

# Conservation Models Influence the Return on Investment in Rangers in the Grauer's Gorilla (*Gorilla beringei graueri*) Range in the Eastern Democratic Republic of Congo

Urbain Ngobobo<sup>1\*</sup>, Zo Hasina Rabemananjara<sup>1</sup>, Bruno Ramamonjisoa<sup>1</sup>, Augustin Basabose<sup>2</sup>

<sup>1</sup>Doctoral School of Natural Resource Management and Development, University of Antananarivo, Antananarivo, Madagascar

<sup>2</sup>Lwiro Natural Science Research Centre, Lwiro, South Kivu, D.R. Congo

Email: urbainngobobo@gmail.com, ungobobo@gorillafund.org

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## Abstract

The Grauer's gorilla is one of the species most affected by biodiversity degradation, and all the protected areas (PAs) in its range face management challenges (Plumptre et al., 2021). This research examines how the combination of rangers' capacity, conservation models, mode of governance, and the presence of armed groups influences the Return On Investment in Rangers (ROIR) for conservation in Grauer's gorilla range. ROIR is expressed in terms of site coverage rate, the level, extent, and trend of poaching in the PAs. The rangers represent investment. We collected data from 11 PAs in Grauer's gorilla range. Among the 11 protected areas (PAs), five are governmentally protected areas (GPAs) and six are community-protected areas (CPAs). Due to the small sample size, the analysis focused on descriptive statistics, including means and comparisons of means. Overall, we found that the rangers' density is low in Grauer's gorilla range (77.05 km<sup>2</sup> per ranger), which is very low compared to the overall average density of a forest landscape (25 km<sup>2</sup> per ranger). The rangers' capacity is also low in the Grauer's gorilla distribution area (22.6 km<sup>2</sup> per ranger). The rangers' capacity, as well as the ROIR, is influenced by several factors, including the presence of armed groups, conservation models, community engagement, and the holding of weapons by rangers. However, the factors studied in this chapter are not the only ones that influence either rangers' capacity and ROIR. However, the negative impact of armed groups on rangers' capacity ROIR can be alleviated or even aggravated by the local communities' collaboration, not by holding firearms by rangers. In conclusion, community forestry for conservation has a better ROIR overall than Fortress, with the highest site coverage rate, a low level of poaching and hunting, and a decreasing

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poaching trend, while the extent of poaching is the same in both Fortress and community forestry for conservation. Additionally, ForesCom is more resilient to the presence of armed groups than Fortress. Community forestry for conservation appears to be a viable option for expanding conservation efforts in Grauer's gorilla range, ensuring its control and combating poaching with a limited number of rangers.

### Keywords

Return in Investment, Grauer's Gorilla Range, Site Coverage Rate, Site Area, Conservation Model, Governance Mode, Nkuba Conservation Area, Fortress, Community Forestry, Protected Area

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## 1. Introduction

Biodiversity has deteriorated at an alarming rate worldwide, while conservation efforts to date have been largely insufficient to reverse biodiversity loss (Poisson, 2009). Area-based protection is a cornerstone of global efforts to conserve biodiversity. (Watson et al., 2014; Doumenge et al., 2015; Jones et al., 2018; Appleton et al., 2022) and associated ecosystem services (Stolton, 2015), maintain human health and welfare (Naidoo et al., 2019), and support unique human cultures (Juffe-Bignoli et al., 2014). The Convention on Biological Diversity's 2020 target (Aichi target 11') for protection of at least 17% of terrestrial and 10% of marine areas of significance for biodiversity conservation and ecosystem services has been almost met (Bingham et al., 2021) through formerly recognized governmentally protected areas (GPAs) and community-protected areas (CPAs), which are revealed as other effective conservation measures (OECMs). However, achieving the parallel target of managing these areas effectively has been far less successful (Maxwell et al., 2020). As governments pursue the "30 by 30" target of increasing the land and marine area covered by GPAs and OECMs to 30% and ensuring their effective control by 2030 (Hannah et al., 2020; WCPA, 2020; Krosby et al., 2023), addressing those factors that continue to challenge effective management of global protected areas is a critical requirement for preserving biodiversity and essential ecosystem services (Dinerstein et al., 2019; IPBES, 2019), achieving the relevant Sustainable Development Goals (SDGs) (Kettunen, 2021), and mitigating the effects of climate change (Bruner et al., 2001; Coad et al., 2019; Geldmann et al., 2019; Graham et al., 2021; Pörtner, 2021).

