Protected Areas' Trends Assessment and Adaptive Management on the basis of long-term Conservation Objectives (PA's TAAMCO Analytic Model): Theoretical framework and Case study of the Rusizi National Park (Burundi) in the context of climate change

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I. Introduction and Background

- Now, it is established and known that **climate change and biodiversity losses are the most important and interactive environmental crises**. Climate change and global warming are the greatest threats to biodiversity and protected areas systems and natural ecosystems offer one of the most effective solutions for adaptation and mitigation (IPCC, 2007; UNEP, 2009; Dudley and al. 2010).
- Given the fact that 89% of the world's natural systems are already affected by climate change (McCarty 2001, Gilles 2012) and most of protected areas have been established under the assumption of a stable climate (Hannah and al, 2002, Hannah and al, 2005), projected climate changes call for **questioning management hypothesis, goals and plans** (McCarty, 2001) and **adaptive management**.
- The protected areas' adaptive management requires and strongly needs reliable researches, methods, tools and data on management systems (Eva and al, 2006, Dudley and al, 2010). It should be objectively based on regular trend assessments reference made to long-term conservation goals **assuming that the global evolutions of most of protected areas in tropical regions have never been assessed since their normative classifications for updated management plans**

I. Introduction and Background

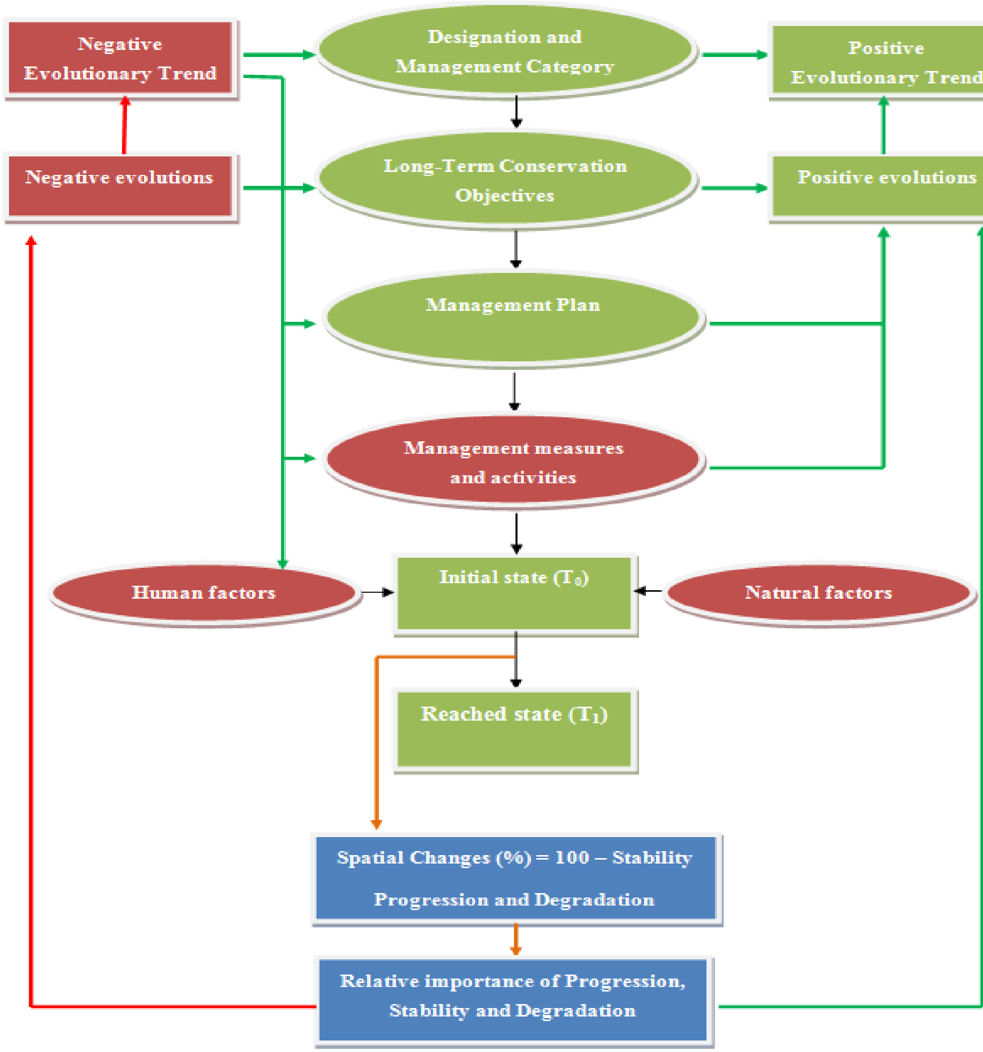
- Despite their obvious interest, current methods used to assess protected areas' evolutions like WWF and WCPA ones have **limitations for detailed analysis** because of **their qualitative nature, their small extent or their high costs**.
- **Habitats being the key component of biodiversity** (Mauchamp, 2012) and their destruction the 1st threat to most of species (Baillie and al, 2004), the **analysis of land cover changes** gives the best description of deforestation, degradation and desertification processes responsible for biodiversity losses (Lambin and al., 2001).
- **For this purpose, the quite recent and increasing importance of spatial remote sensing and GIS techniques** for the study and the monitoring of natural ecosystems and land cover dynamics have been facilitated by: (1) the creation of the Global Earth Observation System of Systems (GEOSS), which covers 9 societal benefit areas among them ecosystems and biodiversity and (2) the setting up of GEONET Cast Network for spatial data dissemination worldwide for free.
- The Protected Areas' Trends Assessment and Adaptive Management on the basis of Conservation Objectives **(PA's TAAMCO) is a new and innovative model which makes use of these facilities and opportunities** to assess protected areas' evolutionary trends at a global scale and promote adaptive management.

II. Protected Areas'TAAMCO Analytic Model
Context and theoretical framework

- Protected areas and biodiversity hotspots being facing important and quick degradation, especially in tropical regions (WWF, 2012), there is a real need for regular protected areas' assessment at a global scale using appropriated methods and tools. **The required dynamic and efficient management is still missing objective and integrated indicators for rigorous assessment** of periodical evolutionary trends and the performance of management methods in relation with specific long-term conservation objectives or desired goals and evolutions.
- The "**PA's TAAMCO theoretical and practical Model**" presented below was designed to meet this need. It is a methodological approach used for the determination of periodical "**Trend indices**" and "**Evolutionary trends**" which are the two core indicators describing historical protected areas' developments for well planned, adaptive and sustainable management.
- The **starting point** for the application of PA's TAAMCO Model is the **knowledge of the type and the management category** from which long-term **conservation objectives, management plans and management activities** are defined in order to reach the desired evolutions **from a reference state to a final state**. The type and relative importance of spatial changes between the 2 states allow the definition **of Evolutionary trends which are either positive when they carry desired evolutions or negative in the opposite**. The management gaps and negative evolutions then command new or updated management system. In other words, the PA' TAAMCO Model is an Assessment Tool for periodical adjustment of management systems.

II. Protected Areas'TAAMCO Analytic Model

Adaptive and Sustainable Management Modeling



II. Protected Areas'TAAMCO Analytic Model

Context and Theoretical framework

- The PA's TAAMCO Model is theoretically based on land cover concepts (stability, conversion, modification) and landscape dynamics described by transition matrices which are derived from the superposition of interannual land cover maps and related cartographic analysis.
- Protected areas can be affected by 6 spatial changes: (1) stabilities (no change), (2) non-vegetal conversions (conversions between non vegetal classes), (3) positive conversions (vegetation appearance) (4) negative conversions (vegetation disappearance), (5) positive modifications (vegetation qualitative gain) and (6) negative modifications (vegetation qualitative loss).
- In terms of vegetation cover, **non-vegetal conversions** are neutral. **Positive conversions and modifications** constitute a "**progression**" and a positive evolution for the conservation while **negative conversions and modifications** form a "regression" and a negative evolution for the conservation.
- Positive and negative modifications **refer to the natural and spontaneous evolution of vegetation** (ITTO, 2012) while positive and negative conversions refer to **physical appearance and disappearance of vegetation**, whatever their nature.
- **Habitats and vegetation's developments or stabilities being the main conservation goals** in most of Protected areas, "vegetation regressions" and "neutral conversions" are negative and neutral processes, contrary to the evolutions expected while "vegetation progressions" and "land cover stability" are positive processes for the conservation.

