of the eastern gorilla and the two principal lakes considered as two aquatic ecoregions housing several other endemic aquatic species (Devers and Weghe 2006; Inogwabini et al 2007; De wasseige et al 2008; Samndong and Nhantumbo 2015). The essential flora community performing important carbon sink (Devers and Weghe 2006). Finally, two prominent natural reserves- the Tumba-Ledima recognised in 1997 and the Ngiri natural reserve recognised in 2011 overlapped with several logging concession, and dominant economic activities for livelihood (Serckx 2014). This area which encroaches into both the Eastern Republic of Congo and the western segment of the Democratic Republic of Congo is

bordered to the south by city of Bandundu and the Rivers Kasai and River Fimi which drains the Lake Maindombe. The Northern extend is bordered by the city of Mbandaka (Fig. 2). This area contains the most extensive continental freshwater mass with extensive underground resources and rich biodiversity which is principal in sustaining the environmental and economic health of the sub-region region (OSFAC 2010).

Anthropogenic hotspots in the Case study area

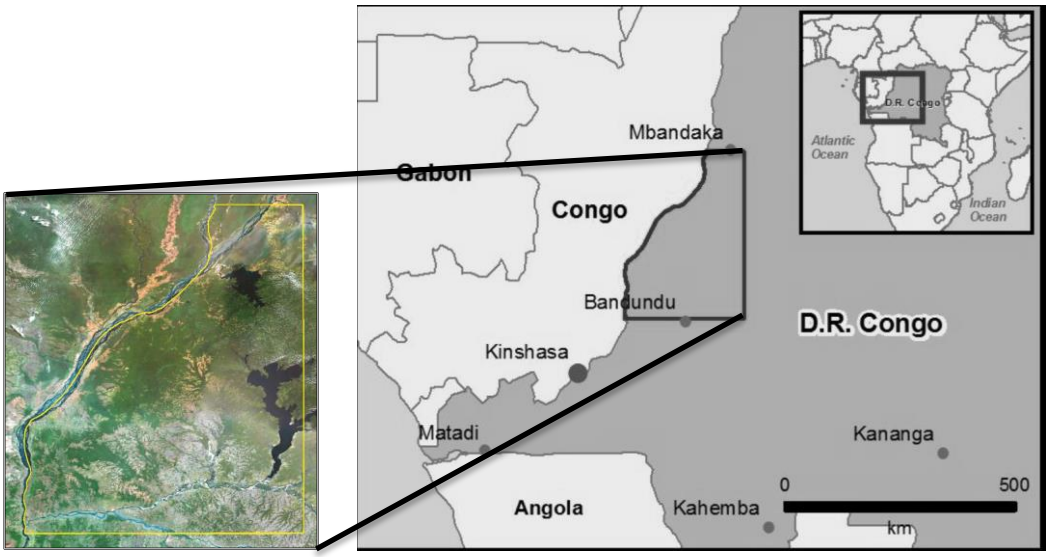


Figure 2; Area of maximum concentration of anthropogenic disturbances (Source: ReCover 2015)

3. 3. Method

3. 3. 1. Satellite remotely sensed imagery acquisition and preparation

The rationale is to discriminate expanses of transformation in the wetlands. These time series datasets corresponds with the decade period under study. This serves as a qualification for change detection so that observed transformations are not interpreted adversely. The general paucity of quantitative data on wetlands of the Congo Basin has been attributed the partly to the inaccessibility of the physical environments and to a greater extent, technical underdevelopment of this sun- region. Several empirical researches reveal that satellite remote sensing technology is handy in providing quantitative data on freshwater wetland dynamics (Hidayat et al 2012; Ward et al 2012). The primary dataset for this study are high resolution L-HH archival imagery mosaics satellite imagery of Landsat and

ALOS AVNIR-2, RapidEye as-well-as different genre of SAR radars from ERS-2 SAR, Envisat ASAR and ALOS Palsar; of 8-bit and 32-bit respectively at 10m-30m resolution from ICESat GLAS ReCover EU-FP7 (2010-2013) aimed at fostering and expanding a science based remote sensing facilities to manage the tropical forest in bit to control emissions from deforestation and degradation in the tropics, through OSFAC on request (Zhuravleva et al 2013). The C-band previously employed in this process was affected by significant surface contaminations and environmental effects producing inconsistence results on soil moisture and inundations status in the wetland (Mayaux et al 2000; Lang et al 2008). The OSFAC was one of the service users of the ICESat GLAS ReCover EU-FP7 project; representing the Democratic Republic of Congo. Hess et al 2003 successfully used L-HH to discriminate soil moisture and inundation dynamics even at significant canopy, cloud cover and smoke cover circumstances (Hess et al 2003; Lang et al 2008). These imageries are complemented with correlating datasets to build a modelled justification of wetland landscape transformation from external entropy in the study area against which scenarios could be assessed. High resolution satellite imagery has been instrumental in physical features change assessment and has enhanced the delineation of potential stepping-stone fragment that may serve as a corridor in anthropogenic induced transformed landscape assessment (Boyle et al 2014). Tackling the research subject, the best compromise is drawn between precipitous assessment of thematic features and hyperspectral imageries of change dynamics in wetland classes were compared to correspondingly reclassified maps to ascertain the significance of reduce class modification to enhance quality. To comprehend this datasets the research utilizes analytical method to illuminate the empirical works as well as the trigger-pressure tandems in wetland landscape alterations in Ngiri-Tumba-Maindombe.

3. 3. 2. Satellite remotely sensed imagery processing.

The dataset were processed using an algorithm based on synergy amongst ERS SAR and optical images, for mutual satellite imagery production, updating, amplification so as to extract the best thematic information. Thematic and topographic maps processed using ERS SAR data allow one to detect and identify specific features of structural change which are particularly important in for ecological functional analysis. The imagery mosaics subsequently produced are based on a sampling of parallel optical imagery of Landsat and ALOS AVNIR-2, RapidEye as-well-as different genre of SAR radars from ERS-2 SAR, Envisat

ASAR and ALOS Palsar through temporal sampling based on iterations between 2000 and 2010 on two equal interval periods. Temporal sampling is a significant instrument for scrutinising natural and anthropogenic transformations in a scene (Shaw and Burke 2003; Haarpaintner et al 2015). This is Subsequently decomposed with a multiscale and filtering for various imagery bands using histogram matching of the various bands, ascertaining observed changes are not due to radiometric differences, provided an opportunity for resampling of the images on multiple strips in space at a 30meters using bilinear resolution at 87% and 88% precision according to end user precision, using the Norut's in-house developed GSAR software using the SRTM V4. Suggesting consistency and viability in the dataset and making it possible for the end user to analyse the different points of interest. Since some pixels were not decomposed to complex pixel regions, maximum likelihood (MLH) and support vector machine (SVM) classification were extracted from 2009/2010 Kompsat-2 VHR images for Landsat and from fieldwork ground observation carried out from 18-26 March 2013 in the Maindombe lake area (Haarpaintner et al 2015). Training polygon extracted from 2009/2010/ Kompsat-2 and post classification was carried out with successive majority filters. In this way the entirety of the obtained data were presented more accurately. Quantitative dataset from local dynamics in wetland are only consistent with complete process evolution in a space remotely sensed. To satisfy this, quantitative data needs, multiple strips sample and assembled over space in a time series (Hoekman et al 2009).