Only a minimal number of PAs worldwide, 24%, are effectively controlled, with both insufficient numbers of rangers and ranger capacity, or the surface area that one ranger can effectively patrol, widely recognized as significant limiting factors (Juffe-Bignoli et al., 2014; Baghai et al., 2018). This is because monitoring, coverage, and combating poaching rely mainly on ranger patrols (Geldmann et al., 2013; Nuno, Bunnefeld, & Milner-Gulland, 2017), as ranger patrols play a central

deterrent role in preventing illegal activities such as poaching (Geldmann et al., 2013). Thus, having sufficient and high-capacity rangers is fundamental for effective site control (Leader-Williams & Milner-Gulland, 1993; Gray & Kalpers, 2005; Belecky, Parry Jones & Singh, 2021; Kuiper et al., 2021; Singh et al., 2021; Anagnostou et al., 2022). However, ranger capacity is influenced by several factors, including the geographical accessibility of the site (determined by the terrain and size of the site), sociological factors (relations with local communities and armed groups), logistical resources (frequency of patrols and bush equipment), financial resources, a reasonable density of guards (number of rangers relative to site size) and ranger skills (ranger training) (Wyatt, Singh, & Belecky, 2022; Ngobobo et al., 2025). For example, a site facing equipment challenges, poor financial resources, or the presence of armed groups may experience reduced ranger capacity and consequently require increased ranger density to achieve adequate site coverage.

Given the persistence of constraints that have contributed to the failure of the parallel Aichi targets (Belecky, Singh, & Moreto, 2019; Belecky, Parry Jones, & Singh, 2021), the 30 by 30 targets may seem ambitious, unrealistic, and unattainable. However, this target is a boon for specific species and landscapes in areas that are not yet formally protected, as is the case for critically endangered Grauer's gorilla in the Democratic Republic of Congo, 74% of whose range is located outside the GPAs (Plumptre et al., 2015).

Unfortunately, existing GPAs in Grauer's gorilla range face serious management, coverage, and control issues, as well as poaching (Plumptre et al., 2017). Among the causes of these problems are insufficient numbers and capacity of rangers (Bruner et al., 2001; Mathys, 2017; Coad et al., 2019; Geldmann et al., 2019; Graham et al., 2021; Appleton et al., 2022), the presence of armed groups (Mathys, 2017), and the inappropriate size of the governmentally managed protected area (GPA) to ensure adequate site coverage (Brugière, Chardonnet, & Scholte, 2015; Chardonnet, 2019) in the context of funding shortages (Bruner et al., 2001; Anthony et al., 2015; Trigg & Tshimanga, 2020; Graham et al., 2021). For example, despite the launch of forest ranger patrols in 60% of the Greater Virunga landscape, these patrols were reported to effectively cover only 22% of the territory for various reasons (Plumptre et al., 2014).

With the priority of extending the Grauer's gorilla range conservation area beyond the APGs by incorporating new forests with high gorilla densities, other stakeholders argue that it is helpful to consider different models, such as CPAs, to ensure effective control and mitigate existing and potential threats to these great apes (Butchart, Di Marco, & Watson, 2016; Armsworth et al., 2018; Plumptre et al., 2021). However, none of these conservation models can claim to be uniformly effective across all landscapes, as effectiveness depends on the context and objectives (Albuquerque & Oliveira, 2007; Armenteras, Rodríguez, & Retana, 2009). Further, no studies have been conducted within Grauer's gorilla range to assess the effectiveness of different conservation models and governance modes or the factors associated with their performance, such as training, equipment, and insti-

tutional and social support. Contextualized studies of the effectiveness of different conservation models that consider ranger capacity are therefore needed (Crichtlow et al., 2017).

One approach to evaluate the effectiveness of different conservation models is the general criterion of “return on investment in conservation” (Kristen, Paul, & Bijay, 2019). However, conservation investment is multifaceted, encompassing land investment, guard investment, financial investment, and many other aspects. The present analysis focuses on Investment in ranger-based protection efforts (ROIR). High ranger capacity is essential for achieving a good ROIR at a site. When ROIR is considered adequate, site control rates are generally better, illegal activities are fewer and tend to decline, and wildlife populations increase. (Fischer et al., 2014). Related simulations show that higher ranger capacity improves the effectiveness of ROIR (Milner-Gulland & Leader-Williams, 1992).