II. Protected Areas' TAAMCO Analytic Model

Key indicators and definitions

- The Protected area's **Trend index (T_I)** is a **synthetic indicator which quantifies and qualifies the global evolutionary trend** of a protected area over a period of time and provides an objective, rigorous and periodic assessment of the effectiveness of the conservation measures to ensure adaptive management.
- The basic principle of the methodology used for its determination is the **adjustment of the quantitative and qualitative spatial changes** affecting land cover classes **to protected areas' specific long-term conservation objectives**.
- The Protected Area's **Evolutionary trend (Et)** is a **meaningful interpretation of the Trend indices' values and classes** which is a combinatorial reading of the labels of change rates and change balances expressed by a "quantitative and qualitative synthetic formulation" which clearly reflects "**the intensity of spatial changes**" and "**the dominating direction of a protected area's evolution**", which is either progression (development), stability (no change) or regression (degradation).

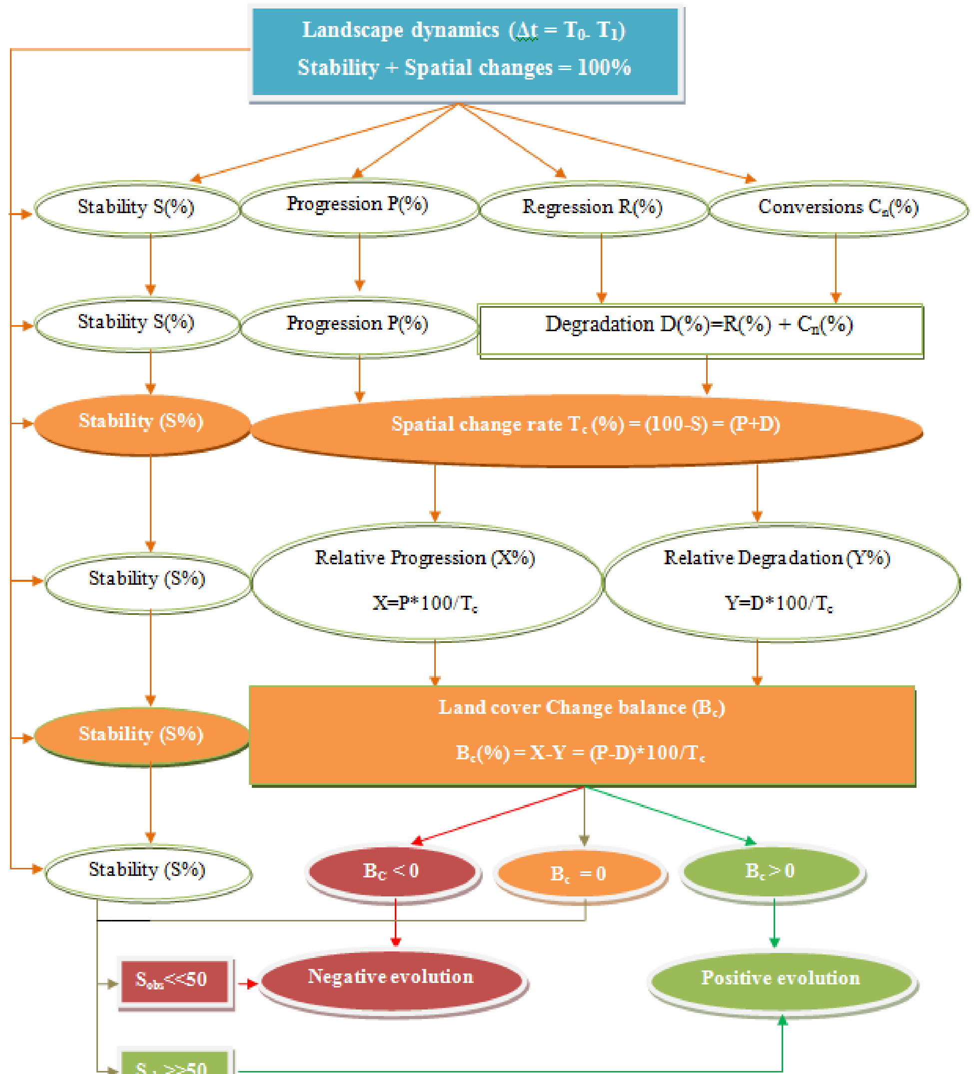
II. Protected Areas'TAAMCO Analytic Model

Trend Index's computation-Evolutionary Trend

- Trend index's computation is focused on the **comparison between the overall regressions (R), progressions (P), neutral conversions (C_n) and stability (S)** values which are the input data. The values of S, P, R and C_n from which degradation (D), relative progression (X), relative degradation (Y), change rate (T_c) and change balance (B_c) are calculated **are directly derived from cartographic analysis of Remote Sensing images and land cover transition matrices**.
- The trend index incorporates 3 variables: "**change rate "(T_c), "change dominating direction" and "change balance (B_c)**". T_c represents the proportion of spatial changes compared to land cover overall stability (%). The change direction is the + or - sign of the difference between relative progression (X) and relative degradation (Y) which are resulting from a mathematical linearization which recalculates the total progression (P) and the total degradation (D) reference made to the change rate considered to be representing 100% of a protected area. The change balance B_c is the absolute value of the difference between the two quantities.
- **When B_c > 0, the evolutionary trend is positive. When B_c < 0 , the evolutionary trend is negative. If B_c = 0, the evolutionary trend is determined by the relative importance of change rate T_c and the global stability S**. Here, the threshold value considered for the stability (S_s) is equal to 50% which is the solution of the equation $B_c = S$.
- Assuming that in the field of conservation "**stability is less than a progression and better than a degradation**", we consider that for equal relative progression and relative degradation corresponding to the equation Bc = 0, the better the stability is, the better the evolution is and vice versa. If the measured stability $S_{obs} \geq S_s$, the evolutionary trend is positive. Otherwise, it is negative.

II. Protected Areas' TAAMCO Analytic Model

Evolutionary Trend's Decision Tree



II. Protected Areas' TAAMCO Analytic Model

Trend index's and Evolutionary trend Classification Grid

- In the Grid, the **change rates** are divided into **4 classes of 25% intervals**, which mean from 0% to 100% "a low evolution" coded (1), "a moderate evolution" coded (2), "a strong evolution" coded (3) and " a very strong evolution" coded (4).
- The **change balances** are divided into **8 classes of 25% intervals** with 4 negative values classes and 4 positive values classes . Negative balance mean from -100% to 0%, "a very strong negative trend" coded (a), "a strong negative trend" coded (b), "a moderate negative trend" coded (c) and "a low negative trend" coded (d). Positive balance express from 0% to 100% "a low positive trend" coded (D), "a moderate positive trend" coded (C), "a strong positive trend" coded (B) and "a very strong positive trend" coded (A). The negative balance classes (a to d) and positive balance classes (D to A) are symmetrical with respect to the value axis (6).
- Therefore, **Trend indices are alphanumeric combinations ranging from (1d) to (4a) for extreme negative trends and (1D) to (4A) for positive trends**. The interpretation of Trend indices' values gives the evolutionary trends which are **combinatorial readings of the labels of the change rates and the change balances**.
- For example, a Trend index of Ti [(77, -64), 4b] corresponds to "a very strong evolution (4)" with "a strong negative trend (b)" which is characterized by spatial changes affecting 77% of the whole protected area's surface, consisting of 82% degradation and 18% progression, resulting in a global negative evolution of 64%.

