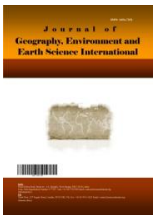

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Frequency, Harmfulness and Vulnerability (FHV) Multicriteria Method for Integrated Analysis of Illegal Exploitations and Strategic Participatory Management of Protected Areas in Africa

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Authors' contributions

This work was carried out in collaboration among all authors. Authors NE, UT, NC, KA and MF designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ML and TA managed the analyses of the study. Authors NI and NE managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

In Africa, protected areas are facing hudge illegal exploitations and accelerated degradation. Illegal exploitations are interesting indicators of local socio-economic needs and hostility of populations to conservation activities. The study aimed to develop a specific method for the analysis of illegal exploitations and the promotion of successful participatory management. Basically, the Multicriteria method used to determine the impact and the gravity of illegal exploitations relies on three criteria based on offenses themselves and affected resources. The method combines statistical analysis of management data using ANOVA and χ^2 tests, field observations and semi-structured interviews for validation. For the tested Rusizi national Park, the findings showed that the number of supervised exploitations increased from 1988 to 2015 while the number of supervised operators is limited and highly fluctuating between resources and periods. The public integration ratio is 8 $^0/_{000}$ and corresponds to 61 supervised operators of which 84% are involved in vegetal resources exploitations. In total, 10 illegal exploitations whose impact values range from 1 to 20 and belong to very high and high impact classes were reported. Average, 651 cases of which 71% cover direct cuts of vegetation were reported annually. Statistically, the most damaging illegal exploitations are made of tree and vegetation cuts, cattle grazing and fishing. Illegal exploitations are seasonal and more important in dry season than in rainy season. They are more important in Delta sector than in Palmeraie sector. The shift from gracious exploitations to lucrative operations, over-taxation of supervised exploitations, low ratio of public integration, political conflicts and unarmed protection contributed to increase and strengthen significantly illegal exploitations. Ultimately, the results revealed the limits of participatory management on illegal exploitations. Consequently, the success of participatory management in Rusizi national Park requires strategic and concerted development projects, more responsive regulatory measures and relevant partnerships with peripheral village.

Keywords: Protected area; multi-criteria method; illegal exploitation; illegal exploitation's impact; participatory management; Rusizi national park; Africa.

1. INTRODUCTION

In African countries, different studies showed that protected areas are facing severe human pressures, hudge illegal exploitations and accelerated degradation, particularly in the tropics due to many factors including a rapid population growth, a great rural poverty, recurrent peripheral conflicts, weak governance systems and climate change impacts [1-13]. Increased human pressures are as more worrying as the world's natural systems are known to be natural solutions for climate change mitigation and adaptation [14]. In Africa, natural resources illegal exploitations from the periphery of protected areas have become a real thermometer of the basic socio-economic needs of local populations and a clear proof of their continued hostility to conservation activities that do not provide credible alternatives for their survival [15,16]. They are major socio-economic indicators of protected areas management that represent both a denial and a challenge for conservation [17,15]. Therefore, one of the best indicators of protected areas management effectiveness in African contexts should be the stabilization or substantial reduction of illegal exploitations that are undoubtedly the main factor of protected areas degradation. Participatory management policies have been specifically designed and implemented to mitigate the fraudulent and uncontrolled protected areas exploitations [18-22]. Nevertheless, these policies have generally been designed without prior and in-depth studies on illegal exploitations and on the real needs of local populations. Indeed, even if peripheral conflicts and illegal activities are still important and persistent in most of African protected areas [23,4,24,6,7,25,11,12, 15], no rigorous and thorough researches have yet been conducted to analyze scientifically the relative gravity and impact of illegal exploitations for the promotion of adaptive, efficient and sustainable protected areas management. Current methods and tools used for the management, the monitoring and the evaluation of protected areas [26,17,20,27,22,28] analyze illegal exploitations only in qualitative and descriptive terms despite their relevance as objective indicators of anthropogenic pressures. Additionally to the lack or insufficiency of precise management data on illegal exploitations, the absence of specific methods of analysis justifies this situation and does not make it possible to exploit the hudge masses of data often found in protected areas management reports. Indeed, in

many African protected areas, multi-year technical management reports constitute important databases that are often unexploited or poorly exploited. The research was initiated to address this methodological and analytical concern and to promote sustainable and participatory conservation on a scientific basis. The objective of the study is to develop and apply a multi-criteria method to provide policy makers and protected areas managers with a tool for rigorous analysis of illegal exploitations and rational adjustment of participatory management strategies and options. The method is intended to complete and enrich usefully the Management Effectiveness Tracking Tool (METT) tool [29-31]. Despite the obvious interest of the tool for the assessment of protected area management effectiveness, indeed, this one presents serious limits for an objective and rigorous evaluation due to its participatory and rapid self-evaluation character.

2. METHODOLOGY

The methodology used in the study consisted of four steps: (1) conceptualization of the severity and impact of illegal exploitations, (2) application of the concepts and method to the analysis of data on protected areas illegal exploitations between two reference dates T_1 and T_2, (3) field investigations for the validation of analytic results on illegal exploitations, and (4) the reasoned and consistent definition of new strategies and options for successful participatory management. Field investigations are based on: (i) direct and random observations of traces of fraudulent products in peripheral zones [16] and (ii) individual and focus group semi-structured interviews with key stakeholders composed of successive park's managers, oldest rangers, local administration officers, NGOs staff, local technical officers, farmers, shepherds, handcraft cooperative members and supervised fishermen, dead wood collectors, mineral resources extractors and vegetation resources operators. The identification, enumeration and characterization of illegal exploitations are based on the systematic analysis of technical management reports between dates T_1 and T_2. The analysis of illegal exploitations using the Multi-criteria method relies on the following assumptions and hypothesis: (i) due to limited personnel, the real number of illegal exploitations is more important than the reported one, (ii) most of illegal exploitations that occur in protected areas are reported and (iii) all illegal exploitations reported are true.