The “return” on this investment can be assessed through indicators of threat levels (e.g., poaching) and wildlife diversity. These indicators provide one set of measures of the rangers’ capacity to control the site and combat poaching (Wilson et al., 2006; Buchanan, Donald, & Butchart, 2011).

In this article, investment in conservation is the ranger. Meanwhile, return on investment is measured using five indicators, including site coverage, poaching level, poaching extent, poaching trend, and poaching trend. Thus, the analyses in this chapter primarily focus on how and to what extent the ranger generates a return on investment, i.e., analyzing their effectiveness in site control and anti-poaching efforts.

Therefore, the primary objective was to estimate the ROIR of each conservation and governance mode within Grauer’s gorilla range and identify which mode has the highest ROIR with the fewest rangers. Thus, ROIR is used as a criterion to determine the most efficient conservation model and governance mode.

This study determines ROIR of different conservation models and governance modes in the Grauer’s gorilla range, as a measure of their effectiveness that can inform strategies to extend conservation efforts in the Grauer’s gorilla distribution area. First, as one approach to measuring a site’s “investment” in rangers, we assess the current number and density of rangers and site area patrolled per ranger in the Grauer gorilla distribution area. While “ranger capacity” is influenced by other constraints (e.g., financial resources, training, available equipment) that impact patrol effectiveness and agility, these quantitative measures are available for comparison across sites and provide a valuable starting point for assessing ranger investment. Second, we consider “return” on this investment in rangers through indicators of the level, geographic extent, and changes over time in both threats (e.g., poaching) and wildlife diversity within protected areas. Finally, we analyze whether different conservation models, modes of governance and presence/absence of armed groups are associated with differences in measures of ROIR, specifically to identify which conservation model is associated with the highest return from the smallest number of rangers.

## 2. Materials And Methods

### Study area

We collected data on 11 sites in Grauer's gorilla range in eastern DRC (**Figure 1**). Among the 11 sites, five are GPAs and six are CPAs. From the five GPAs, the state directly manages two through the Institut Congolais Conservation Nature (ICCN), Maiko National Park (PNM) and Itombwe Natural Reserve (INR); conservation organizations manage two others through a public-private partnership (PPP) governance mode, —Virunga National Park (PNVi) and Kahuzi Biega National Park (KBNP); and the last one is managed through another type of partnership between local communities and the Congolese state, the Kisimba Ikobo Primates Reserve (RPKI). Among the six CPAs, five are directly managed by the communities themselves, including the Oku Community Reserve (RCO), Usala Gorilla Reserve (RGU), Utunda and Wassa Gorilla Reserve (REGOUWA), Muhuzi-Buhinda Gorilla Reserve (RGMB), and Lubutu Gorilla Reserve (REGOLU), and the last one, Nkuba Conservation Area (NCA), is managed through a partnership between local communities and a non-governmental conservation organization and designated as a separate management entity (SEM) governance mode. (**Figure 1**).

### Data collection

In 2023, we solicited data from the managers of 11 PAs, all six CPAs, and chief park wardens for the five GPAs via a French questionnaire. The questionnaire included both open-ended questions and multiple-choice questions (see the questionnaire in the appendix). This questionnaire enabled us to collect information on the total surface area of the site; the surface area covered by ranger patrols in the site; the number of rangers; the level, geographic extent, and trends over time in poaching or hunting, and in wildlife abundance trends; and the presence of armed groups. We also collected data on the carrying of firearms by rangers during their patrols to assess the impact of carrying weapons on the rangers' ability to control the site and combat poaching. We finally collected data on collaboration between the site and local communities to assess the impact of local community collaboration on the site's capacity to control and combat poaching.