II. Protected Areas'TAAMCO Analytic Model

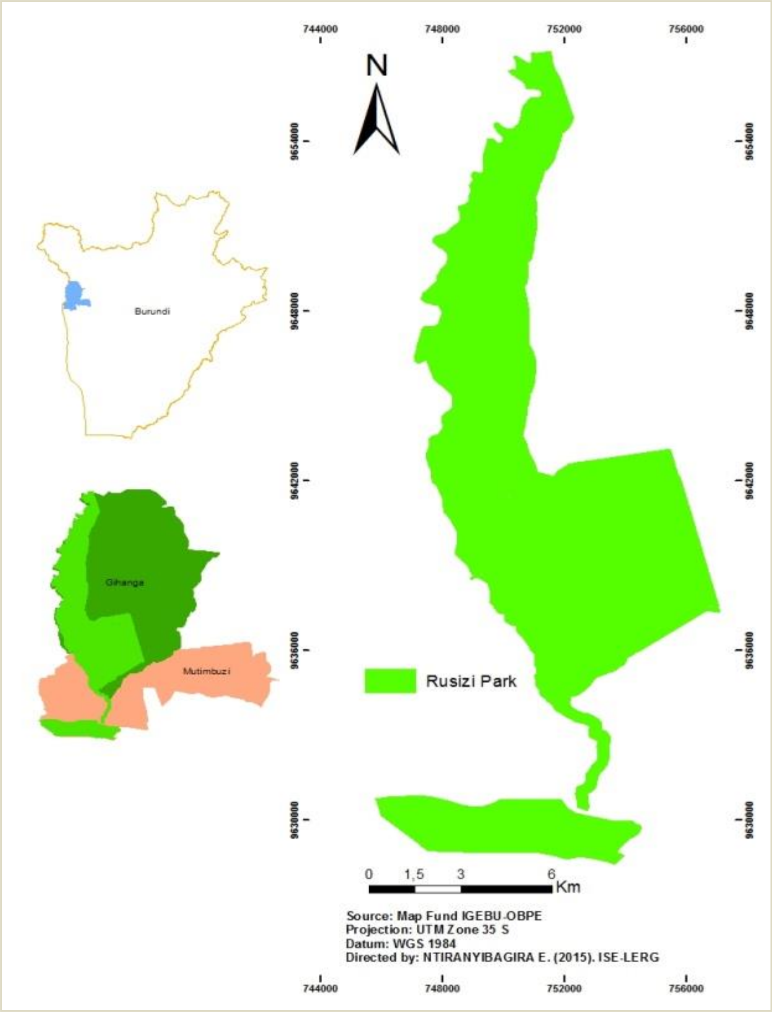
Trend index 's Classification Grid

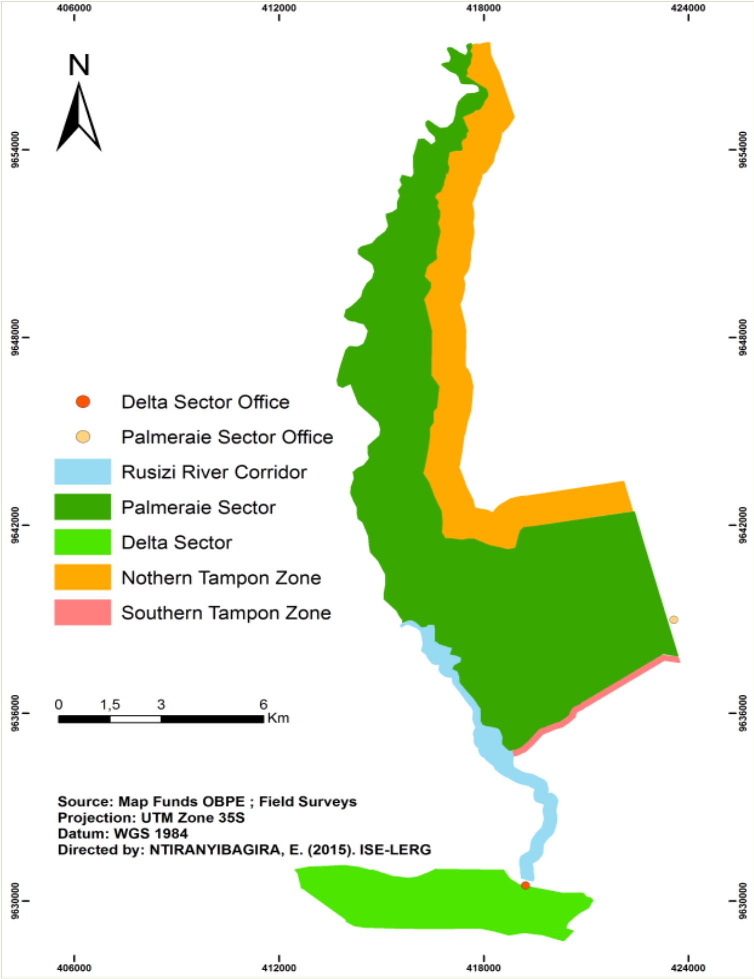
Variables			Change rate (T_c %)			
			[0-25]	] 25-50]	] 50-75]	] 75-100]
Change balance (Bc%)	Degradation	[-100,-75[	1a	2a	3a	4a
		[-75,-50[	1b	2b	3b	4b
		[-50,-25[	1c	2c	3c	4b
		[-25, 0]	1d	2d	3d	4d
	Progression	[0-25]	1D	2D	3D	4D
		] 25-50]	1C	2C	3C	4C
		] 50-75]	1B	2B	3B	4B
		] 75-100]	1A	2A	3A	4A

Period	Methodological steps for the computation of trend indices values	Indice values/classes
Δt	{T_c= (100-S) = x ϵ] α-β] class i; Bc = (X-Y) = y ϵ [γ-δ] (>, <) 0 class j}	I_t = [(x, y); ij]

III. Case study-Rusizi national Park

Location and physical configuration





III. Case study-Rusizi national Park

Study goals and Methodology

- The case study aims to make an integrated analysis of: (1) Landscape transformations and changes, (2) Evolutionary trends of the protected area for 5 periods using TAAMAO Model, (3) Spatial indicators and processes carrying the observed dynamics and (4) Factors of evolution **with reference to conservation statutes of Reserve (1980-1990, 2000-2011) and of Park (1990-2000, 2011-2015)**.
- The methodology was based on **the diachronic analysis of land cover from 1984 to 2015** through 5 steps: (1) RS data and GIS techniques for land cover mapping and land cover change detections, (2) Transition matrices analysis, (3) Spatial structure indices computation and STPs analysis using landscape ecology tools (Bogaert and al, 2004), (4) Trend indices and Evolutionary trends computation (Ntiranyibagira and al, 2017) and (5) socio-economic and climatic data analysis.
- **Ortho-rectified, georeferenced and 30m main spatial resolution Landsat images were used**: 1984, 1990 and 2011 (TM), 2000 (ETM^+) and 2015 (OLI-TIRS). The satellite images processing and analysis were done using Envi 4.5 software. The results of the classification of images were vectorized and exported to ArcGIS 10.1 for mapping, cartographic analysis and extraction of land cover statistics.

IV. Main analytic results

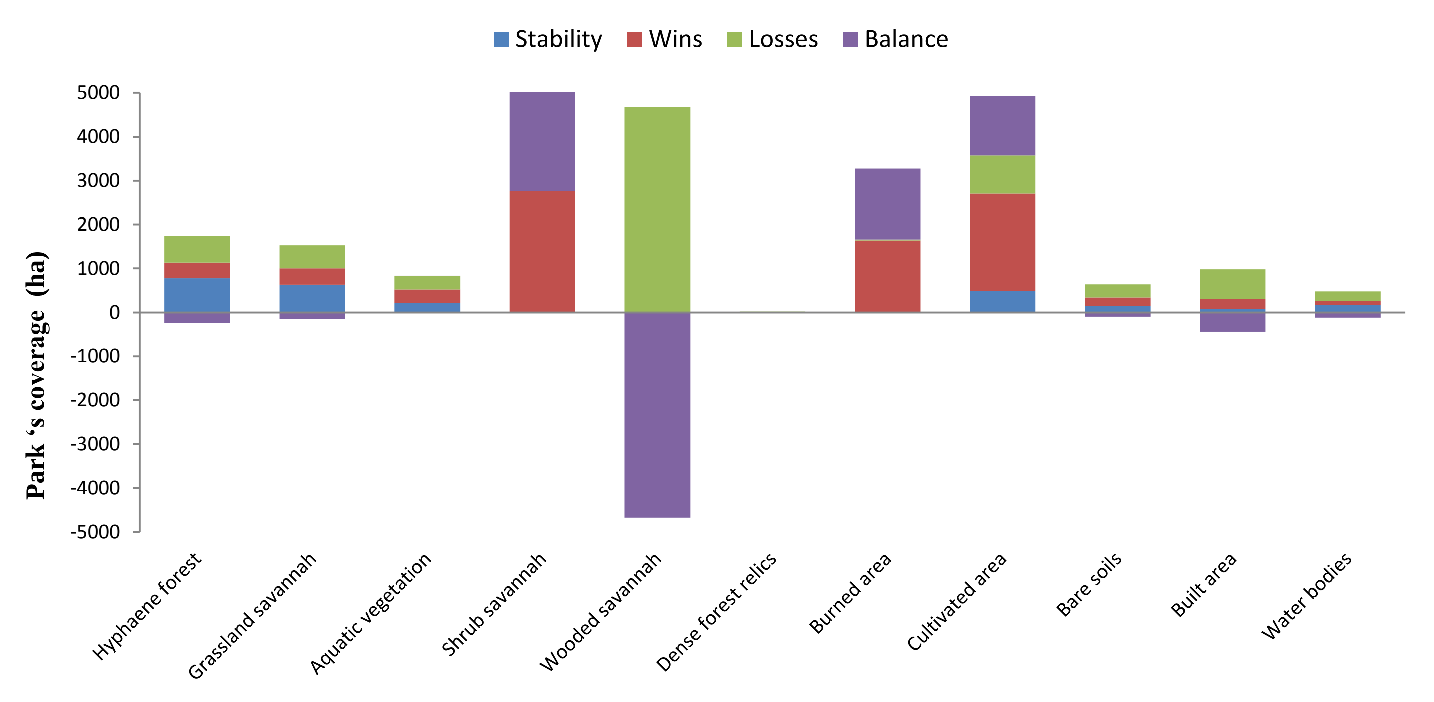
Overall Transition Matrix (1984-2015)