2.1 Background and Theoretical Framework

Beyond historical, socio-economical and bio-physical reasons [32,23,33-37,15], the diversification and strengthening of protected areas illegal exploitations in Africa result from strongly restrictive conditions for public integration [18], low incomes and financial benefits from participatory management and indirect conservation measures [38,39,12,40], the relegation of the population socio-economic interests by sorting and selective conservation strategies [24,6,25,41] and finally, the failure of most of participatory management mechanisms [12,15]. Since the failure of the participatory management approaches results from the lack of prior studies and well-documented baseline situations for rigorous definition and planning of public integration projects, the objective and in-depth study of illegal exploitations provides basic data and information for the adjustment of participatory management options and strategies. In practice, well adapted and successfully participatory management projects and activities have to emerge from rigorous evaluations of human pressures and protected areas management effectiveness [28,17]. The "Frequency-Harmfulness-Vulnerability" Multicriteria method (FHV Multicriteria method) designed for the analysis of protected areas illegal exploitations is an objective basis for the definition of reasoned participatory management options that rely on: (1) the theoretical study of the "Pressure" component of the Driving Forces, Pressure, State, Impact and Responses (DPSIR) Assessment Model [42] and (2) the protected areas management data for field validation. Theoretically and practically, the Frequency, Harmfulness and Vulnerability (FHV) Multicriteria method postulates that the "impact" of an illegal exploitation is the combination of its "intrinsic gravity" and the "sensitivity" of the affected resources and sites. Indeed, illegal exploitations do not have the same gravity and impact on natural resources. For example, a case of bush fire does not have the same effect on a protected area than a case of poaching like a case of endemic tree cuts does not have the same impact than a case of common cuts of regenerative species. If a case of illegal cuts of forest trees is equivalent to the case of a bush fire devastating 100 ha of a protected area in numerical terms, it is less impacting reference made to the geographic extent and the diversity of natural resources affected by two illegal exploitations. Likewise, illegal fishing does not

affect equally fisheries resources depending on the populations and habitats impacted. These simple examples show that the number of cases reported on a specific illegal exploitation does not fully reflect its severity and impact, whereas in most protected areas it is the only objective parameter that is reported in technical management reports. Most of the time, the extent of areas and the quantity of natural sources affected by instantaneous illegal exploitations are not reported due to the lack of appropriate methods, tools, competences, time or interest. Therefore, the comparative characterization and the determination of the impact of illegal exploitations require adding to the number of reported cases the harmfulness of illegal exploitations and the vulnerability of the natural resources that they specifically affect. As environmental indicators [17], the three variables or criteria are fundamentally numeric, ecological and biological by nature. The number and harmfulness of illegal exploitations form their intrinsic gravity that affects the sensitivity or specific vulnerability of natural resources. Ultimately, the realand specific impacts of illegal exploitations on a protected area result from a combination of the three criteria. In practice, the Multicriteria method considers illegal exploitations reported by protected areas managers, and not potential threats in and around protected areas [43,16].

2.2 Presentation of FHV Multicriteria Method

The Multicriteria method uses three variables or criteria for the characterization, hierarchical classification and in-depth statistical analysis of illegal exploitations. These are the Frequency (F) or repetitiveness of illegal exploitations (Criteria A), the Harmfulness (H) of illegal exploitations (Criteria B) and the Vulnerability (V) of exploited natural resources and sites (Criteria C). For a given illegal exploitation and the duration of field observations, the Frequency is the "*average annual number*" of recorded cases, the Harmfulness "*the nature and extent of its effects*" expressed in terms of intensity of direct and/or indirect effects on resources and sites and the Vulnerability, the "*current level of availability, sensitivity and resilience*" of affected resources and sites expressed in terms of abundance and evolutionary trends. The final classification of illegal exploitations by severity order is based on a process of criteria scoring using a scale of values and the hierarchical ranking of illegal exploitations using impact values and classes resulting from the product of the criteria scoring (Table 1). As indicated in the Table, small values correspond to high illegal exploitations damages and vice-versa. Finally, the name of FHV Multicriteria method comes from the combination of the initials of the three variables or criteria. According to the types and the number of different illegal exploitations recorded in a given protected area, the statistical analysis will cover 5 to 10 most damaging illegal exploitations with reference to the impact values and classes for different types of illegal exploitations.

2.3 Determination of the Criteria Values for the Classification of Illegal Exploitations

2.3.1 Frequency of illegal exploitations

The frequency (F) of an illegal exploitation is determined in 5 steps. Firstly, a systematic analysis of illegal exploitations reported in the monthly management reports is done and the appellations redrafted if necessary. Secondly, the average number of monthly or annual cases for each type of illegal exploitations over the study period is calculated. Thirdly, all average numbers of monthly or annual cases are classified using a decreasing order. Fourthly, the average numbers of periodical cases are distributed into 5 classes having the same interval and ranging from the greatest values to the smallest ones. Fifth, each illegal exploitation is assigned a score ranging from 1 to 5 according to the specific class that its average number of periodical cases belongs to.

2.3.2 Harmfulness of illegal exploitations

The harmfulness of an illegal exploitation is measured by the intensity of its direct and/or indirect effects on the natural resources and sites that it specifically affects. The scoring scale of the harmfulness comprises 5 levels or classes which are, by decreasing harmfulness for conservation: (1) intense direct effects (Class 1), (2) moderate direct effects (Class 2), (3) intense indirect effects (Class 3), (4) moderate indirect effects (Class 4), and (5) weak direct and indirect effects (Class 5). In case of multiple effects from the same illegal exploitation, the class of harmfulness corresponding to the most damaging effects is attributed. Fundamentally, the attribution of the class value is done by a team of experts.

Table 1. Description and scoring scales of the criteria used for the classification of illegal exploitations

Criteria	Class levels by decreasing gravity	Class values by decreasing impact				
		1	2	3	4	5
Frequency	Highest averages (Class 1)					
	Second rank averages (Class 2)					
	Third rank averages (Class 3)					
	Forth rank averages (Class 4)					
	Lowest rank averages (Class 5)					
Harmfulness	Intense direct impacts					
	Moderate direct impacts					
	Intense indirect impacts					
	Moderate indirect impacts					
	Low direct and indirect impacts					
Vulnerability	Resources threatened with extinction					
	Resources in decline					
	Resources in balance					
	Resources under moderate increase					
	Resources under strong growth					
Resulting impacts and classification	Impact value (Iv)	$Iv = f * h * v$ (1^3 à 5^3ou 1 à 125)				
	Impact class (Ic)	[1-8] Very High	] 8-27] High	] 27-64] Moderate	]64-125] Low	
	Hierarchical order (Ho)	Final ranking of illegal exploitations using impact values				

2.3.3 Vulnerability of natural resources and sites

The vulnerability of a natural resource is determined using the current status of the resource in terms of availability, fragility and resilience. The vulnerability scale of natural resources consists of 5 levels or classes that are ranked as follow, according to vulnerability decreasing order: (1) endangered resources (Class 1), (2) resources under regression (Class 2), (3) balanced resources (Class 3), (4) resources under moderate progression (Class 4), and (5) resources under great extension (Class 5). When an illegal exploitation affects several types of resources at the same time, the class of vulnerability corresponding to the most vulnerable or the less resilient natural resource will be considered. Fundamentally, the attribution of the class value is done by a team of experts.

2.3.4 Impact value and class

The impact of an illegal exploitation on the natural resources of a protected area and on the protected area itself is defined by the product f*h*v of the Frequency, the Harmfulness and the Vulnerability; where f, h and v are respectively the values of the classes assigned to the variables after the evaluation and classification processes. The values range from 1 to 5 considering decreasing damage levels (Table 1). Thus, the crossing of the values of the three variables or criteria makes it possible to define 30 impact values ranging from 1 to 125 (Table 2). The impact values are divided into 4 impact classes that are bordered by the power 3 of the variables rating levels, namely 1 (1^3), 8 (2^3), 27 (3^3), 64 (4^3) and 125 (5^3). The 4 impact classes are therefore: (1) very high impact class [1-8] (Class 1), high impact class [8-27] (Class 2), moderate impact class [27-64] (Class 3) and low impact class [64-125] (Class 4).