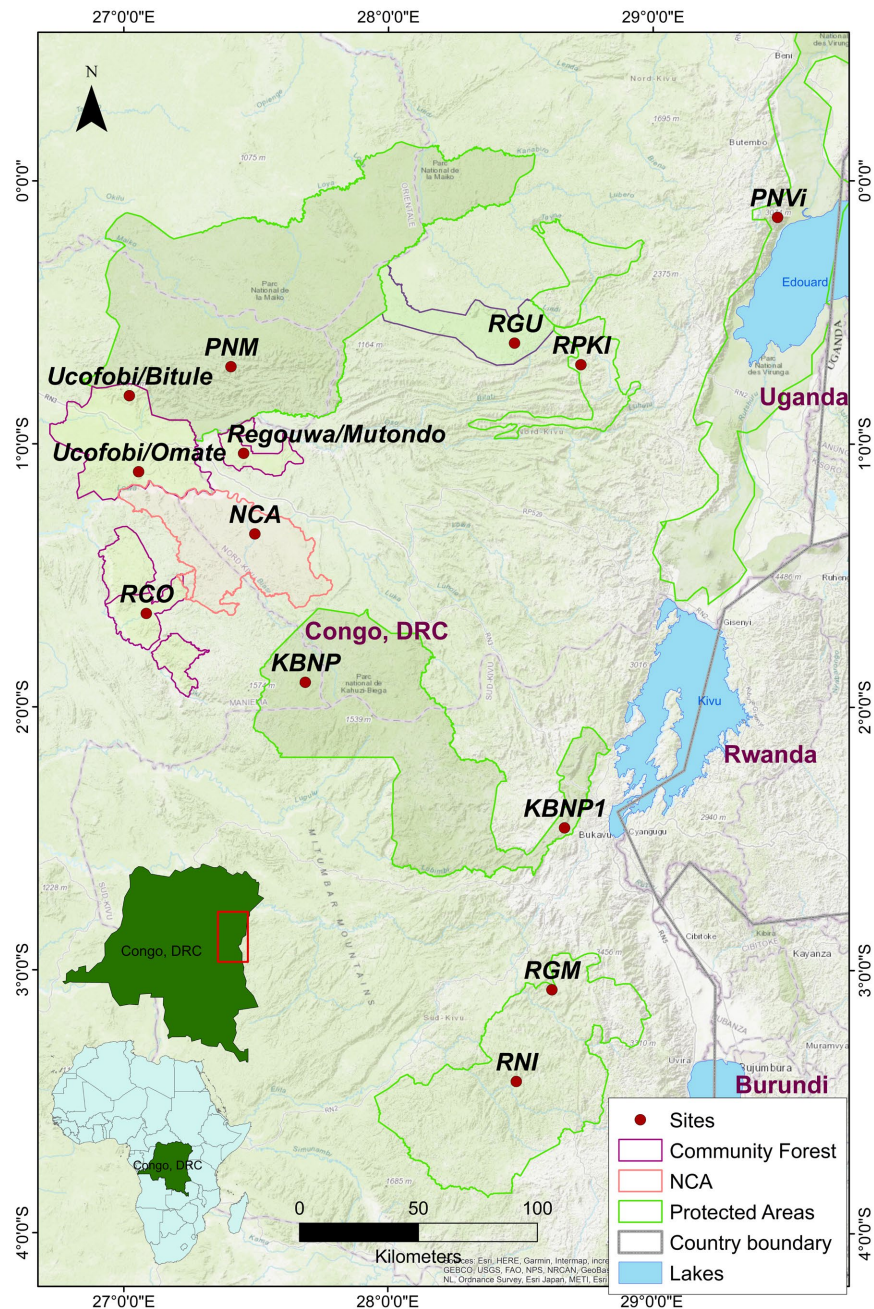
In this study, the term “ranger” is used in the sense recognized by the International Ranger Federation, which defines a “ranger” as a field-based member of a conservation team who monitors and manages species and ecosystems. (**Wyatt, Singh, & Belecky, 2022**). The “ranger patrol” refers to the mission carried out in forests by a team of rangers to collect data on evidence of illegal activity, counteract those activities, and record observations of biodiversity, animal behavior, and vegetation conditions. (**Gavin, Solomon, & Blank, 2010**).

### Data analysis

Based on the survey responses, we used the following measures to quantify ROIR, for each of the sites included in this study.