		Year 2015										
Year 1984	Classes	A	B	C	D*	E	F	G	H	I	J	**Total**
	A	1,51	0,63	0,22	0,02	0,24	0,00	0,31	0,53		0,06	**3,52**
	B	0,38	**5,88**	0,86	0,14	0,59	0,02	1,09	1,81		0,03	**10,80**
	C	0,03	0,80	**7,29**	0,66	1,57	-	0,91	1,64		0,01	**12,91**
	D	0,02	0,21	0,22	17,92	**8,96**	0,97	0,07	**13,93**		1,42	**43,72**
	E	0,00	0,05	0,00	0,03	0,02	-	0,01	0,11		-	**0,22**
	F	0,00	0,00	-	1,66	0,03	1,36	-	0,73		0,33	**4,11**
	G	0,31	0,53	0,77	0,15	0,66	0,01	2,01	0,35		0,02	**4,81**
	H	0,14	1,12	1,26	1,98	2,77	0,04	0,48	**4,58**		0,32	**12,69**
	I	0,01	0,09	0,00	-	0,01	-	0,02	0,02	**	-	**0,15**
	J	0,03	0,07	0,00	**3,27**	0,48	0,80	0,01	1,64		0,73	**7,03**
	Total	**2,43**	**9,38**	**10,62**	**25,83**	**15,33**	**3,20**	**4,91**	**25,34**		**2,92**	**100**

A: Water bodies B: Grassy savannah C: *Hyphaene* forest D: Wooded savannah D*: Shrub savannah
E: Burned areas F: Bare soils G: Aquatic vegetation H: Cultivated areas I**: Dense forest disappearance J : Built areas

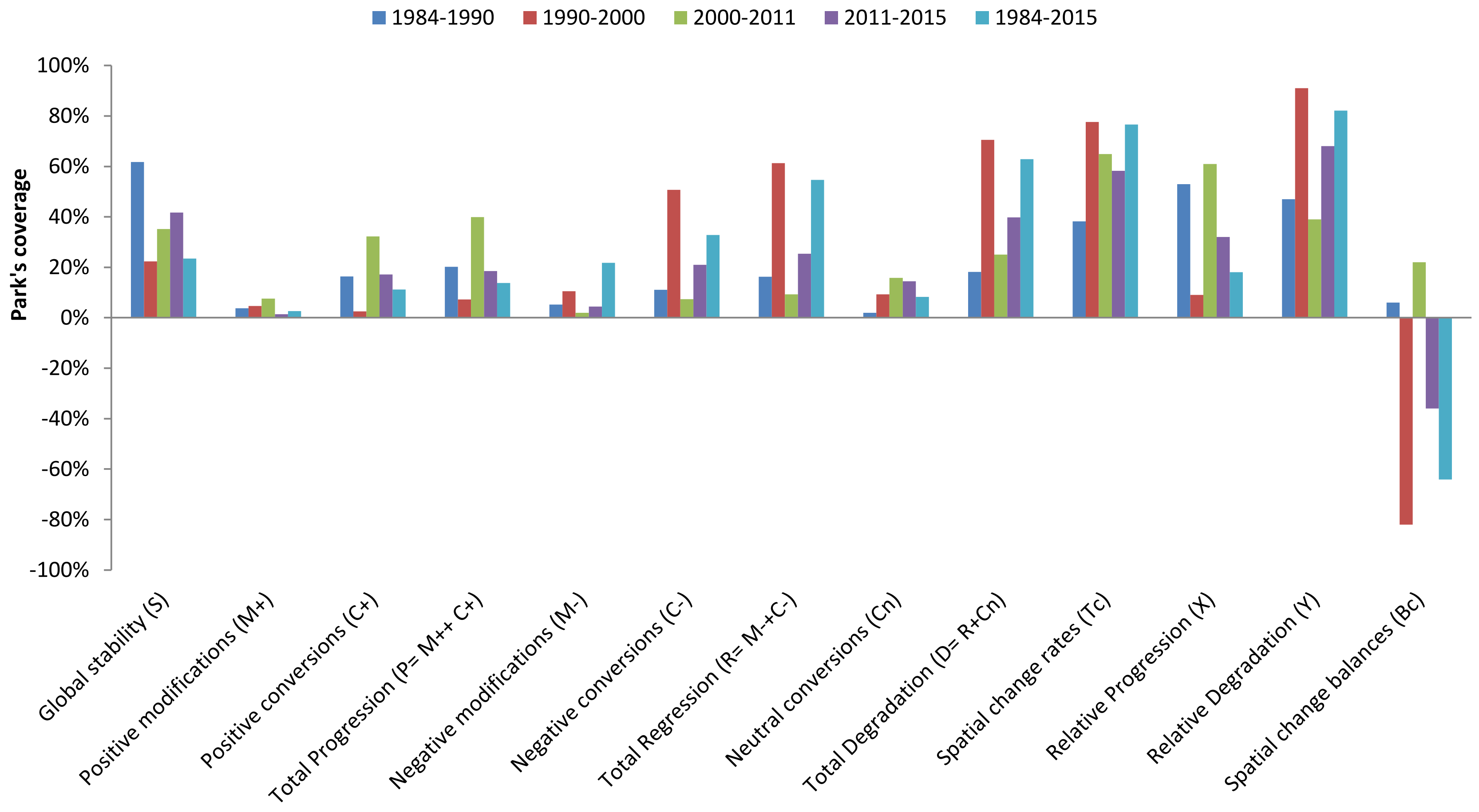
IV. Main analytic results

Overall balance sheets (1984-2015)



	1984-1990	1990-2000	2000-2011	2011-2015	1984-2015
Vegetation cover	7,40%	-61,80%	83,80%	-6,90%	-29,90%
Anthropogenic areas	-25,70%	278,90%	-37,50%	10,60%	94,50%
Water resources' coverage	23,1 %	-41,2%	22,2%	-22,3%	-31,3%