3. 3. 2. 1. Production of controlled digital Image mosaic (SAR)

Wide-range multi-resolution and multi-temporal ERS-2 Synthetic Aperture Radar (SAR) of the EU-FP7 tropical African project was used in producing the digital mosaics (Haarpaintner et al 2015). Mosaicking is instrumental in the characterization of inundation conditions in the swamp forest of Central Congo basin (Rosenqvist and Birkett 2002). These datasets consist of two time series sub-samples carried out between 2000 and 2010, of medium resolution radar and very high optical resolution of Kompsat-2, ALOS AVNIR-2 and Landsat dataset to discriminate the land use and land cover change. All the datasets are produced at the same UTM zone 33S and configured to a common grid; georeferenced, radiometric calibrated and topographically adjusted with in-house built Generic Synthetic Aperture Radar (GSAR) software of Norut IT, using NASA SRTM V_4 DEM (Larsen et al 2005;

Haarpaintner et al 2015). The datasets were pre-processed with advanced radar backscattering coefficient in order to resolve the incidence angle effects from the target surface so as to enhance imagery quality (Kaasalainen et al 2011). The backscatter cross-section is related to the illuminated target area. As the target range increases so the illumination and the backscatter effects magnifies with respect to R^2. Therefore, capacity of the backscattered signal is inversely proportional to R for homogeneous targets spreading over the entire laser footprint but varies with linear objects (Wagner et al 2008; Kaasalainen et al 2011). Mosaicking the datasets is very necessary for complex environments like the freshwater wetlands in the Cuvette Central, as it enhances quality in datasets (Hussain 2013), and very relevant for authenticating on any wall-to-wall mapping process.

The mosaics were reprocessed using algorithms could validate wetland fragmentation and degradation from anthropogenic pressures through the estimation above ground biomass, typical are leaf moisture content, and other physical parameters such as tree structures from multi-frequency and multi-polarization observations of their radar backscattering coefficients (Sarabandi Kamal 1989; Myneni et al 1995). Stabilizing remote sensor imagery for radiometric corrections which modifies the DN values to account for noise and conversion of data to ground coordinates of the same UTM at 30metres by removal of distortions from sensor that recognises the significance of quantifiable reflectance from objects which produces variance between real reflectance from the biosphere and the real digital image number from the differences in the time lapse and space variability of the samples. With supplementary field data the and by using Landsat and the Geoscience Laser Altimeter System (GLAS) mounted on Ice Cloud and Land Elevation Satellite (ICESat), Above Ground Biomass (AGB) was discriminated into inaccessible forest wetlands, open forest and inundated forest wetlands. Using RapidEye mosaics from 2003-2009 calibrated with GLAS, the height and distribution of AGB distribution was estimated with allometry equation (Haarpaintner 2015).

3. 3. 2. 2. Production of controlled digital Image mosaic (Optical)

The optical mosaicking is based on Landsat 2001 and ALOS AVINIR-2 2010 and RapidEye 2012, with characteristic 10% of mixed-clouded pixels which resulted in temporal and spatial discrepancies in the consequential contamination of the downstream data. These

results were reprocessed with algorithms which configure the ALOS Avnir-2 datasets. This converts satellite radiance to reflectance by correcting solar band radiance and solar zenith angles though it makes no impact on atmospheric backscatter (Chavez 1996); With a spectral band value that is significant to each pixel, enhancing the 30 meter on a supervised maximum likelihood classification of the normal distribution with significance given to characteristic trail of area space over time to describe the mean values parameter for each recognizable class pixels by using information on spatial relationships of neighbouring pixels in for the various pixels classes (Pedrazzani et al 2012), dampened the variance for an enhanced image quality.

3. 3. 2. 2. 3. Production of landscape transformation maps (Digital SAR/Optical).

Change detection is not concluded in isolating land cover changes but analytical qualification competences using digital technological tools. Analytical discrimination of images is critical in change detection studies. Using a general parametric algorithm in land cover changes in a wetland landscape as a function of freshwater wetland landscape transformation, assume a spherical model from points focus to pattern of each class based on statistical assumption, of multivariate normal distribution within each class.

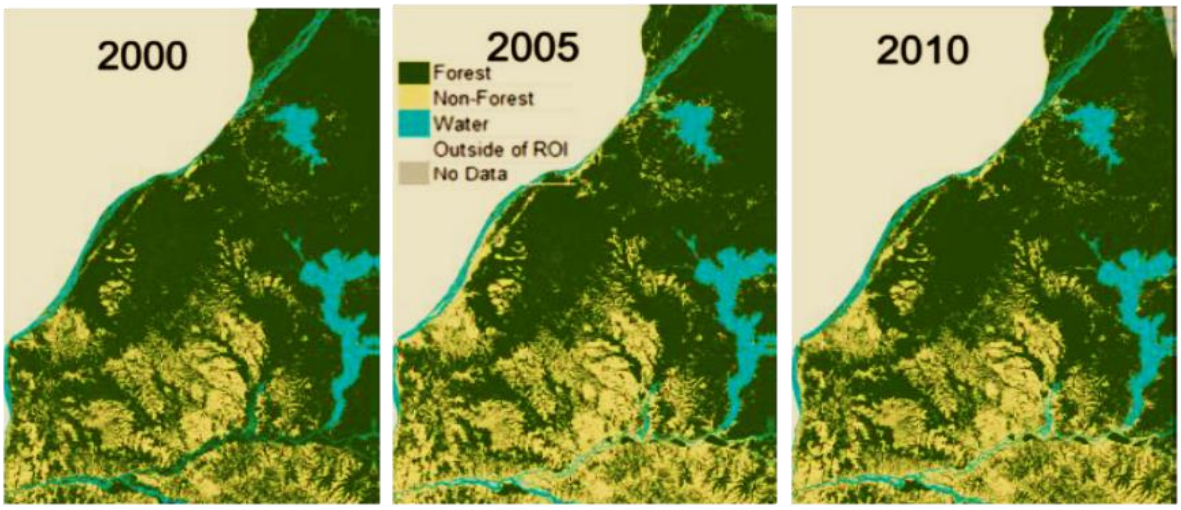


Figure 3; SAR Mosaics, 2000-2010. (Left ASAR WS, middle Envisat ASAR and right ALOS Palsar FBD/FBS). Source: Haarpainrner et al 2015.

Vegetation cover and aquifer layer are two most correlated determinants of freshwater wetland success. Using lands cover changes, the landscape transformation map was derived from SAR and optical forest and non-forest cover changed maps from 2000 to 2010. Using

SAR, only identifiable land cover as per the field exercise was significant with time series analysis performed on the available ERS-2, Envirsat-2 ASAR and ALOS PALSAR datasets in bit to establish the ideal samples and reduce the impact of data contamination from cloud, mist and canopy cover. The final output (Figure 3) established by maximum likelihood classification based on training polygon class concealing the water bodies from extracts of FACET map (Haarpaintner et al 2015).