2.3.5 Hierarchical classification number of Illegal exploitations

Once the impact values and classes of illegal exploitations are determined, the impact values are ranked according to decreasing severity or damage to natural resources and protected areas. The ranking process or the hierarchical classification of different illegal exploitations orders them from the lowest impact values (greatest damages) to the highest impact values (lowest damages). For equal impact values, the priority in ranking goes to the most frequent and/or the most harmful illegal exploitation;

Table 2. Theoretical impact values for the classification of illegal exploitations

Criteria A*B	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25
Criteria C	**(A*B)*C new values**				
2	18	24	30	32	40
	50				
3	27	36	45	48	60
	75				
4	64	80	100		
5	125				

assuming that the frequency and the harmfulness of an illegal exploitation are the most important factors that are responsible for the degradation of natural resources and protected areas. At the end, the hierarchical classification numbers of illegal exploitations range from 1 to X; where X is the total number of the types of illegal exploitations recorded in a specific protected area. In the method, we propose to consider only the 5 to 10 most damaging illegal exploitations for advanced statistical analyses, taking into account the typology and the number of illegal exploitations. Doing so allows decision makers and managers to avoid insignificant illegal exploitations for the management planning. The impact value and the hierarchical classification number are objective and relevant indicators of the damage caused by illegal exploitations that make it possible to define the priorities for intervention and judicious allocation of human, financial and logistical resources.

2.3.6 Statistical analyses of significant illegal exploitations

Raw numerical data or data time series of the 5 to 10 most damaging illegal exploitations resulting from the process of hierarchical classification are subject to advanced statistical analyses that are based on the Analysis of Variance (ANOVA) and the χ^2 independence test using common specialized statistical softwares like SPSS or SPHINX.

3. VALIDATION TEST TO RUSIZI NATIONAL PARK (BURUNDI)

3.1 Data and Analysis Tools

For the case of Rusizi national Park which is the most threatened protected area in Burundi, the multi-criteria analysis of illegal exploitations covered monthly data collected between 1988 and 2015. The qualitative analysis of technical management reports for the study period was focused on: (1) the types of supervised or authorized exploitations with regard to the participatory management launched in 1987, (2) the typology of illegal exploitations, (3) the nature of fraudulent products found in peripheral villages, (4) the places where fraudulent products are mostly found and (5) the identity and geographical origin of illegal operators. The quantitative analysis of technical management reports was interested by: (1) the number of supervised operators, (2) the taxes paid for supervised exploitations, (3) the proportion or ratio of supervised operators in the total peripheral dependent population, (4) the number of cases of each illegal exploitation, (5) the park's revenue from penalties and (6) the park's revenue from the sale of seizures of fraudulent products. Missing data in the time series were determined using the technique of moving averages. Since numerical recording of illegal exploitations was suspended in 2008, the statistical analyses of quantitative data only covered the time series from 1988 to 2007 and used SPSS 16.0 software. The analysis of illegal exploitations from year 2008 was carried out thanks to the narrative management reports and individual and focus groups semi-structured interviews involving key stakeholders composed of park managers, local administration officers, park protection associations, associations of supervised operators and local community members. Semi-structured interviews were focused on: (1) the monthly and annual income of supervised operators, (2) the typology and relative importance of illegal exploitations, (3) the distribution of illegal exploitations over the year, (4) the finality of the products resulting from

illegal exploitations, (5) the main causes of illegal exploitations, (6) the identity and geographical origin of illegal operators, (7) the conditions and limitations of supervised or authorized exploitations and (8) the possible and credible alternatives to illegal exploitations.

3.2 Research Findings

3.2.1 Typology and characteristics of supervised exploitations

The findings showed that between 1988 and 2015, the number of natural resources under supervised exploitations have increased from 3 in 1988 (*Phragmites mauritianus* cut, wood collection, salt mineral extractions), to 4 resources in 1995 (+ fishing) and finally to 5 resources in 1997 (+ *Hyphaene benguellensis* cut). Since many years, the exploitation of salty soils feeds a very flourishing national trade for livestock activities. The results of simulated calculations on the evolution of the number of supervised operators showed that except wood collectors whose annual numbers remain high and comparable, other supervised operators are in limited and highly fluctuating numbers (Figure 1). The ANOVA 2 of the numbers of supervised operators showed that there are highly significant differences between supervised exploitations (t-test, P-value = 0.00 < α = 0.05). It allowed distinguishing two groups of homogeneous means. The highest number is composed of wood collectors, while the lowest numbers refer to other supervised exploitations (*Phragmites mauritianus* cut, salt mineral extractions, fishing, *Hyphaene benguellensis* cut). The annual average numbers of wood collectors, *Phragmites mauritianus* cutters, salt mineral extractors, fishermen and *Hyphaene benguellensis* cutters were respectively 41, 8, 6, 5 and 4. The general inter-annual average of supervised operators was 61 of which only 19 are merchants or traders (Fig. 1). The exploitation of vegetal resources is the main category of authorized exploitations. It occupies 84% of supervised operators that are divided between wood collectors (66%), *Phragmites mauritianus* cutters (13%) and *Hyphaene benguellensis* cutters (5%). The ANOVA 2 of the total annual numbers of supervised operators indicated that there are highly significant differences between years (t-test, P-value = 0.00 < α = 0.05). It highlights three groups of homogeneous means. The highest numbers were recorded during the period 1996-2005, intermediate numbers during the period 2005-2015 and the lowest numbers between 1988 and 1995. After year 1995, the remarkable increase of the number of supervised operators is largely dominated by women collectors of dead wood as shown in Fig. 1.

The results presented in Fig. 2 showed that the ratio between the annual number of supervised operators and the total peripheral population depending on the natural resources of the park for their survival varies between 14 operators per 10 000 inhabitants in 1996 and 5 operators per 10 000 inhabitants in 2015. The general inter-annual average of 8 operators per 10 000 inhabitants is too low to ensure a sufficient quantitative supply of natural resources on local markets and contribute to the decrease of illegal exploitations with the very restrictive modes and rates of exploitation in force.