IV. Main analytic results
Periodical synthetic landscape dynamics



IV. Main analytic results
Trends indices – Evolutionary trends

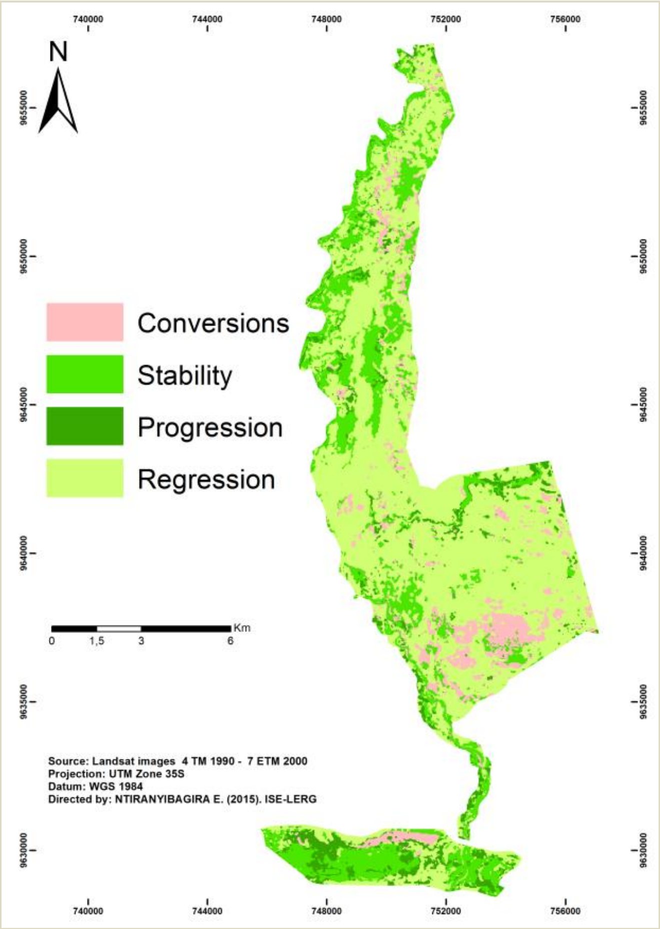
	Trend indices values and classes				
Période	1984-1990	1990-2000	2000-2011	2011-2015	1984-2015
Index value	(38%, 6%)	(77%, -82%)	(65%, 24%)	(58%, -34%)	(77%, -64%)
Index class	2D	4a	3D	3c	4b
Trend index	[(38%, 6%) ; 2D]	[(77%, -82%) ; 4a]	[(65%, 24%) ; 3D]	[(58%, -34%) ; 3c]	[(77%, -64%) ; 4b]

Period	Class Code	Evolutionary trend
1984-1990	2D	a moderate evolution (2)" with "a low positive trend (D)" (I)
1990-2000	4a	a very strong evolution (4)" with "a very strong negative trend (a) (II)
2000-2011	3D	a strong evolution (3)" with "a low positive trend (D) (III)
2011-2015	3c	a strong evolution (3)" with "a moderate negative trend (c) (IV)
1984-2015	4b	a very strong evolution (4)" with "a strong negative trend (b) 77% of protected area affected by spatial transformations whose 82% are under degradation and 18% under progression

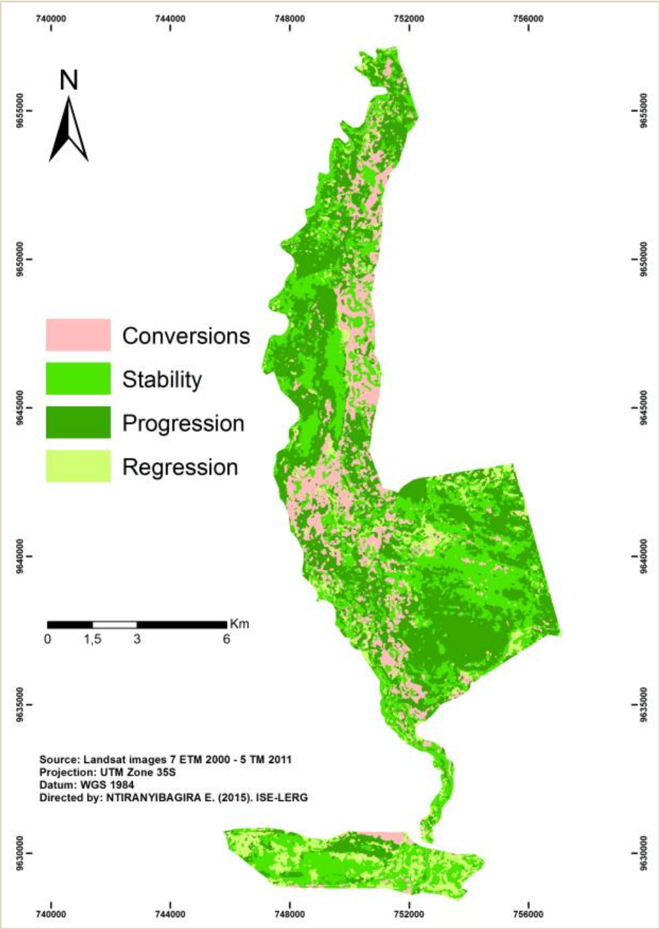
IV. Main analytic results

Overall Landscape Dynamics

1990-2000 (Worse Period: 1993 civil war)

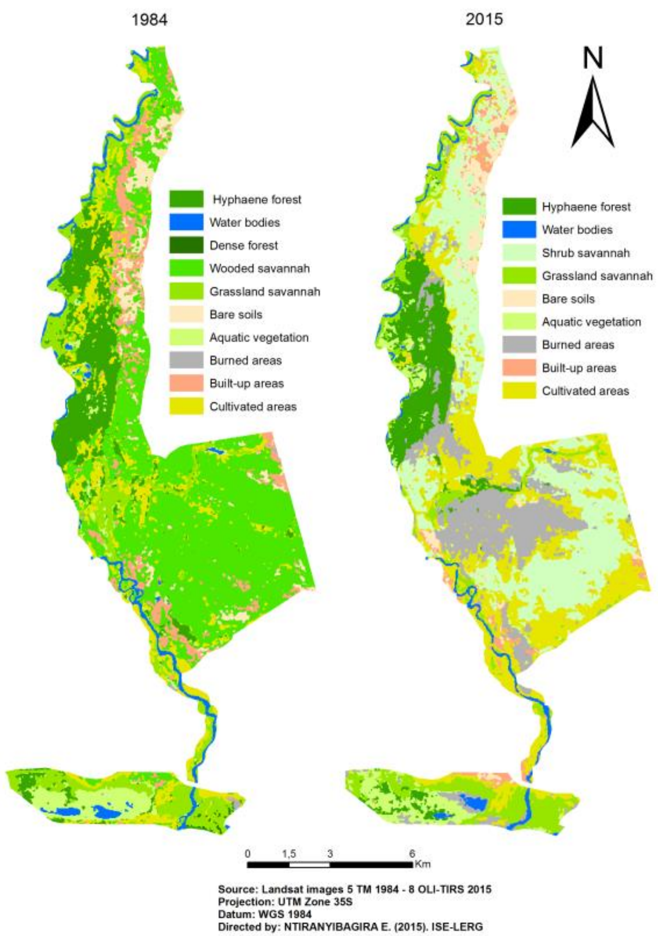


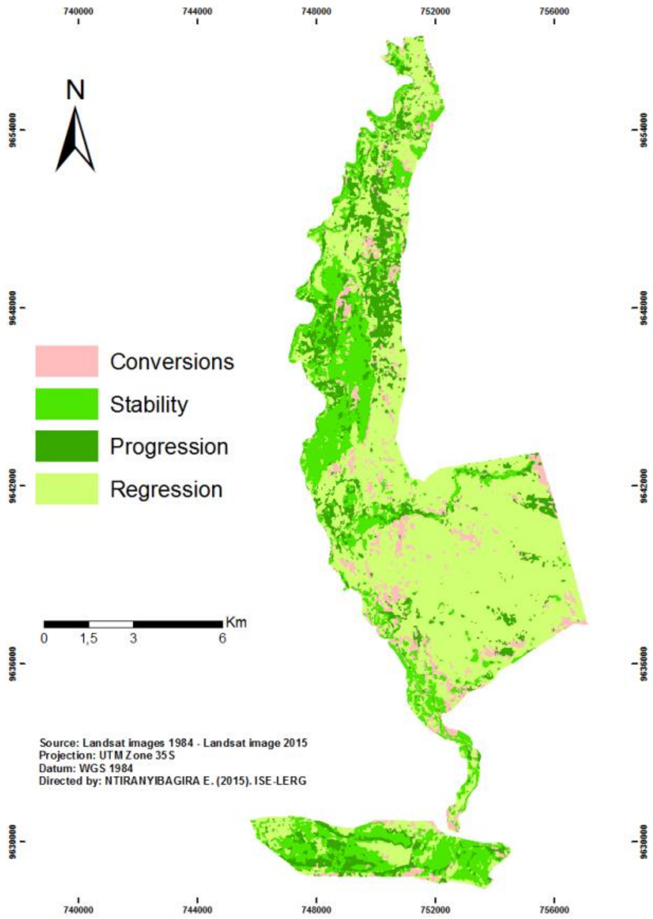
2000-2011 (Best Period: Peace recovery)