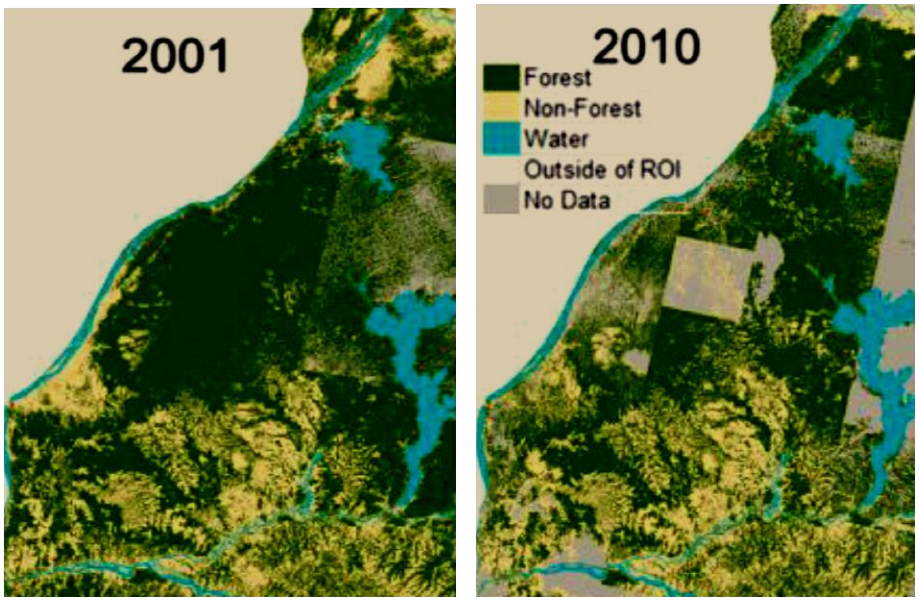


Figure 4; Optical Mosaic 2001-2010 based on Landsat-7 ETM (left) and ALOS Avnir (right). (Source: Haarpaintner et al 2015)

Discriminating the land cover changes derived from optical land cover maps was based on supervised maximum likelihood classification. To amplify the dataset and enhance data quality, the Normalized Difference Vegetation Index (NDVI) to each sample was added an additional synthetic band.

The optimum classifications of forest and non-forest areas are based on SAR and Optical mosaic maps. As this model required ground validation, training polygons extracted from Landsat 2001 and ALOS Avnir-2 for the 2010 is used to produce land cover change map (Haarpaintner et al 2012). This algorithm reduces the heterogeneity amongst the datasets and produces a final configured map (Figure 5) disguising water and settlement. The configuration depicts land cover change mainly along river course and the two major lakes. This is significant in the southwestern of the Congo River basin and north of Lake Maindombe stretching to adjacent areas of the Lake Tumba.

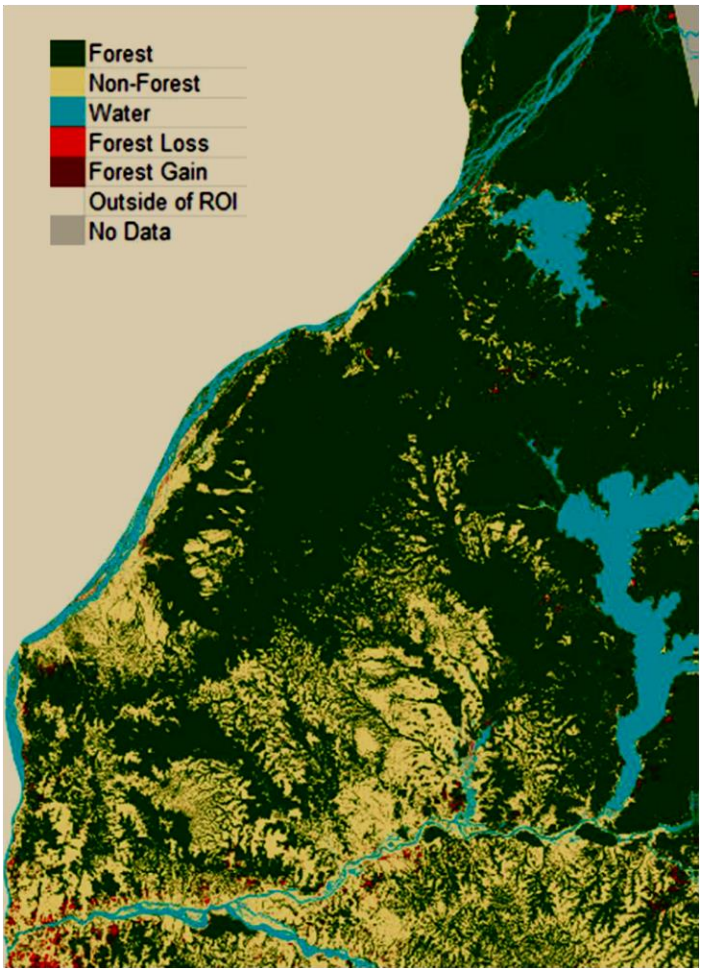


Figure 5**:** 2000-2010 land cover change based on optical and SAR.

(Source: Haarpaintner et al 2015)

The configuration depicts land cover change mainly along river course (Red spots in figure 5 above) and the two major lakes. This is significant in the southwestern of the Congo River basin and north of Lake Maindombe stretching to adjacent areas of the Lake Tumba.

Chapter Four

4. Results and interpretation.

4. 1. Satellite detection of anthropogenic footprint in the case study area

The prototypical satellite imagery for this research is Landsat 7 ETM+, ALOS-PALSAR and RapidEye based on ICESat GLAS (Haarpaintner et al 2015). The analysis of the satellite imagery is carried out with the algorithms based on mosaicking and training polygon extracted from 2009/2010/ Kompsat-2. Applying multiple realization of white noise image for each synthesis which allows photorealistic generation of ensembles of statistical texture with final output harmonised to a 30m resolution based on a bilinear algorithm to enhance site phenomenon by increasing the pixel points in eliminating the errors based on end user threshold values, making it possible for the end user to analyse different points of interest. Since some pixels were not decomposed in complex pixel regions, maximum likelihood (MLH) and support vector machine (SVM) classification were extracted from 2009/2010 Kompsat-2 VHR images for Landsat and from fieldwork ground observation. Post classification was carried out with successive majority filters. In this way, the entirety of the obtained data could be expressed more accurately. The detection of the field component on the imagery were configured from a field operation carried out from 18-26 March 2013 along the road R204 from Inongo/Selenge to Benye in the Mai- Ndombe district as well as by boat in an inundated forest region in the North-west of Lac Mai-Ndombe (Haarpaintner et al 2015)

Qualitative comparison of the final maps of 2000 and 2010 and the complementary dataset revealed precisions of 87% and 88% for optical and SAR radar sensors respectively, indicating consistency of the method based on the Norut's in-house GSAR developed software using the SRTM V4. A cascade landscape change from a decade forest cover loss (2000-2010) in the Lake Télé-Lake Tumba landscape precisely around the Lakes Tumba, Maindombe is revealed (Fig 6). This could partly be attributed to policy decision, economic activities and demographic growth. A field study carried by Milton in the Lake Télé-Lake Tumba landscape depicts a host of villages and towns cluttered around the Lake Tumba, Lake Maindombe and river courses, characteristic of high dependency on natural resources for their livelihoods (Milton 2015).