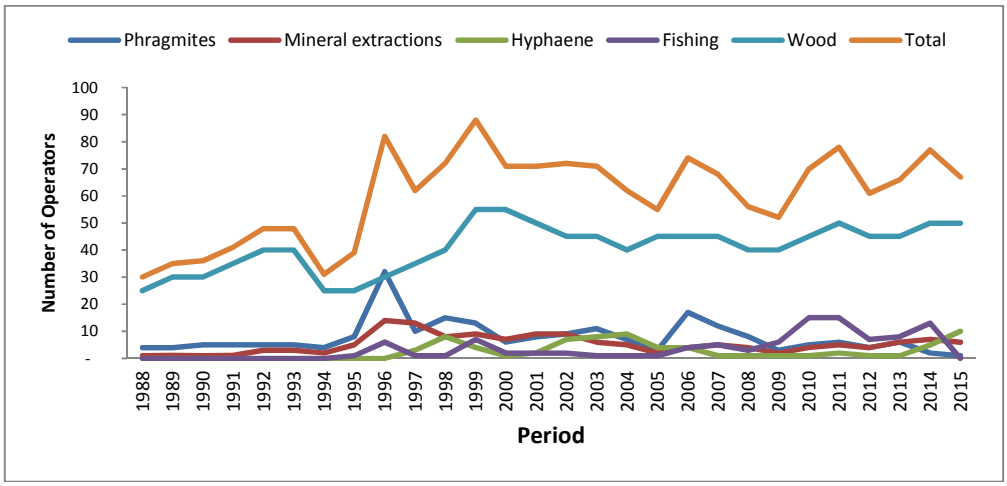

Fig. 1. Repartition and evolution of the numbers of supervised operators

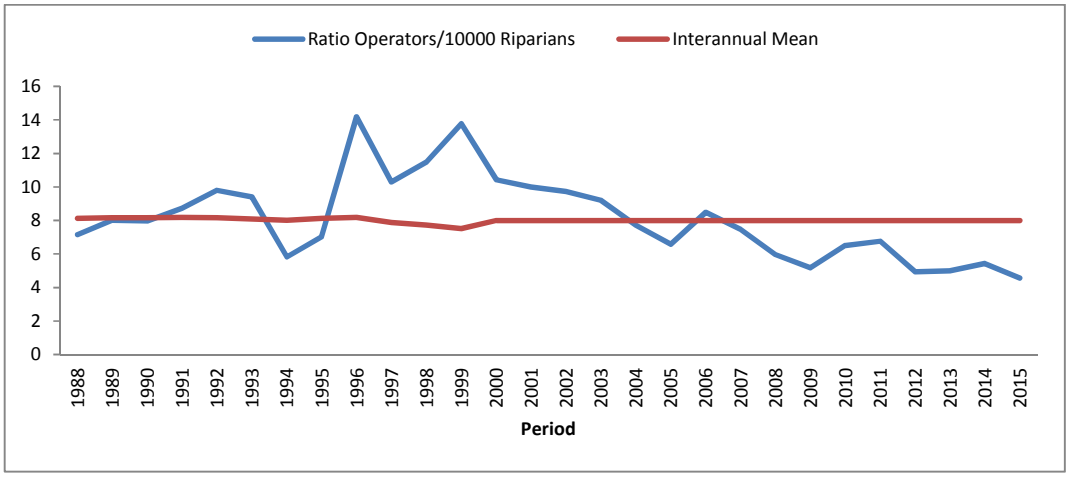

Fig. 2. Evolution of the ratio between the number of operators and peripheral populations

3.2.2 Typology and relative importance of illegal exploitations

The analytic results on illegal exploitations between 1988 and 2007 showed that the Rusizi national Park recorded 10 main types of illegal exploitations (Fig. 3). They indicated that the exploitation of vegetal resources counts for 84% of the total fraudulent exploitations. It is by far the most important threat to the overall evolution of vegetation, ecosystems and protected area. It can be divided between the cut of all types of vegetation (71%), cattle grazing (9%), crops and housing (2%) and bush fires (2%). Poaching and mineral extractions represent respectively 12% and 4% of the total number of cases of illegal exploitations. On one hand, plant cuts consist of tree cuts (44%) and *Hyphaene benguellensis* cuts (7%); representing 51% of non-regenerative and destructive cuts. On the other hand, they consist of *Phragmites mauritianus* cuts (40%) and cuts of various herbs (9%); what represents 49% of regenerative cuts (Fig. 3). This results in a significant and continuous degradation of the protected area by the phenomenon of deforestation.

The results showed that the annual number of cases of illegal exploitations gradually decreased from 1988 to 2007 even though they have practically spread to the entire protected area. Indeed, it went from 1135 cases in 1988 to 446 cases in 2007 what represents a fall of 61% over 20 years and an annual average of 651 cases of illegal exploitations, all categories combined (Fig. 4).

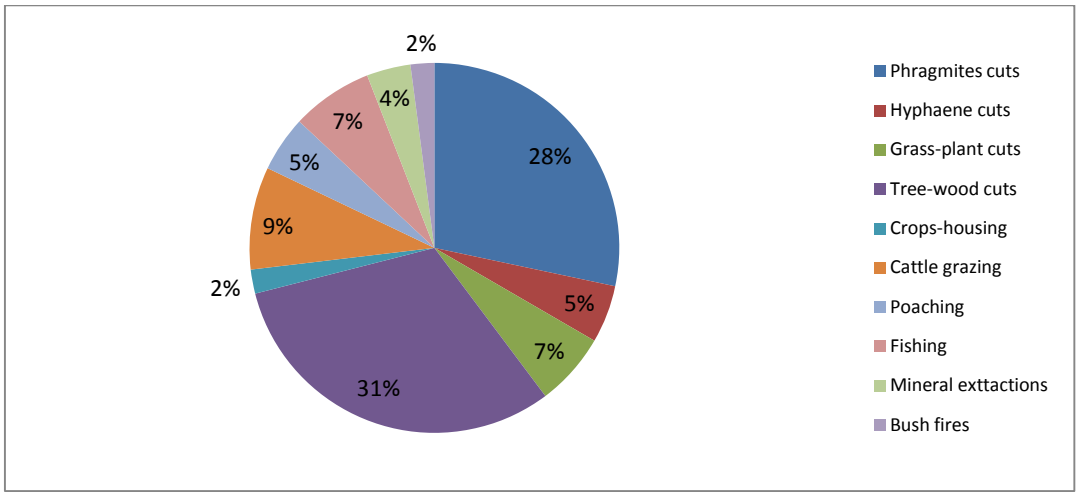

Fig. 3. Types and relative importance of illegal exploitations from 1988 to 2007

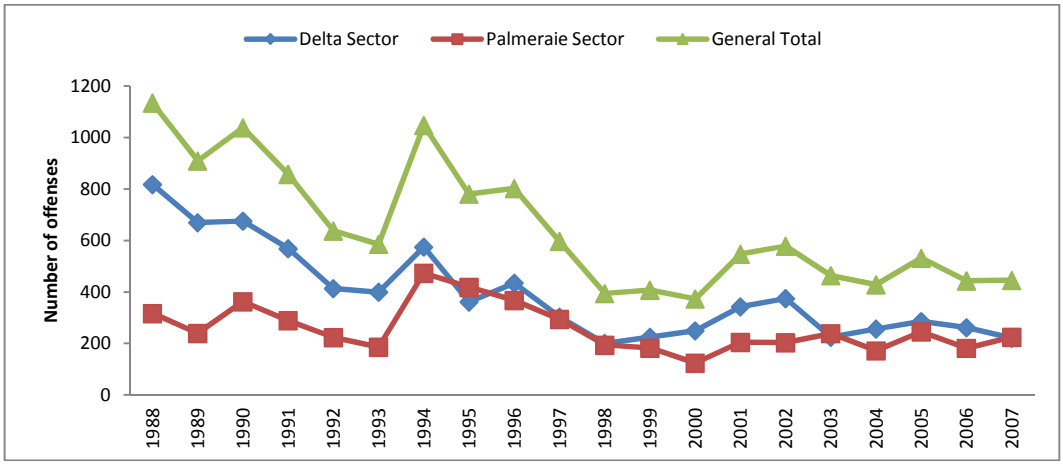

Fig. 4. Evolution and spatial distribution of illegal exploitations from 1988 to 2007