Measures of investment in rangers:

- 1) “Site coverage rate” (SCR) is the ratio between the area of the site covered by



**Figure 1.** Study area east of the Democratic Republic of Congo. The polygons delimited by green lines represent government-based protected areas (GPA), and the light red polygons represent community-based protected areas (CPA). Name of protected areas: NCA, Nkuba Conservation Area; KBNP, Kahuzi-Biega National Park; RNI, Reserve Naturelle Itombwe; RGMB, Reserve de Gorille de Muhuzi Buhinda; RCO, Reserve Communautaire de Oku; PNM, Parc National de la Maiko; RPKI, Reserve de Primates de Kisimba Ikobo; and RGU, Réserve de Gorille de Usula.

patrols and the total area of the site. It is expressed as a percentage (%). This is distinct from “site total area” (STA), which is the recognized total area of the site, irrespective of how much area is patrolled by rangers.

2) The “ranger density” (Rd) is the ratio of the site’s total area to the number of rangers on site, ensuring adequate coverage. We calculate ranger density by using the following formula:  $Rd = Nr/STS$ . In this formula, “Rd” is the ranger’s density, “STS” is the total size of the site in km<sup>2</sup>, and “Nr” is the number of rangers engaged in the site control task.

3) “Ranger capacity” (Rc) is the ratio of site-controlled area to the number of rangers on site. It was calculated by dividing the area of the site that is controlled or covered by the number of rangers on site using the following formula:

$$Rc = SCA/Nr.$$

In this formula, “Rc” is the ranger’s capacity to control/cover the area, “SCA” is the area controlled/covered in the site, and “Nr” is the number of rangers.

Measures of return on investment:

1) After receiving responses from our respondents, we categorized the level of poaching/hunting as follows: (1) very low (poses few or no obvious threats and negative impacts on the values and integrity of the site are likely to be minor), (2) low (poses some obvious threats, which are localized, but reversible negative impacts are anticipated), (3) high (poses a medium but obvious threat to the site, which may have localized negative impacts on the values and integrity of the site, but which may be reversible) or (4) very high (threats to the site are very high and current and/or predicted future impacts are likely to result in the irreversible loss of the majority of the values and integrity of the site). Where site managers did not provide such information, we classified the situation as “data deficient” (5).

2) We classified the extent of poaching/hunting as follows: (1) everywhere (affecting more than 50% of the surface area), (2) widespread (15% - 50%), (3) dispersed (5% - 15%), or (4) localized (less than 5%). If the distribution of these threats were unknown, we classified this as (5) unknown. Where there was no poaching or hunting, we classified this as (6) not applicable.

3) Trends in poaching and hunting over time were classified as increasing, decreasing, or stable. We employed the same classification for wildlife trends on the site.

Second, we sought to understand the relationship with local communities. Influences ROIR in Grauer’s gorilla range. Due to the limited number of sites in this study, we considered a limited number of independent variables (conservation model, governance mode, and presence of armed groups). We limited our analyses to a descriptive interpretation of our results.

Finally, we predict the number of rangers required to control and cover the entire GG area. This prediction is made in two scenarios based on the mean area patrolled per ranger across all sites representing each conservation model and governance mode. Thus, scenario (1) is based on the GPA model, while scenario (2) is based on the CPA model. When predicting the number of rangers needed to cover the entire Grauer’s gorilla range, we used 19,700 km<sup>2</sup> as the subspecies’ range size (Plumptre et al., 2016). We divided this area by the observed lowest, average, and highest areas patrolled per ranger for each conservation model and

governance mode.

To assess the capacity of rangers in the Grauer's gorilla range compared to the average capacity of rangers in a forested landscape (since Grauer's gorillas live in the forested landscape), we referred to the average coverage capacity of a ranger in the forested landscape reported in other studies, which is 25 km<sup>2</sup>/ranger (Bruner et al., 2001; Chomba et al., 2021; Appleton et al., 2022). Given the limited sample size (n = 11), we limited our analysis to descriptive statistics based on the means. Since we are comparing variables with unequal sample sizes (APC = 6, APG = 5), the variances are likely to be different. We therefore applied the Mann-Whitney U test, as it tests the null hypothesis that two independent samples come from the same distribution. (Hollander, Wolfe, & Chicken, 2015).

When sample sizes are small and normality is questionable, the Mann-Whitney U test provides a valid means of inference. When homoscedasticity (equal variances) is violated, the Mann-Whitney U test is more reliable than the t-test (Gibbons & Chakraborti, 2010). The comparison of means was used to determine the influence of the variables compared (Welch, 1947; Ruxton, 2006).