Anthropogenic footprints around the two major lakes

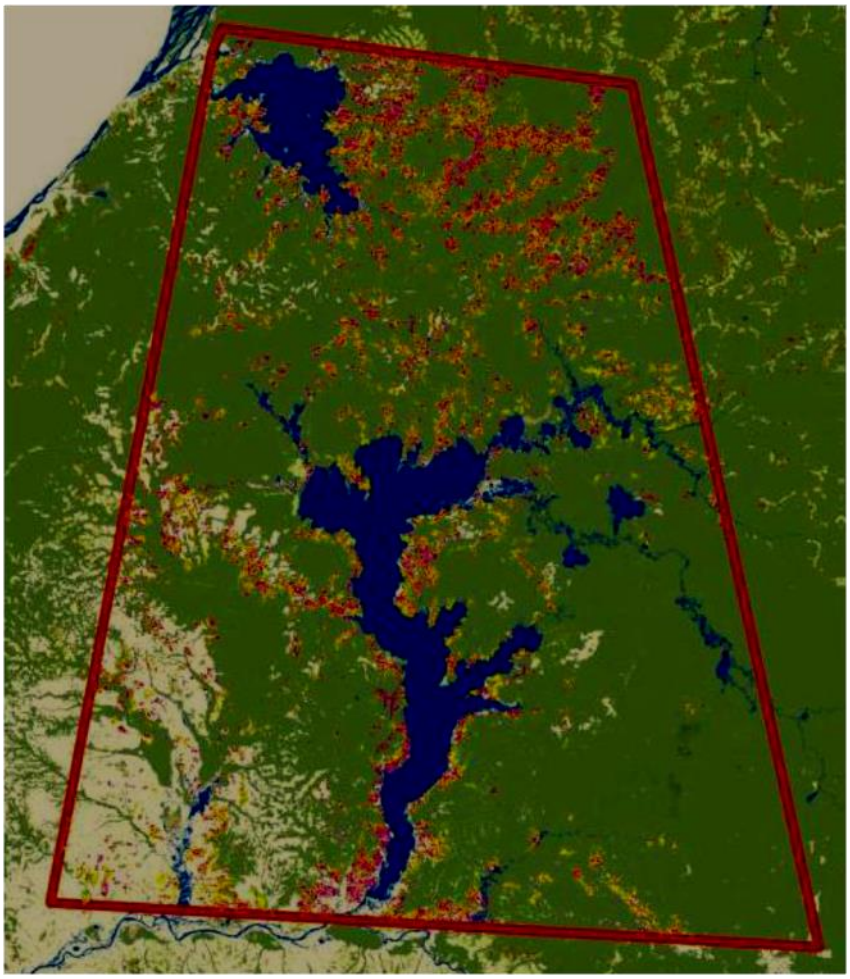


Fig. 6; Source: Modified from Milton 2015

0 20 40 60 80km

Legend

2000-2005 transformations

2005-2010 transformations

Highly significant footprint

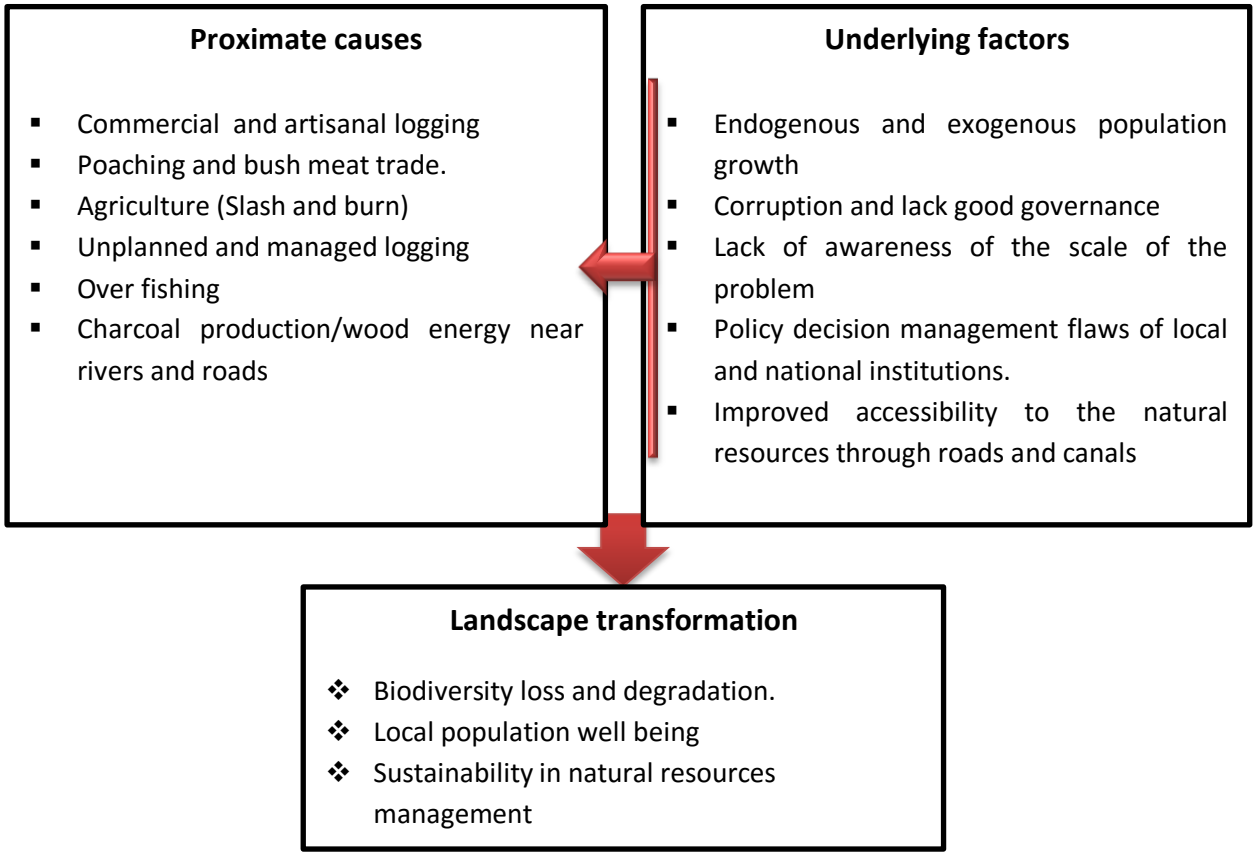
N

The systematic quantitative reduction of keynote community produces asymmetrical impact on the ecosystem landscape. In the Cuvette Central, for convenience, degradation and loss in wetland is assessed from the expansion in land use and land cover loss (Duveiller et al 2008). Wall-to-wall change detection is handy for a broad appraisal of turbulence in the natural system. However, areas of selective logging is manifested by the of logging infrastructures and associated land use; roads and other urban infrastructures associated

with economic developments (Margono et al 2012) which are significant ground data to estimates ecosystem degradation owing to the deficiency in historical data on wetland fragmentation and degradation (Herold et al 2011).

The wetlands of Ngiri-Tumba-Maindombe is a critical ecological hotspot, accommodating diverse biological life including three large primate species of gorillas, chimpanzees and bonobos and other minor fauna species including an extensive forest cover characterised diversity in flora life. The environment and its enormous economic and ecological value provide the much needed energy for the local Communities livelihood. Manipulating the correlation between classification and information technology paradigms based upon the function and activity constraints (table 1) facilitates synchronization between different energies in parallel to attain the trends in the wetland transformation.

Synergy in wetland landscape transformation



Source: Modified from FCPF-ERPIN 2014

The significance of the landscape transformation from 2000–2005 and 2005–2010 as a function of human induced turbulence on the landscapes operates in a time series, results in

some form of comprehensive layers (triggers-stress networking) critical to altered patches and degradation in the ecosystem.