IV. Main analytic results

Overall Landscape Dynamics (1984-2015)

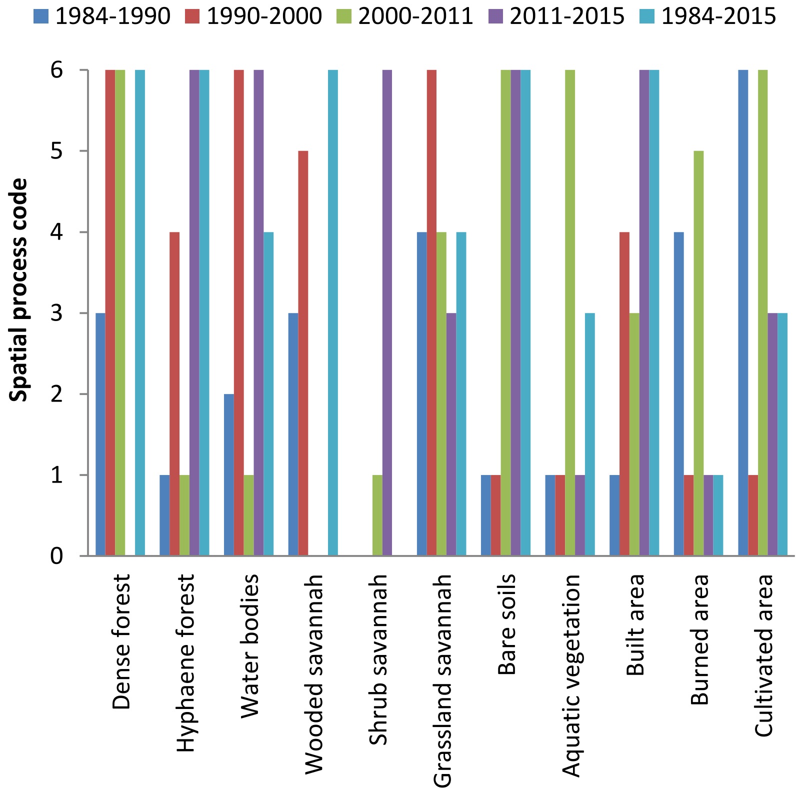


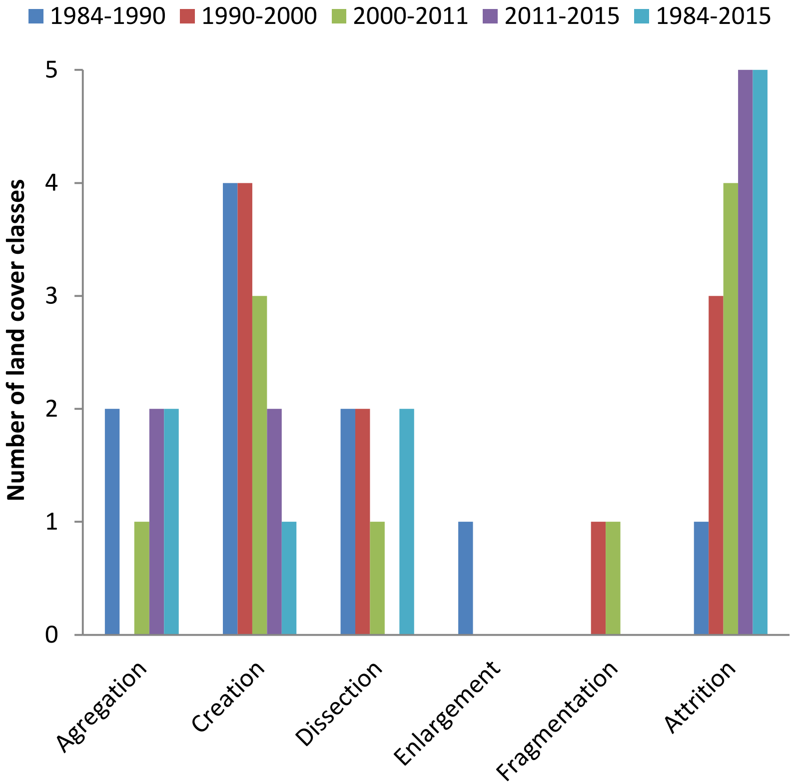


IV. Main analytic results
Spatial Transformation Processes

Codes : 1. Creation, 2. Enlargement, 3. Aggregation, 4. Dissection, 5. Fragmentation, 6. Attrition and cover classes are affected differently

Patch Attrition 37 %, Patch Creation 29%. Great variability of spatial processes demonstrate Existence of deep, quick and contrasted changes in park's land cover.