### 3. Results

#### Ranger density and area patrolled in Grauer's gorilla range.

Mean ranger density was 77 km<sup>2</sup>/ranger across the Grauer's gorilla range, but this varied substantially across APs (range 7.33 km<sup>2</sup>/ranger - 259.41 km<sup>2</sup>/ranger). (Table 1). When only the area actively patrolled within sites was considered, the mean area patrolled per ranger across the Grauer's gorilla range was 22.60 km<sup>2</sup>/ranger (range 4.0 km<sup>2</sup>/ranger - 51.18 km<sup>2</sup>/ranger).

When we consider the area patrolled per ranger across sites, there is substantial overlap in this measure between conservation models and the presence versus the absence of armed groups, collaboration with the local community and across sites where rangers do and do not carry weapons during patrols. However, some observed trends of these site characteristics are described below.

Firstly, armed groups are present in nearly all Grauer's gorilla range sites. Their presence is linked to a decrease in ranger sites and, consequently, a reduction in SCR (Figure 3). Mann-Whitney U test = -1.014, indicating a negative mean difference.

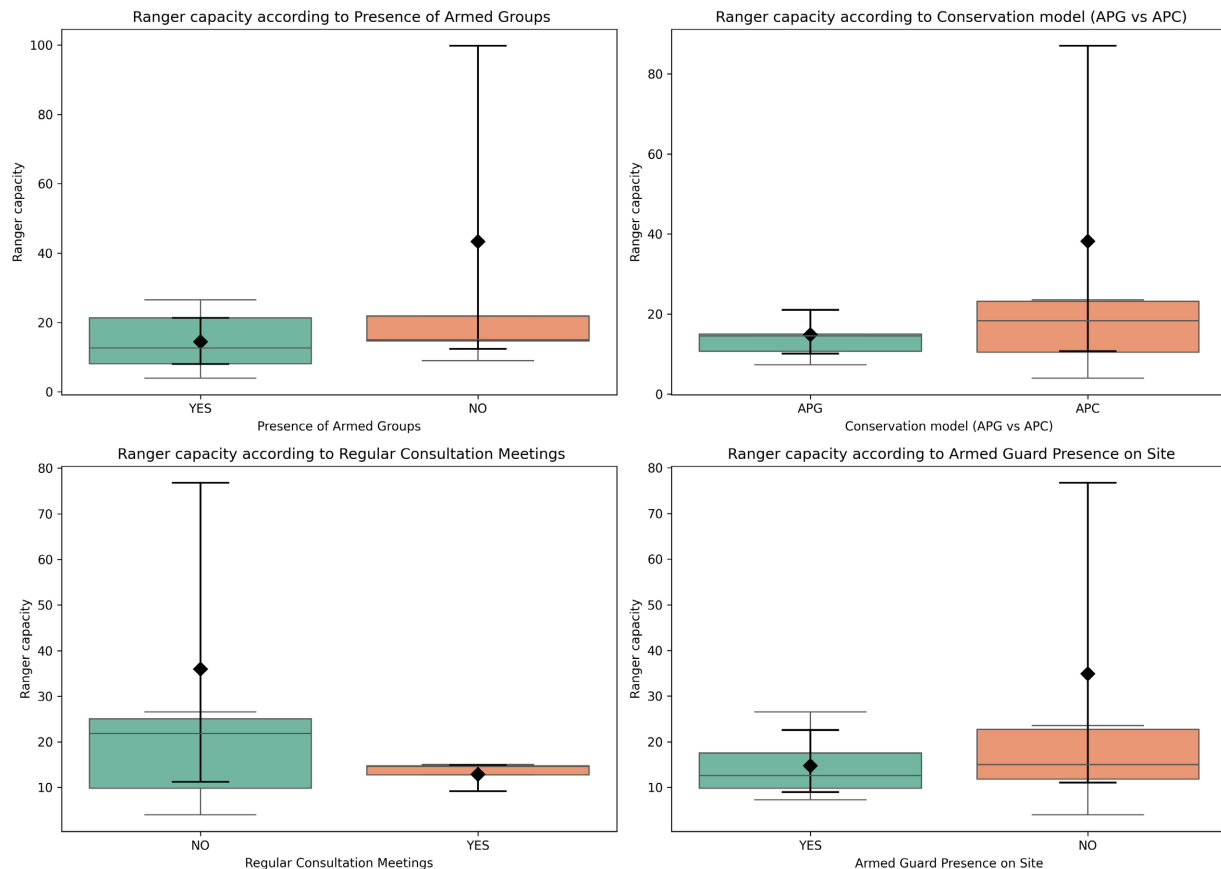
Nevertheless, in 80% of the GPAs where we collect data, rangers carry fire guns, while they do not in CPAs (Table 1). In contrast, most of the GPAs where rangers carry firearms for their patrol and protection. It appears that carrying weapons doesn't increase the area patrolled per ranger. In contrast, the test of the means reveals that when rangers carry weapons, their mean area patrolled per ranger is reduced (rangers' capacity). It is 14.77 Km<sup>2</sup>, compared to 34.87 Km<sup>2</sup>/ranger in the absence of firearms, a mean difference of 20.12 Km<sup>2</sup>/ranger (Figure 2).