Networking in wetland landscape transformation

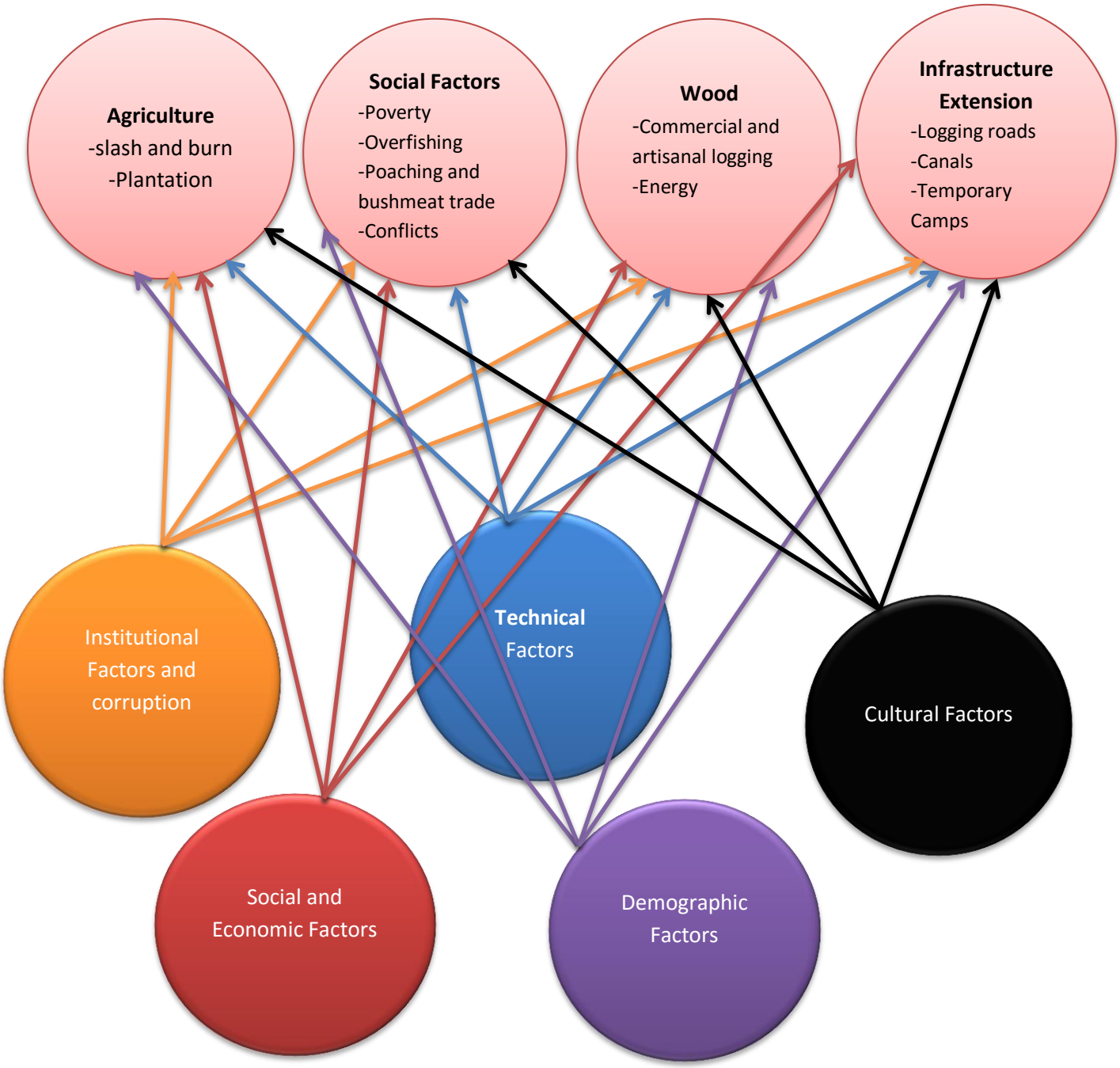


Fig. 7; Triggers-pressures tandem in wetland landscape transformation (Source: modified from Ashley Milton 2015)

The trigger-stress networking–demonstrated from particular trigger sequence and empirical datasets validates the hypothesis of causality in variables responsible for the layers in freshwater wetland landscape transformation (Figure 7), as triggers directly correlated to

pressures in some modelled networking (Geist and Lambin 2001). This is typical in the case study primary – secondary land cover degradation from logging-agriculture processes tendencies and other essential points exaggerated by accessibility to the deep intact wetlands by infrastructural development (roads-agricultural extension inducing urban development form demographic growth), ultimately causing land cover decline in function and structure, introducing new landscapes (Bamba et al 2011)

Detecting these triggers in the case study presents a contextual understanding of land management decisions and the interactions of variables that are significant in processes modification in the DRC. Several of the deep rooted triggers in this circumstance are constraints, which are transforming corridors. Others are associated with the appropriation of modern-day economic possibilities by land management policy decision which seeks to attain returns, conservation and maintaining customary systems. A host of these triggers are endogenous; typical is natural resource paucity, greater susceptibility and transformations in societal designs, propelling the complex exogenous forcing of changing world order in terms of natural resource demand and supply. Although the exogenous are significant determinants, these complex variables either transforms gradually at an incremental scale in time over a span or abrupt, or as a combination with synergetic interplay (table 1), setting a significant turbulence that impact precipitously the ecosystem dynamics producing modified ecological space (Gabarrón-Galeote et al 2013). Two major exogenous drivers in place in the case study are natural resource paucity and land policy decision management of tenure, concession and conservation. Mapping the products of the triggers is more complex than mapping the process. Typical is discriminatory logging as a factor of fragmentation and degradation does not really reflect from low intensity satellite imagery. Logging infrastructures and their complimentary products (for example settlement for employee) are very significant in assessing the degree of anthropogenic threats in a typical wetland environment like the Cuvette Central and a significant variable to estimate the magnitude of ecosystem degradation and loss (Zhuravleva et al 2013)

4. 2. Trends in the wetland Landscape transformation

4. 2. 1. Anthropogenic infringement, unrestricted and unsustainable land Use

Land use and land cover change at multi-spatial and multi-temporal scales is among the principal anthropogenic indicators associated landscapes transformations. Anthropogenic

disturbances with significant impacts on LULC are land degradation, including agriculture expansion, deforestation and it associated features like urbanization. These entropies more often produce ecological brink consequences that stimulate modification of biodiversity. Additionally, these turbulences generate trajectories through which unrestricted and unsustain anthropogenic can infringed deep into the most undisturbed portion of the environment resulting to proximities to potential vectors of transformation.

Development in the recent decades in remote sensing technologies, spatial statistical methods and computational competences simplified analysis and quantification of anthropogenic landscape disturbances, furnishing the necessary instruments to correlate landscape qualities to biodiversity incidence and to predict ecological scenarios across landscape in a time series.

From the satellite imagery mosaics of 2000-2010, significant decadal patterns of wetland landscape change is revealed. Using the trigger-pressure tandem, significant human impact is felt along the major water courses with the highest concentration around the Bandundu Province and parts of the Equateur Province (Bailey et al 2015). Comparing the site fidelity on predator, estimation of change on environmental variable, is significant correlation with the specie density and site variables. Quantitative dataset revealed that resources availability at the nesting site' significantly influenced the number of nests as in term of resource security (Serckx 2014). Human as a significant environmental predator, will significantly impact the distribution and abundance of biodiversity. The exponential growth in human population is not only associated to change in land use, but also with environmental stochasticity. The freshwater wetlands of the Cuvette Central are particularly sensitive to environmental changes, since they are biochemically, physiologically and behaviourally dependent on their natural environments. Their abundance is particularly driven by the natural environment therefore anthropogenic disturbance is acute for the endemic biodiversity since in this typical region, natural environment response to alterations is disproportionate relative to other environments.