Even if the number of cases of illegal exploitations was no longer registered after 2007, it was noted a proliferation of illegal markets and the increase of the amount of penalties and seizures. This evolution shows that the number of cases of illegal exploitations should have increased. Indeed, ANOVA 2 (P-value = 0.001 < α = 0.05) showed that the amount of penalties and seizures differ significantly before and after 2007. They are higher after 2007 than before. Moreover, the normality test of Kolmogorov-Smirnov and the correlation study by means of the coefficient of Bravais Pearson indicated that the number of supervised operators is strongly and negatively correlated with the number of cases of illegal exploitations (R^2 = 0.79). The Fig. 4 provides the comparative typology and relative importance of illegal exploitations in the Palmeraie Sector in the northern part of Rusizi national Park and in Delta sector in the southern part of the protected area. The Fig. 5 shows that the most important illegal exploitations in Delta sector are *Phragmites mauritianus* cuts (43%), tree cuts and dead wood collection (22%), grass and plant cuts (10%) and cattle grazing (10%).

The Fig. 6 shows that the largest illegal exploitations in Palmeraie sector are tree cuts and dead wood collection (45%), *Hyphaene benguellensis* cuts (12%) and fishing (12%).

The analytic results of the monthly distribution of illegal exploitations over the year showed that these ones are characterized by a great seasonality. Illegal exploitations are more important during the dry season than during the rainy season. The total number of cases of illegal exploitations varies between 71 in August and 38 in November; with a monthly average of 54 (Fig. 7).

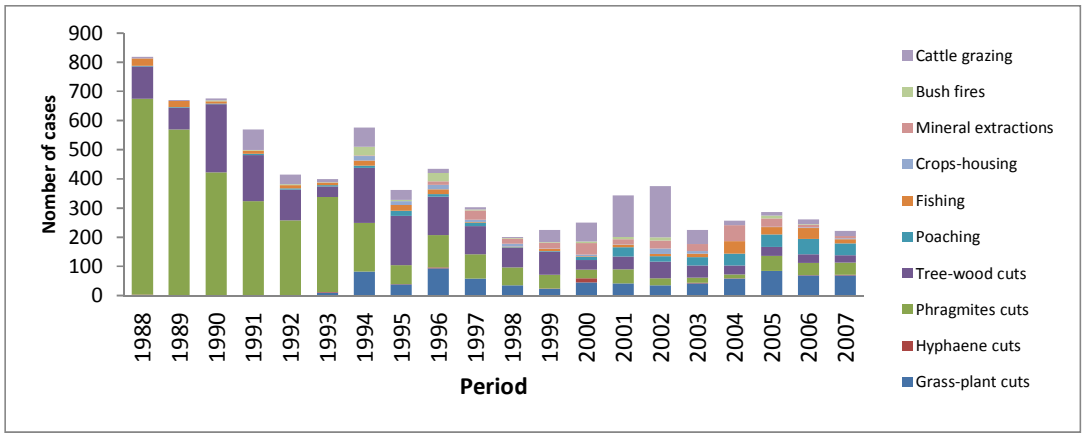

Fig. 5. Type and relative importance of illegal exploitations in Delta sector

The analysis of indicators associated with the protected area management and the monitoring of the exploitation of resources showed that the "*guarding density*" defined as the number of forest rangers per area unit has increased from 4 rangers/100 km² in 1988 to 66 rangers/100 km² in 2007 and 34 rangers/100 km² in 2015. During the period, "*the offense density*" that is the number of illegal exploitations per area unit decreased from 1300 illegal exploitations/100 km² in 1988 to 800 illegal exploitations/100 km² in 2007 as indicated in Fig. 8. The comparative analysis of the evolution of the guarding density and of the number of cases of illegal exploitations showed that two management indicators generally vary in opposite directions (Fig. 8).

3.2.3 Hierarchical classification of illegal exploitations

The results of the hierarchical classification presented in Fig. 9 showed that the 10 most damaging illegal exploitations are respectively: (1) Tree cuts and dead wood collection, (2) *Hyphaene benguellensis* cuts, (3) *Phragmites mauritianus* cuts, (4) Cattle grazing, (5) Fishing, (6) Poaching, (7) Crops and housing, (8) Bush fires, (9) Extractions of mineral and building materials, and (10) Cuts of grass and medicinal plant. Illegal exploitations can be divided and classified into 4 categories: (1) Direct cuts of vegetal resources (Trees, Phragmites, Hyphaene, and Grass), (2) Destructive exploitations of vegetal resources (Cattle grazing, Crops and housing, and Bush fires), (3) Exploitations of fisheries and animal resources (Fishing, Hunting, Trapping) and (4) Extraction of various minerals (mineral salts, sands, bricks). As shown in Fig. 9, all the 10 most damaging illegal exploitations have impact values comprise between 1 and 20. These values correspond to Very high impact class or Class 1 (Tree-wood cuts, *Phragmites mauritianus* cuts, Cattle grazing) and High impact class or Class 2 (Grass and plant cuts, Fishing, *Hyphaene benguellensis* cuts, Mineral extractions, Bush fires, Poaching, Crops). Tree and *Phragmites mauritianus* cuts are the most frequent illegal exploitations, with yearly averages of 203 and 184 reported cases. Opposite, crops, bush fires and mineral extractions are the least frequent illegal exploitations, with yearly averages of 14, 14 and 25 reported cases.