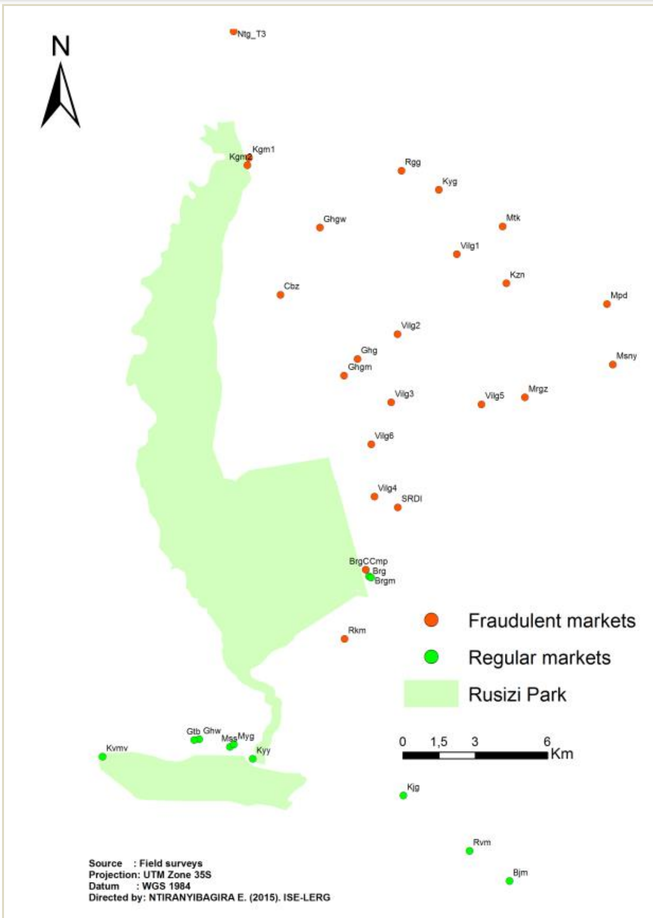




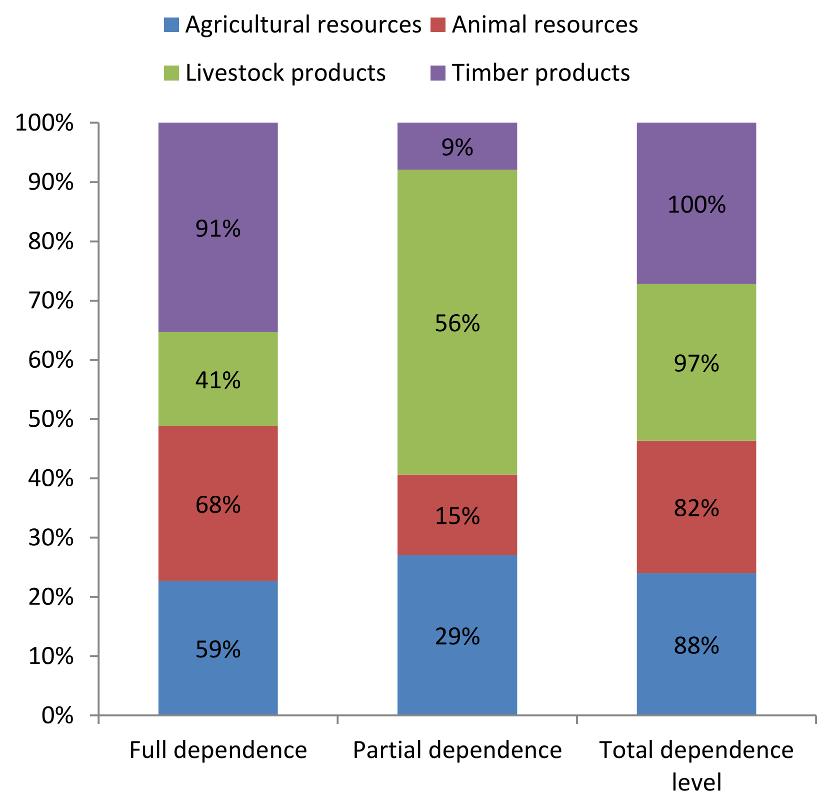
IV. Main analytic results

Socio-economic dependence and Peripheral threats

Distribution of riparian villages and products' markets



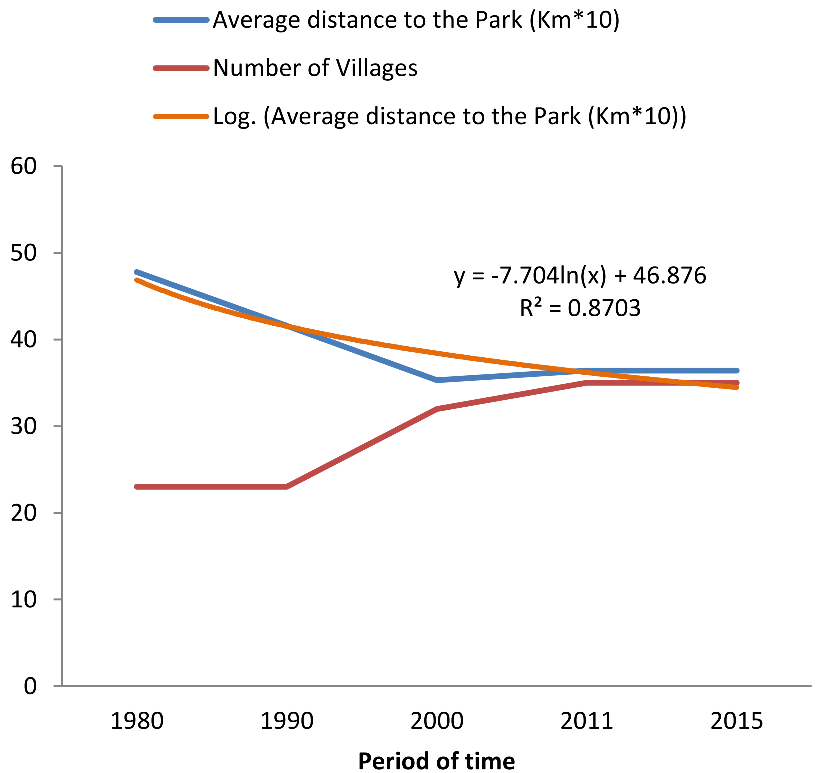
Socio-economic dependence of villages



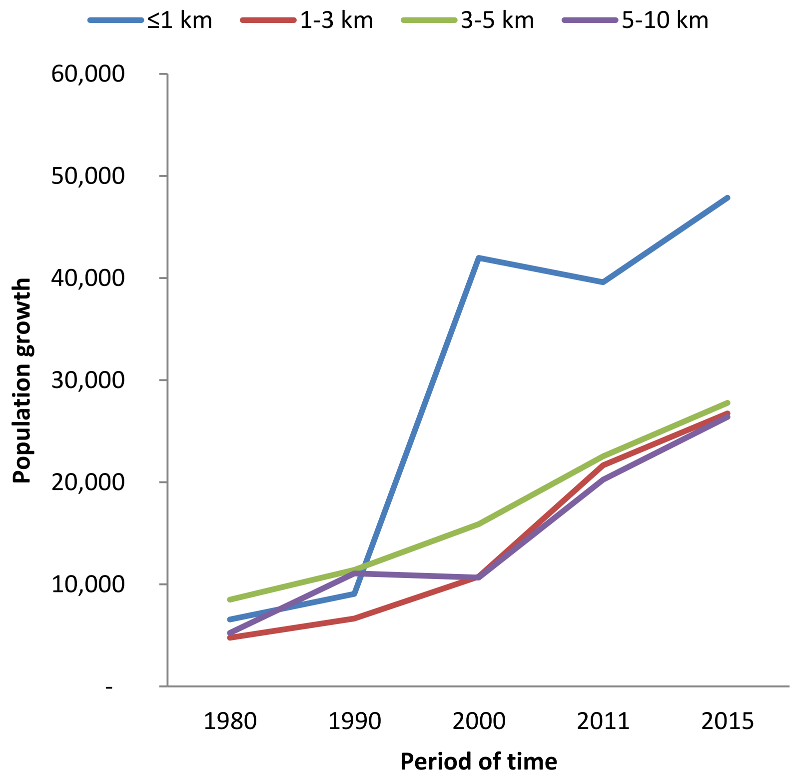
IV. Main analytic results

Spatial distribution of Peripheral threats

Spatial characteristics of peripheral localities



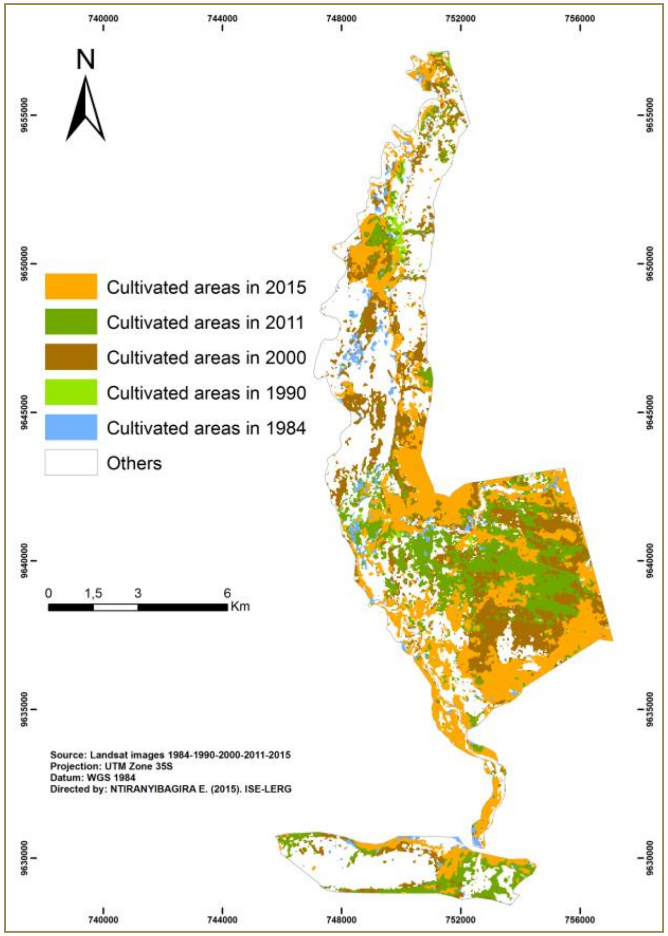
Spatial distribution of peripheral population



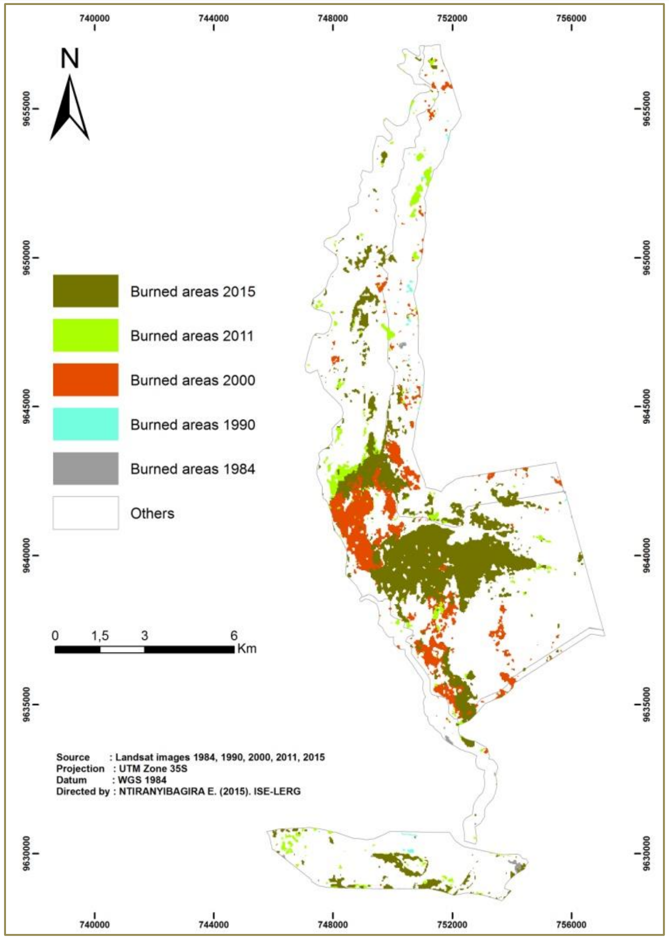
IV. Main analytic results

Spatial distribution of illegal activities (loggings)