4. 2. 1. 1. Land Tenure

Right to land ownership in the DRC is governed by a top bottom approach based on the Land Tenure Act passed some four decades ago given the state and traditional leaders absolute control over soil and subsoil resource. Though ordinary Congolese could benefit

from concession rights, the administrative procedures have never been completed; leaving local communities without a legal framework to enforce their rights. Therefore the land tenure is guide by separate legal regimes. The customary regime gives right to the communities while under the civil law the state is the protector leading to conflicts of interest. This Land use policy constraints overlaps into local communities in relation to land ownership and economic activities. Poverty levels are directly correlated to dedicated reliance on local natural resources, where resource extraction is basically unsustainable, hardly restrained and depends on basic traditional methodologies. In view of limited alternatives, it is unbiased to ascertain that the existing inclination of anthropogenic brunt on the freshwater wetlands will persist in the Cuvette Central of the Congo basin. The Lake Télé – Lake Tumba landscape harbours some two millions and more people from diverse ethnic communities. These include some temporal migrants fleeing wars from politically turbulent neighbouring countries (Zhuravleva et al 2013) all of whom exert pressures the local natural landscape. This is largely, unrestrained and even made worse by the limited information about the real population scenario and natural resource usage. Almost 700.000-800.000 people are concentrated in the town Mbandaka the capital of Equateur province (IES 2009). With a host of smaller towns and villages concentrated along the two major lakes (Lake Tumba and Lake Maindombe), major rivers and their tributaries and along transport roads. This population depend on subsistence agriculture, hunting, fishing, collection of firewood and charcoal production which constitute a bulk of their incomes for survival (Scholes et al 2006). Using supplementary datasets the flora and fauna decadal fragmentation and degradation from land use induced land cover change stands at 1.02% (Zhuravleva et al 2013).

4. 2. 1. 2. Agriculture and Urbanization

Subsistence agriculture remains the main activity involving a vast majority of the work force in Ngiri-Tumba-maindombe landscape. The production methods are basically subsistence based on the slash-and-burn or swidden agriculture coupled with systematic settlement development. A recent cluster analysis by Miltton (2015) in the two lake areas on pressures and landscape transformation, a significant network could be traced between poverty-agriculture-temporary camps. While 41% of the locals in Maindombe blame agricultures activities transformations in landscape, 38% blame temporary camps; whereas, in almost

99% in the Lke Tumba area blamed agricultural practices for new landscapes (Milton 2015). The Miandombe lake area alone account for more than 81% of primary land cover loss. Contrary, the Tumba lake area is basically secondary forest usage for agriculture with much of it plantation based (Milton 2015). Agricultural expansion between 2000 and 2010 basically involved the slash-and-burn with some substantial drift towards plantation agriculture. Subsistence agriculture practices in and around the wetlands, sustains a highly significant portion of the food security basket. Notwithstanding, this traditional methods based on "swidden" farming, deposits significant landscape change through biodiversity loss. The two shocks of the decadal study period of 2000–2005 to 2005–2010 left almost 13.8% land cover loss with the greatest effects felt within the primary forest principally from agricultural due to population growth (Potapov et al 2012) affecting the critical biological diversity of this environment. This is highly significant on the Hyperolius leleupi, the Hyperolius leucotaenius and the Leptopelis karissimbensis community which depend on this natural environment (IUCN and ICCN 2012). Equally significantly impacted is the bonobo's and other primate communities from urban development in the Provinces Bandundu and the Equateur. This sequence was intensified with the post-war rehabilitation of infrastructure and with the expansion of such commercial endeavours as oil palm plantations (IUCN and ICCN 2012; Mallon et al 2015). Typical on the slash-and-burn in the high population density areas are long fallow periods translated to shorter period from a high demand for land. It impacts the biodiversity landscape adversely in three major layers: the ecosystem, the species and the genes within the species. The slash-and-burn system of agriculture is not necessarily a threat in a low population density scenario as the inverse relationship between land demand and population size allows longer follow period which guarantees regrowth period of the species (IPCC 2003; Pelletier et al 2012). The significant factor here is the general land cover clearing for cultivation and settlement. Once depletion in yield is steps in, , the farmer moves dwelling and farm practice to a new site extending the spatial scale of the impacted environment. This is typical along the in the Ubangi and Ngiri rivers inducing silt accumulation in the river bed from washed out soil from cleared surfaces along these river banks (Colom et al 2006)

4. 2. 1. 3. Poaching and Bush Meat trade

The wild forms a very significant portion of cheap protein source, making some 30-80% of the protein basis for dwellers in and on adjacent landscape to the wetlands in the Congo basin (Usongo and Nagahuedi 2008; Nlom 2011). Poaching and bushmeat trade generates negative scenarios with tacit impacts an ecosystem landscape, in terms of functioning and structural of specie communities (Nasi et al. 2011). The subsistence method of snares typical to this wetland is exceptionally devastating on wildlife. This is typical with the bonobo which move on the ground. The fortunate wildlife that succeeds to escape is either mutilated or later die of infections. In poaching, virtually every vertebrate species is extracted. Already in the Ngiri-Tumba-Maindombe wetlands, vast spatial extent has already been emptied. As this wild landscape are progressively impoverished, the poaching community move further inland into the more intact blocks for whatever could be got (IUCN 2012-2022). Wildlife poaching is made possible deep to the intact areas principally through the ancient canals through which hunters poach deep for 5-10km in boats and equally transports their large quantities via the same routes to the markets. Presently, some nine terrestrial and a host of marine and freshwater fauna species landscape have already been transformed by local communities who heavily depend on the wild for their entire subsistence (IUCN 2012-2022). The “invisible” trade in wild for clothing, medicines, soap, spices and other necessities is estimated to generate much of the incomes for daily livelihood. Poaching and bushmeat trade like other unsustainable anthropogenic extractive activity is contingent on scale, when valued as an activity that sets turbulence in the natural equilibrium in the ecosystem (Nasi et al 2011). The endemic bonobo (pygmy chimpanzee), the common chimpanzee (Pan troglodytes), and the Gorilla gorilla, consists of only a few individuals still remaining in their wild. The "great apes" are perilously close to extinction. Estimates presents about 270 bonobos killed annually from a poaching catchment of about 12,000 km² (IUCN 2012-2022). In the case of the endangered African wild dog, it is rapidly declining numbers; more than half of all adult deaths are due high-speed vehicles, guns, snares and poisons. The shrews and rats community is fast shrinking, their declining population is indicative of the overwhelming anthropogenic stress on the primary forest facilitating their habitats fragmentation and loss (Susan Dorling 2016). The fragmentation of wildlife community and a loss in their population significantly produced disruptive ecological and evolutionary processes with a general truncating of the biological diversity (Nasi et al 2011)

4. 2. 1. 4. Over fishing

There is still scanty data on the fish composition in the DRC. The situation is even critical in the Cuvette Central where essential portions of the aquatic landscape have almost gone for decades without any reasonable scientific research (Thieme et al 2005). The available estimates present some 80% endemic fish species in seven hundred fish species present in DRC of which almost two hundred and six are concentrated in Cuvette Central with just 5% a endemic (Brooks et al 2011).

This Freshwater landscape constitutes a very significant portion of sustenance for almost 78% of the local communities who derive much of their protein and income from subsistence fishing (Brooks et al 2011; Inogwabini 2014) through canals to fishing sites where small camps are built and subsequently transformed into permanent villages. Typical are the small villages in the adjacent landscapes to the two major lakes notably along the Ubangi and the Congo rivers (Colom et al 2006; Milton 2015).