3.2.4 Statistical analysis of illegal exploitations

The 10 most damaging illegal exploitations resulting from the process of hierarchical classification have been statistically analyzed. The ANOVA 2 test of the number of illegal exploitations showed that there are highly significant differences between the types of illegal exploitations (P-Value = 0.00 < α = 0.05) and allowed to identify three groups of homogeneous means. The group of highest means is composed of tree-wood cuts and *Phragmites mauritianus* cuts, the group of lowest means made of bush fires and crops and housing, and the group of intermediate means composed of cattle grazing, fishing, grass-plant cuts, *Hyphaene benguellensis* cuts, poaching, and mineral extractions. The χ^2 statistical

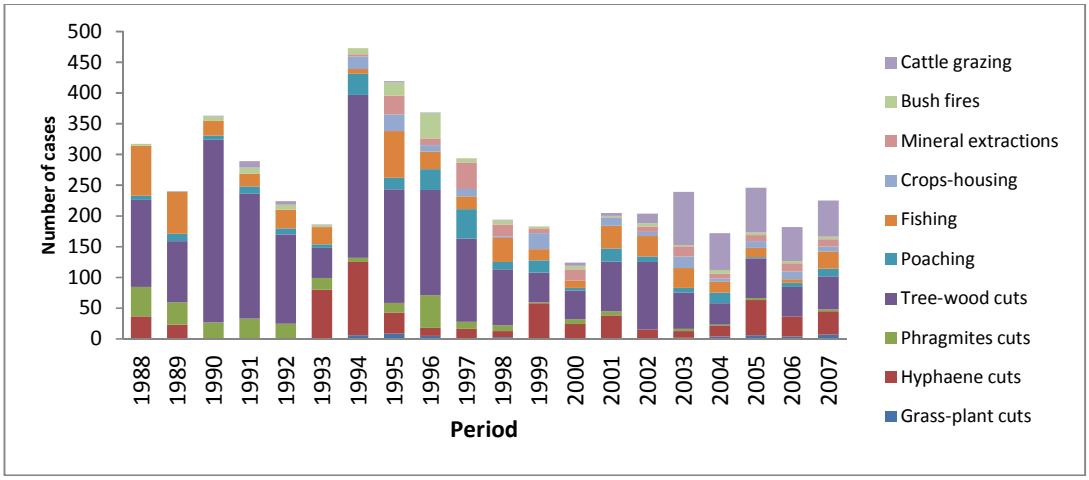

Fig. 6. Type and relative importance of illegal activities in palmeraie sector

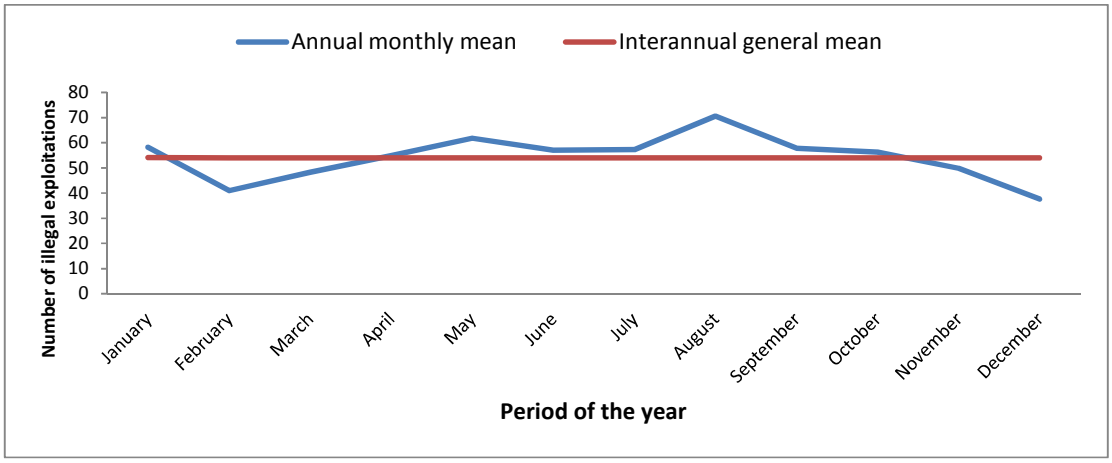

Fig. 7. Monthly distribution of the cases of illegal exploitations from 1988 and 2007

independence test (P-value = 0.00 < α = 0.05) showed that there is a significant link between the period and the type of illegal exploitations. With respect to tree-wood cuts and *Phragmites mauritianus* cuts that are the most frequent illegal exploitations, the ANOVA 2 test revealed the existence of three groups of homogeneous means. For the cuts of *Phragmites mauritianus*, the highest means were observed between 1988 and 1993, the moderate means between 1994 and 1997 and the lowest ones between 1998 and 2007. For tree cuts and dead wood collection, the highest means were recorded between 1988 and 1993, the moderate means between 1994 and 1998 and the lowest ones between 1999 and 2007. The significant decline of the number of cases of cuts of *Phragmites mauritianus* and tree cuts justifies the general decrease of illegal exploitations observed from 1998 onwards (Fig. 8). The ANOVA 2 test of the monthly number of cases of illegal exploitations showed that there are significant interactions between the number of illegal exploitations and the period of the year. The seasonal coefficients obtained by the "Holt-Winters Additive" method indicated that the most critical months or with a strong illegal activity (α > 0) are January, April, May, June, July, August, September and October. The months of August and May are those that experience the biggest threats with 71 and 62 cases of illegal exploitations, respectively. The other months of the year, namely February, March, November and December are less critical (α < 0) because their illegal activity is lower than the general monthly average of 54 cases of illegal exploitations (Fig. 7). The months of November and February have the lowest illegal activity, with 38 and 41 cases of illegal exploitation, respectively. The results showed that illegal exploitations are more important in dry season (May-October) than in rainy season (November-April). The seasonality of illegal exploitations constitutes an additional stress to the climatic stress that is already important for all natural resources in the dry season, as more as supervised exploitations are themselves seasonal. The χ^2 statistical test (P-value = 0.000 < α = 0.05) showed that there is a significant link between the guarding sectors and the types and number of illegal exploitations. Illegal exploitations are more frequent in Delta sector than in Palmeraie sector (Fig. 4). In Delta sector, *Phragmites mauritianus* and tree-wood cuts are dominating (Fig. 5) while in Palmeraie sector; tree-wood cuts are the most harmful illegal exploitations (Fig. 6). However, the interviews revealed that the Palmeraie sector is actually facing a great number of illegal exploitations that are unfortunately not reported due to prevailing insecurity, limited personnel and insufficient supervised exploitations. Products from illegal exploitations are found on different village markets that extend to a radius of 13 km from the protected area; 69% of them being fraudulent against 31% that are authorized. The results of interviews also showed that even authorized markets are regularly invaded by fraudulent products.