Agricultural activities

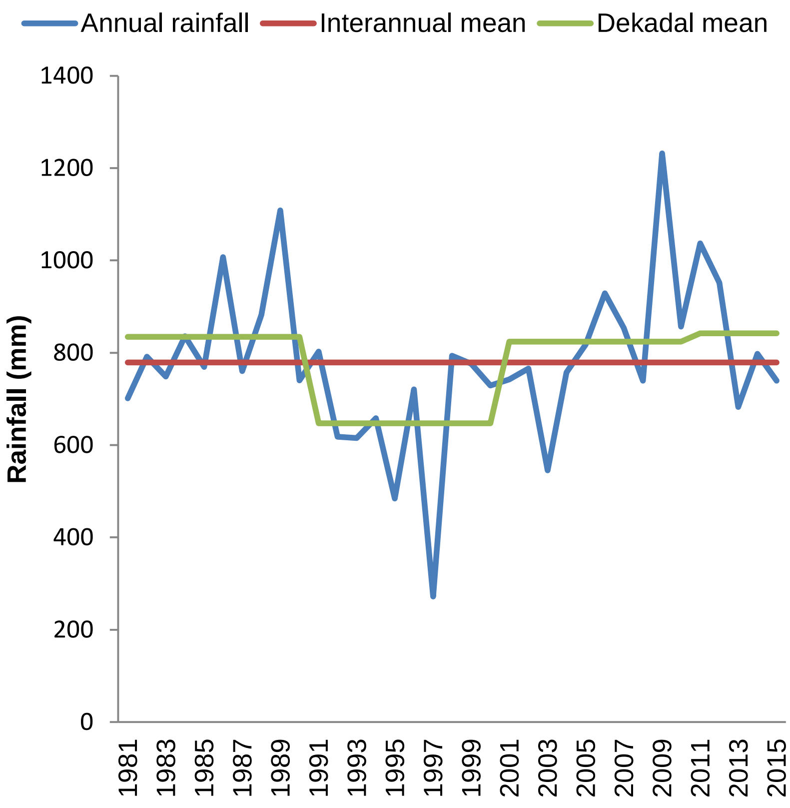


Bush fires and pastoral activities

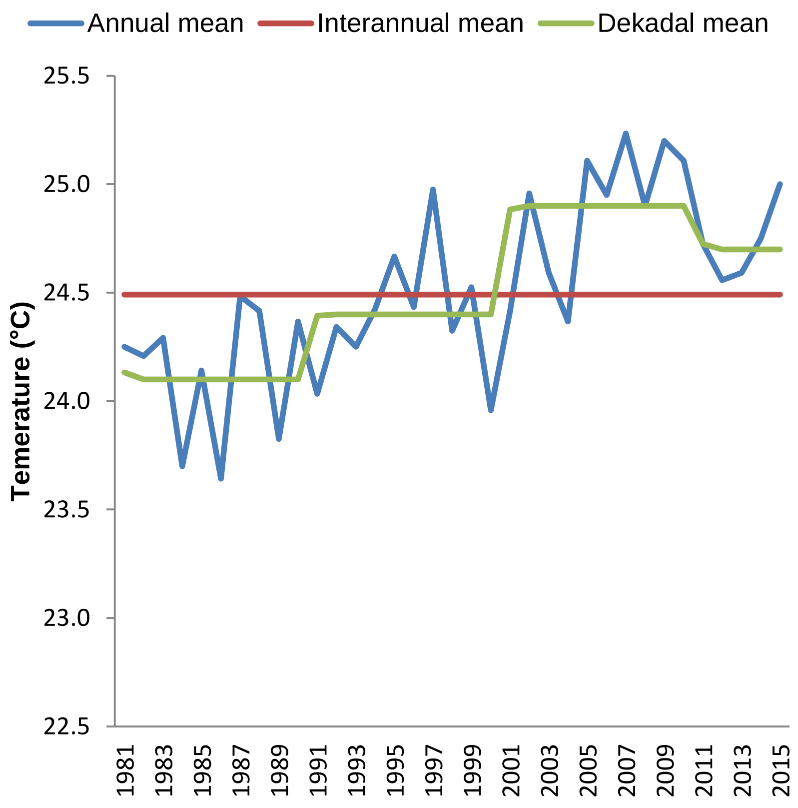


V. Main analytic results
Climatic conditions (1981-2015)

Rainfall variability: decadal cycle



Temperature increase: +0.3 °C/Decade



V. Conclusion and challenges

- The results show that the Rusizi Park has experienced l**imited positive evolutions under statutes of "Reserve"** and **negative ones with high amplitude under statutes of " Park**. The park finally underwent a **4b trend index** with strong quantitative and qualitative degradations carried by **spatial changes affecting 77% of the total area, of which 82% are under decline,** because of highly increased human and climatic stresses. The evolutions observed resulted from **6 different STPs which are dominated by radical and opposed processes of patch creation and patch attrition**. The contrasted STPs have led to a significant extension of anthropogenic areas and to deep regressions of water resources and vegetation cover.
- The case study showed that PA's TAAMCO analytic model is an interesting approach and tool to assess the conservation policies and practices especially in **African countries where reported degradations are always described qualitatively due to the lack of quantitative and rigorous indicators**. However, it's practical use can be limited by the recurrent absence of conservation objectives and management plans.
- The **biggest challenges that most of African protected areas** are currently facing are: (1) The **lack of negotiated, validated and applied management plans**, (2) **the failure of recurrent conservation policies** based on inhabited protected, (3) **the ignorance of the extent of the zone of socio-economic interactions and dependence** which objectively delimits the **protected areas' real periphery** and (4) the **lack of complete and reliable field data**
- The **availability of near real time, free of charge and open access Copernicus global land products** for the monitoring of natural ecosystems provides a very good opportunity to take for regular evolutionary trends' assessments and well planned protected areas' management

VI. PA's TAAMCO Analytic Model and Copernicus Global Land Products

- The PA's TAAMCO Analytic Model being of general application, it can easily be applied to assess Protected areas' evolutionary trends using PROBA-V data which have a spatial resolution ranging from 300m to 100m. For protected areas' large scale analysis indeed, this resolution is suitable enough, especially for big PAs. The interests of Copernicus global land products and land cover dynamic maps for assessment and improvement of protected areas' management making use of TAAMCO Model are: **(1) the great regularity and availability of data (quite near real time), (2) their open access status and (3) their free of charge character** which allow low costs and frequent protected areas' assessments for reliable change detections and continuous adjustments of management goals, plans and activities.
- The use of Copernicus Global Land Products to assess protected areas' management and evolutionary trends using PA's TAAMCO Model can be performed according 2 methods : (1) By using directly DN or PV **variations** between 2 dates for the identification, the qualification and the quantification of land cover changes reference made to appropriate correspondences between BIOPAR values and specific land cover types. This needs a **coding system of** time series data before making the superposition of land cover and coded maps and (2) By making **technical data transformations** and **moving from BIOPAR values such as NDVI to vector data corresponding to specific land cover types** before starting with the analysis of spatial changes, landscape dynamics and evolutionary trends at a global level instead of showing annual changes considering point values
- For this purpose, there is a urgent need for large scale training of researchers, professionals and managers in specialized methods and tools with appropriate equipments. This is exactly **one of the main missions of ICE-RTSDA** which was recently set up in Rwanda for the **promotion of innovative methods, tools and products for efficient environment monitoring and management** in partnership with african and international institutions.

THANK YOU FOR YOUR KIND ATTENTION