The most significant threats on fish community are the destruction of their habitat and fragmentation of their community. This is typical with increase sedimentation in lakes, rivers and other waterways from upland deforestation, agricultural expansion and infrastructural developments, typical is the logging north of the Bambou and Lebomo streams with subsequent ranching activities, clearing of spawning sites, other traditional fishing methods as fish poisoning (Milton 2015) and increase urban water pollution from domestic dwelling, and agro-alimentary factories. Besides, the wetlands is characteristic of ever increasing invasive aquatic species from segments under the pressure of water P^H and conductivity from existing hydroelectricity generation

4. 2. 1. 5. Legal logging and illegal artisanal Logging

Legal logging and illegal artisanal logging linked to concession directly fragmented and transformed the landscape. Among the Congo basin countries, the DRC alone had some 8000 artisanal logging operators who mostly operated at the edge of the forest setting pace secondary forest user. This is typical with the subsistence agricultural expansions based on the traditional slash-and-burn farming methods (Samndong and Nhantumbo 2015). Approximately 90% of logging in the DRC is illegal artisanal logging supplying regional markets. From 2005-2010 the volume of extraction doubled that of 2000-2005; in response

to the growing population demands and income levels (FCPF-ERPIN 2014; Sam Lawson 2014).

Logging concessions in Maindombe Lake area between 1990-2010

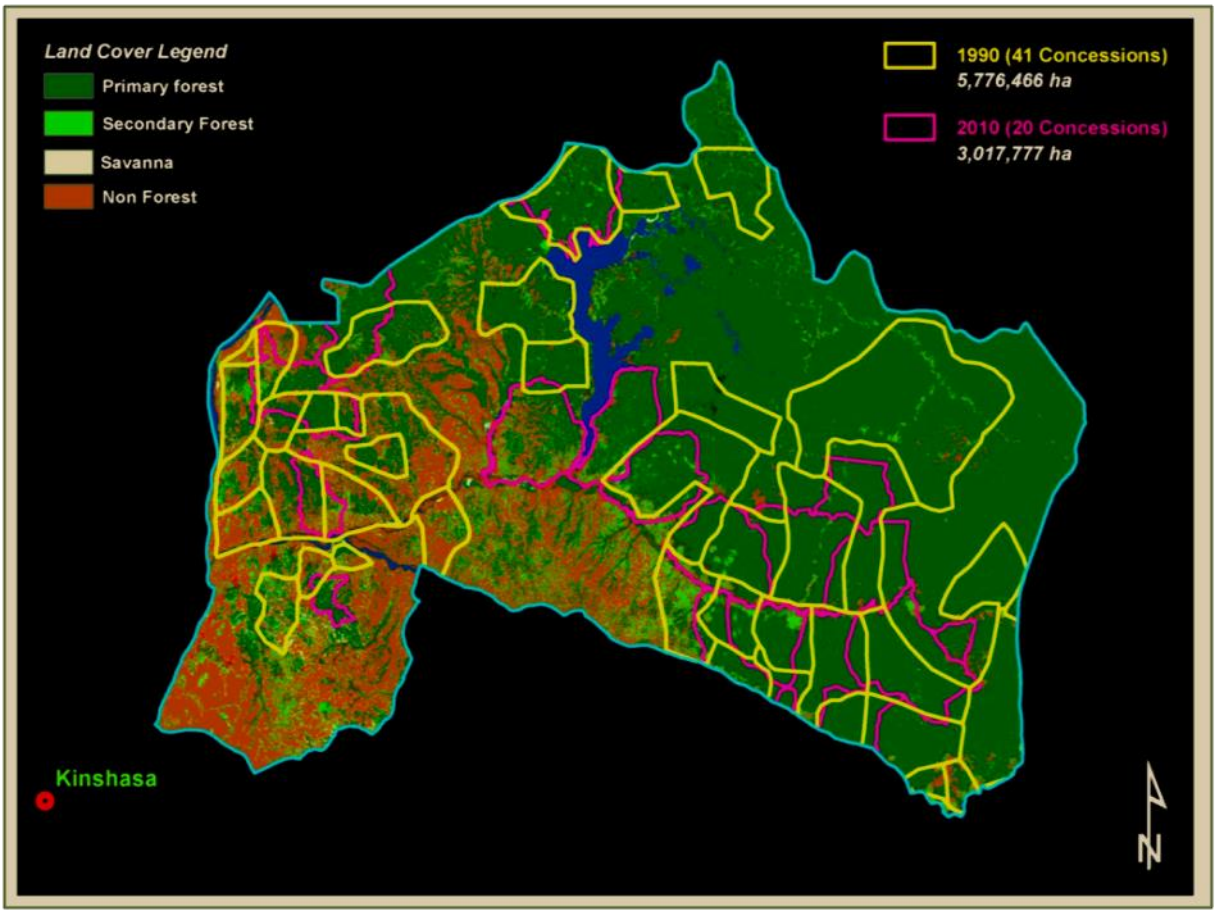


Fig. 8; Source: FCPF-ERPIN 2014

FACET reports on the state of the forest in the DRC presents the provinces of Equateur and Bandundu attributed the fragmentation and degradation of the freshwater wetland LTLT landscape to the rate of forest cover loss. Only during the decadal study period, 2.5% in the Equateur and 2.2% in the Bandundu Provinces were lost to timber products extraction from primary and secondary forests with the lake Maindombe landscape (fig. 8) having the highest concentration of concession contract between 2000and 2010 (OSFAC 2010). Since the natural forests and biodiversity landscape are indissolubly correlated, the transformation of the intact forest is used as fragmentation and degradation indicators for the freshwater wetlands ecological landscape. Indisputably, even a minuscular fragment of forest that occurs across a landscape can be very significant for wildlife habitat and flora life. Any faced of forest fragments presents access trajectories not only for poaching but migration and wild species (USAID 2005). Transformations from primary to secondary forest

characterises the extension of agriculture into heretofore intact natural environment. The characteristic “swidden” agriculture practiced in LTLT landscape injects energies with consequential modifications of floristic composition, fauna composition and subsequent ecosystem within the spatial entity (Potapov et al 2012).

The Lac Tumba landscape is home to iconic and endangered species such as the bonobo (Pan paniscus) and chimpanzee (Pan troglodytes). Elephant (Loxodonta Africana Cyclotis), buffalo (Syncerus Caffer), hippopotamus (Hippopotamus amphibious), and leopard (Pantherapardus) and the vulnerable Baka (pygmy) population. This region is under mounting development pressure from the city of Kinshasa, most importantly due to its growing population of almost 8 million inhabitants who depend on a consistent source of charcoal stocks and other timber and non-timber forest products (MCNT 2012; FCPF-ERPIN 2014). The land cover loss in the DRC from 2000-2010 stood at ± 34% mostly concentrated in proximity to large cities characterized by significant pressures from food demand, wood energy, and timber products to support a large and rapidly increasing urban population and rural communities and international export (FCPF-ERPIN 2014).