3.3 Discussion of Findings

3.3.1 Supervised exploitations

The supervised exploitations of natural resources launched since 1987 as part of the programs for public integration and community based conservation were continuously diversified and reinforced. The increase of the number of

supervised operators has been quite beneficial for the control of illegal exploitations until the 1993 civil war, despite the absence of previous studies on the stocks, reproducibility and evolution of natural resources (Fig. 1). After 1993 civil war, supervised exploitations gradually shifted from gracious and self-consuming exploitations against direct support in conservation, to increasingly overtaxed income generating exploitations. This evolution was made possible by the opening of authorized markets for timber and non timber forest products in some peripheral localities and the proliferation of fraudulent markets in others that favored illegal exploitations and the degradation of the park [15,16]. This result confirms the negative and perverse effects of the marketing of biodiversity that have been highlighted by other studies [44,45]. The limitation of the number of supervised operators and the approval of new beneficiaries by specific associations of operators against prohibitive membership fees also contributed to strengthen the merchant spirit of the participatory management by creating a degree of protectionism. Operating conditions and profit based on increasing taxation and strict regulation of resources exploitations have become important socio-economic issues for both supervised operators and the protected area's managers. In fact, since authorized exploitations of natural resources are supervised by the rangers to avoid or limit fraudulent

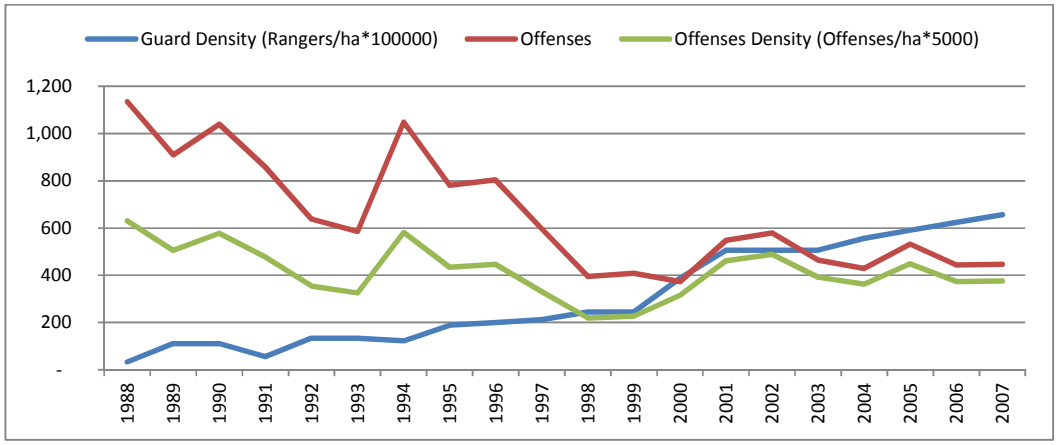

Fig. 8. Comparative evolutions of the number of offenses and management indicators

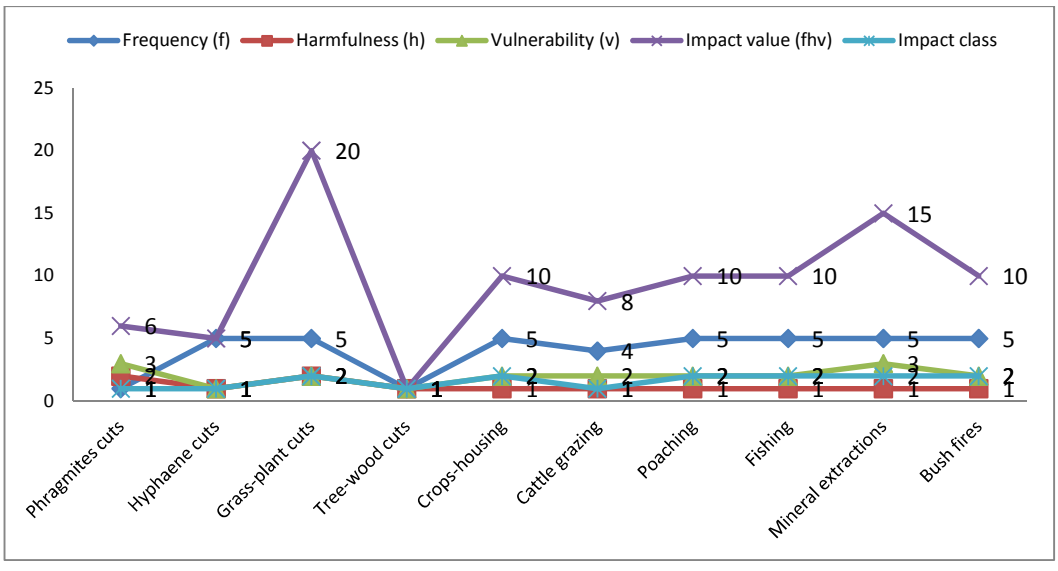

Fig. 9. Characteristics and impact classes of illegal exploitations from 1988 to 2007

exploitations by operators, the real commitment of integrated populations in favor of the conservation are somehow doubtable. The limited number of cases of offenders denouncing by supervised operators and local rangers as a result of corruption, intimidation and neighborhood complicity proves that the true partnership for conservation is still low and inefficient. Such situations have already been established in other African countries [12]. The protectionism of specific associations of supervised operators in the approval of new operators also reflects those complicities and negative solidarities. The increased taxation of supervised exploitations, the largely limited approval of new operators by associations of supervised operators and the contracting with individuals instead of entire peripheral villages [46,47] are therefore inappropriate responses to the challenges of conservation. These factors favor illegal exploitations as a result of the loss of income or the lack of access to income. Commercial supervised exploitations have somehow induced and legitimized illegal exploitations that have become more lucrative than the first ones which are strongly regulated, taxed and penalized in net income. Indeed, the results of interviews with supervised operators showed that the fraudulent products are sold at lower prices and faster than authorized and taxed products. They also indicated that some supervised operators are consequently moving to parallel fraudulent exploitations for increased income. The analytic results also showed that the proportion of supervised operators in the peripheral dependent population, which is one of the objective indicators of the public integration level [47], is insignificant to reduce human pressures and illegal exploitations, especially since supervised production is highly regulated, low and seasonal, and the most searched resource that is wood is self-consumed (Fig. 2). These evolutions highlight the limits of individualized participatory management to meet the population needs in products that have been demonstrated by other authors who are more favorable to village based conservation partnerships and contracts [46,47]. The seasonality of supervised exploitations that are more important in the dry season than in the rainy season is justified by the status and the availability of supervised operators. Indeed, most of supervised operators are basically rural farmers who do not find time for resources exploitation during agricultural campaign. They are only available for the activity after the crop harvest and during the school holidays that takes place in June-July. The great fluctuation of the number of supervised operators during the year is explained by the seasonality of supervised exploitations and the seasonality of the market demand for products.

3.3.2 Illegal exploitations

The findings indicated that the number of illegal exploitations has decreased between 1988 and 1993, when it started to rise up again, as shown in Fig. 4. The increase occurred as a result of the 1993 civil war that weakened the state authority, favored the settlement of armed groups and insecurity in the park and led to a significant concentration of displaced populations in and around the protected area. The adverse effects of the 1993 civil war were aggravated by recurrent underinvestment due to the cuts of budget in state subsidies and the freezing of external financing and a low guarding density of 4 rangers per 10 km² (Fig. 8) that limited the number of regular patrols and full notice of illegal exploitations, in a context of strong peripheral dependence on the park as shown by in-depth and recent studies [15,16]. They have also been reinforced by a considerable increase of the peripheral needs and demand in natural resources for construction, domestic energy and livestock that could not be satisfied by a very limited level of public integration of 8 beneficiaries per 10,000 inhabitants (Fig. 2). The statistical analyses showed that prior to the 1993 civil war, illegal exploitations were mainly limited to the cuts of *Phragmites mauritianus*, tree cuts and fishing in the lagoons of Delta sector. The civil war encouraged and intensified all kinds of illegal exploitations, such as cuts of various plants and vegetal resources, cattle grazing, mineral extractions, poaching and massive land clearings and crops since forest rangers are not armed like in many African countries [48,37]. Despite the cessation of the recordings of illegal exploitations since 2008, the monthly narrative management reports, the statistically significant increase in revenue from penalties and seizures after 2007, the proliferation of fraudulent markets in the periphery of the park and the results of interviews with the stakeholders confirmed the increase of illegal exploitations between 2008 and 2015. The strong negative correlation between the number of supervised operators and the number of illegal exploitations combined with the decrease of the number of supervised operators after 2007 (Fig. 1) also proved that the number of illegal exploitations has increased after 2007. The concentration of illegal

exploitations in the dry season (May-October) is stimulated by the end of competing agricultural activities, better climatic and physical conditions for the exploitation of natural resources, school holidays and a favorable market situation, especially for construction materials. In addition to these political and socio-economic factors, the high eccentric and irregular shape of the park characterized by a high asymmetry coefficient [16], its physical configuration in two separated geographical entities and the important length of the borders increase linear exposure and favor illegal exploitations. The existence of recognized or tolerated activities of agriculture (sugar cane, cotton, rice, palm oil) and livestock [Institut des Sciences Agronomiques du Burundi (ISABU) Livestock Station], the derisory character of the amount of penalties and the protection of the park by unarmed personnel are additional factors that increase the vulnerability and illegal exploitations. As it has been demonstrated by several studies in the context of increasing demography and poverty in the tropics [49,50,9, 51,52], the promotion of industrial crops and land clearings for domestic food exacerbates the deforestation and degradation of protected areas due to inappropriate cuts of vegetation resources and unsustainable resources extractions. The significant spatio-temporal variability of illegal exploitations revealed by statistical analyses demonstrates a great specificity of the socio-economic needs, the natural resources content, the vulnerability of the protected area and the opportunistic mobility of illegal exploitations as shown by previous studies [15,16]. Reference made to the prevention and management of illegal exploitations, the variation of the guarding density and of the number of illegal exploitations in opposite directions between 1988 and 1999 (Fig. 8), confirms the recurring argument from protected areas managers according which strengthened guarding personnel improves the control of illegal exploitations. Indeed, as already shown by other studies [47,12], the recruitment of additional local units with the revenues from natural resources exploitations and ecotourism is an interesting and complementary option to participatory management for protected areas sustainable conservation. After 1999, the effect of the improvement of the guarding density on the density of illegal exploitations is not obvious. As the guarding density increases, the density of illegal exploitations also increases before stabilizing (Fig. 8). This apparent paradox could be explained by the fact that the notice of illegal exploitations would have been better over a more limited area since the size of the park was reduced by 54% in 2000 after the distribution of crop land to local populations for agricultural and livestock activities. These findings showed that the density of illegal exploitations is a more relevant management indicator to consider than the absolute number of illegal exploitations when it comes to properly grasp the intensity of exploitation pressures that weigh on a given protected area. With regard to the nature and purpose of the products resulting from illegal exploitations, field observations and interviews showed that these ones are predominantly identical to the products generated by supervised exploitations and found on fraudulent markets since some supervised operators are at the same time engaged in illegal exploitations. The significant illegal exploitations of natural resources and the shift of supervised operators into illegal exploitations for commercial purposes indicate a visible failure of the participatory management that leads to a weak, inefficient and unsustainable conservation. This situation is as more worrying as we assist to a gradual replacement of illegal exploitations for survival by mass merchant exploitations that are however limited in number. Results from interviews showed that illegal operators are mostly female heads of households, landless and poor people, and jobless youth. They also confirmed the generalization of illegal exploitations, such as crop clearings and bush fires to almost the entire protected area.

3.3.3 Implications and recommendations for successful participatory management

The results of integrated analysis on supervised and illegal exploitations presented and discussed above made it possible to define more relevant strategies and options for successful participatory management in Rusizi national Park. The new strategies and options should be organized around the following axes: (1) the development of forestry and agroforestry projects in peripheral areas to provide energy substitutes and fight against deforestation, (2) the development of more intensive agricultural, livestock and fishing projects in peripheral areas to reduce agricultural conversions of the park, bush fires, overgrazing and illegal fishing, (3) the strengthening of the guarding of the park and of peripheral markets in the dry season to face the intensification of illegal exploitations through the recruitment of temporary staff with the revenues from the exploitations of natural resource and ecotourism, (4) the imposition of restrictions for the exploitation of natural resources in the dry

season to face the amplification of supervised exploitations and the climatic stress, (5) the significant reduction or the exemption of taxes for supervised exploitations, the promotion of self-consumption of natural resources and the discouragement of the marketing of natural resources, (6) the closure and relocation of various internal projects and activities that serve as pretexts for illegal exploitations, and (7) the substitution of individual and associations partnerships by inclusive and conditional village contracts for sustainable exploitation of natural resources and conservation, guarding sector by guarding sector.

4. CONCLUSION

The study aimed to develop and apply a multi-criteria method for the integrated scientific analysis of illegal exploitations of natural resources and the promotion of strategic participatory management of protected areas. The multi-criteria method based on theoretical analysis and a validation test led to interesting findings. The results showed that the Rusizi national Park used for the probatory test has experienced various and increased illegal exploitations between 1988 and 2015. Specifically, they indicated large interannual, seasonal and spatial disparities in the distribution of illegal exploitations that demonstrate the existence of critical sites and periods for the exploitations of natural resources extractions. They also revealed the negative impact of the 1993 to 2005 civil war on the multiplication and amplification of illegal exploitations, resulting in increased seizures and the proliferation of fraudulent markets in peripheral areas. They clearly showed the limits, or even the failure of the public integration for conservation based on direct and controlled exploitations of certain natural resources. Indeed, controlled exploitations have failed to reduce peripheral conflicts, to control illegal exploitations dominated by direct cuts of vegetal resources, to reduce the degradation by deforestation and to ensure sustainable conservation. The competition between agricultural campaigns and exploitations of natural resources for workforce leads to base the participatory management and sustainable conservation of the Rusizi national Park on a strategic agricultural and livestock development in the peripheral zones. Ultimately, the study highlighted the interest of the Multicriteria method for the integrated analysis of illegal exploitations and key management indicators such as participatory management activities, guarding density and financial capacities for the promotion of sufficient adequacy between participatory management investments and the real socio-economic needs of local populations. In this sense, the method and the analytic results will enable decision-makers and African protected areas' managers to develop skills for strategic participatory planning and management, in the context of climate stresses, great population growth and increased anthropogenic pressures.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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