The annual deforestation rate during the first five years of the study decade was twofold that of the previous decade (figure 8). The situation deteriorated during the second half of the study decade. Although, this trend was associated to many pressures, artisanal logging was principally responsible underlying be population growth and weak institutional base (Sam Lawson 2014). The commercial logging campaigns as a factor generally lead to progressive fragmentation and degradation of forest massif within the concession boundaries extending from southeast to northeast into the Maindombe province (figure 8). In these same areas a large proportion of the wetlands are concentrated. Their operations penetrate the forest with access road triggering population growth through employment and other secondary economic activities increasing land pressures. This significantly increases the vulnerability of, primary intact flora and fauna species within range for secondary triggers of land cover loss to fragmentations, inducing habitats loss and definitely the species landscape transformation (MECNT 2012). From 2000-2010 primary forest alone was 86% of the total land area under logging permit of which the primary intact forest made-up 53% mostly under industrial logging permits. The rate of intact forest transformation within the two concession shock stood at 5.3% which was significantly higher than the 1.4% out of the limits of the concessions. Using this as a reference, the

concession area of 1990 presents a degraded primary forest area into a secondary forest presenting during the first half of the decade (Zhuravleva et al 2013). The secondary forest set pace for further clearing for subsistence agriculture, temporary camp development from population expansion, which further affects the vulnerable wildlife with far reaching ecological consequences. Large mammals generally command space for habitat. Species with a wide home range are vulnerable to fragmentation, not only from a genetically isolation point of view but from the truncation of their roaming possibility for food. Most of the fragmentation scenarios present migration options to other less hostile communities producing modified layers of class and composition in the ecological landscape.

CHAPTER 5

5. General Discussion, Conclusion and Recommendations

5. 1. General Discussion

There have been significant developments in the identification and quantification of land-use influence on freshwater wetland quality and quantity over the last decades. Much still need to be researched in the Sub-Sahara Africa before any real comprehensive impact framework from anthropogenic threats could be derived. Innovative time series assessment of land use influences on landscape patterns, have significantly truncated the cloud in this area of research. More elusive wetland changes still need to be better qualified and quantified at a regional scale in the Congo basin. This is specifically the situation with anthropogenic disturbances that significantly interact with natural environmental variability and therefore entails longitudinal time series data for a reliable assessment. Recent analyses of anthropogenic threats based on triggers of land-use change have shifted from simplistic specific trigger layers to an understanding that integrates correlations and causality among the triggers-pressures in a complex network. Wide-ranging scientific approaches for detecting landscape transformations from anthropogenic in a host of empirical works have been acknowledged. Their orientation inclusive procedures paved the way for the elaboration of more pragmatic prototypes in landscape transformation studies. Nevertheless, different schools of perception however incline to diverse justification of the triggers of landscape change as each motivation is in a time series context and region specific in the human environment systems. Whereas the systems standpoint focuses on quantification of gradual time series processes of transformation in space, the agent-based perspective deals with people's own predictable futures at the discrete level. The depiction perception assumes a much protracted time scale laying emphases on significant activities and sudden transformations. There are different time series models postulating conflicting accounts and at the same time elucidating the triggers and consequences of environmental change. A systematic regional scale analysis of landscape transformation conducted over a range of time scale facilitates the understanding conventional theories to provide an explanation and prediction of future scenarios. Improved understanding of the complex

dynamic processes from remote sensing imagery of underlying landscape transformation from the various operational land uses presents more reliable projections and more realistic scenarios awareness for impact analysis studies. Fundamental to scenarios prediction is the identification of elements that induces modifications in natural systems, as these may produce accelerated ecosystem fragmentation and degradation impacting populations that depend on that system.

Distinguishably technological innovation in satellite remote sensing as used in the methodology has led to analysis that may guide policy decisions to help mitigate and reverse the trends in wetland landscape transformations with significant in social and biosphere relationships in a time series. Interestingly, the initial global concerns in man and biosphere relationships surfaced from the recognition of the impacts of induced anthropogenic landscape transformation on ecosystem health and climate change. Whereas the concept of equilibrium used to guide our thoughts about environmental alterations, deviations from the equilibriums, as well as composite system dynamic concepts is now affecting researches in wetland landscape transformations. On the basis of the remote sensing imagery analysis, it was possible to discriminate between different intensities of an anthropogenic impact on the Ngiri-Tumba-Maindombe wetlands through the two half of the study decade. This is consistent with other empirical works on the tropics. Typical is in the Amazonia where significant threats from logging and slash-and-burn agriculture have deposited significant imprints in terms of biomass composition (Pelletier et al 2012). Understanding the dynamics, of salient drivers of wetland landscape transformation provides an edge in environmental change assessment. For example the slash-and-burn methods of agriculture requires some cycles at a minimum frequency of half a cycle before abandonment. The decade study period 2000-2010 helps validate agriculture as a significate driver from the implicit individual patches of agricultural pixels.

5. 2. Conclusion and Recommendation

The application of a multi-data source in the study of the freshwater wetland dynamics from anthropogenic threats in the Cuvette Central enhances classification of the freshwater wetlands in this floodplain. The algorithm was based on full automation digital technology though required field samples for validation. Literature on SAR datasets have always be considered as handy in freshwater wetland characterization data contamination have

proven to be a major constrain in perfectly discriminating impact processes within the multi-communities wetlands of the Central Congo Basin; presenting the strength of multi-data source in this typical studies as each provide complementary information for investigation of the spatial distribution of the impact over time.

Although the datasets used in the research are handy, and fitting to the specificities of the Cuvette Centrale, applying them to some other environment will require adaptation to the geomorphic and ecologic realities of the study area as spatial scale do not refer to any known algorithm. Equally, since no exclusive field exercise was carried out to realise this study, therefore, some relatively minor accuracy question of the dataset comes into play. Caution is stress on the point that, though Satellite imagery are innovative and cost effective they should not but confronted with practical field observation, though nonetheless, their output should be very significant in freshwater wetland management. This is typical to Congo basin rainforest characterised by inaccessible upon which critical biological populations depend (Thieme et al 2007). While the current research has focused largely anthropogenic disturbed wetlands, exploring the correlations between anthropogenic disturbed landscape and ecological health has been very significant as findings suggest that anthropogenic disturbances could be a factor to the spatial distribution biodiversity and central in mapping species extinction risk which is often poorly understood in the Sub-Sahara Africa

Owing to the fact that in this region a majority of the population are in the poverty trap, and exert a lot of pressure on the natural environment for livelihoods, with the present complex human population scenarios in the coming years (UN 2015), complementary livelihood routes like practical education and training based on maintaining the soil quality, and poverty relief are needed to relief these pressures. In this light, management policies should be geared towards the sustainable models in agricultural expansion and further research is needed to assist reversal of the rate of transformation in the wetland in the entire Congo basin sub-region.

Institution of protected areas is important for biodiversity conservation. Extensive protected areas is an almost impossibility as is a trade-off between ecosystem and other livelihood opportunities for forest communities. (Samndong and Nhantumbo 2015). Curbing the rights of indigenous groups that have had unrestricted access to areas for immeasurable generations poses not only a distinctive but an ethical issue and such restrains are

environmentally dangerous, unfavourable for welfare, may not be effective and often increasing economic migration, fosters corruption and lawlessness in the forest communities which further increase the persistent, illegal and unsustainable exploitation of natural resources form animosity and subsistence (Taylor 2011)

Adopting an all-inclusive construction for characterization of drivers-pressures facilitate the development of an integrative human-environment relationships. Further scientific work into an enhanced comprehension of the composite dynamic processes of driver-pressure will facilitates more realistic projections and scenarios of possible future transformations in wetlands. Basically, scenarios will be significant if the concepts of the dynamics in freshwater wetlands transformations are well managed. Central are the positive feedbacks as they energise change mechanism that rapidly fragment and degrade the ecosystem impacting the equilibrium state. Equally crucial are innovative management policies and technology transfer with the potentials to reverse negative feedback that could regulate the rate of change. To this, consistent scientific works be carried out in areas of analysis of the correlation, rationality and divergence between social and biophysical modifications in ecosystem services and processes that cause total landscape transformation.

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