Secondly, the conservation model is also associated with differences in the mean area patrolled per rangers, at 14.82 Km<sup>2</sup>/ranger across GPAs, compared to 38.18 Km<sup>2</sup>/ranger across CPAs (Figure 2).

**Table 1.** Results are grouped by GG conservation model and governance mode.

No	Site	CM	GM	RD (km <sup>2</sup> )	RC (km <sup>2</sup> )	SCR (%)	PAG	SOAG	RCGP	P/H level	P/H range	P/H Trend	Trend of wildlife
I													
I.1. PPP													
1	PNKB	GPA	PPP	19.05	17.87	56	Yes	1 - 10	Yes	High	Dispersed	Increasing	Stable
2	PNVi	GPA	PPP	10.44	5.29	50.63	Yes	11 - 20	Yes	High	Dispersed	Increasing	Decreasing
	Average	GPA	PPP	14.75	11.55	53.31							
I.2. ICCN													
1	PNM	GPA	ICCN	108.7	18.48	16.99	Yes	41 - 50	Yes	Very High	Dispersed	Increasing	Increasing
2	RNI	GPA	ICCN	238.83	45.38	19	Yes	1 - 10	Yes	Very High	Generalized	Increasing	Increasing
	Average	GPA	ICCN	173.77	31.93	17.69							
I.3. Community Forestry of Conservation (CFC)													
3	RPKI	GPA	community		15	65.69	Yes	11 - 20	No	Very High	Dispersed	Decreasing	Stable
			Average GM		15								
			Average GPA	82.55	20.4	41.6							
			Etendue	[10.44 - 238.83]	[5.29 - 45.38]	[17 - 65.7]							
II													
II.1. SME													
1	NCA	CPA	SME	30.34	27.43	90.4	No	NA	No	Low	Dispersed	Decreasing	Increasing
			Average SME		27.43	90.4							
II.2. CM													
1	RCO	CPA	CM	259.41	51.18	19.73	No	NA	No	High	Dispersed	Decreasing	Increasing
2	RGMB	CPA	CM	72.5	35.25	48.62	Yes	21 - 30	No	High	Dispersed	Decreasing	Decreasing
3	REGOUWA	CPA	CM	7.33	4	54.55	Yes	11 - 20	No	ND	Dispersed	Stable	Stable
4	RGU	CPA	CM	43.69	14.44	32.97	Yes	1 - 10	No	High	Dispersed	Decreasing	Stable
5	REGOMOKI	CPA	CM	21.52	14.27	66.26	No	NA	No	ND	Dispersed	Decreasing	Stable
			Average CM	71.22	23.59	47.98							
			Range	[7.33 - 259.41]	[4 - 51.18]	[19.73 - 66.29]							
			Average CPA	72.47	25.66	52.1							
			Range	[7.33 - 259.41]	[4 - 51.18]								
			Average across the Grauer's gorilla zone	77	22.6	47.3							
			Range	7.33 - 259.41]	[4 - 39.55]	[17 - 90.4]							

Abbreviations: CM, Conservation Model; GM, Governance Mode; RD, Ranger Density; RC, Ranger Capacity; SCR, Site Coverage Rate; PAG, Presence of Armed Group; SOAG, Size of the Area Occupied by the Armed Group; RCGP, Rangers Carry Gun During Patrol; H/P Level, Hunting or Poaching Range; Trend of Poaching; and Trend of Wildlife. GPA, Government Protected Area; CPA, Community Protected Area; PPP, Public-Private Partnership; SME, Separate Management Entity.

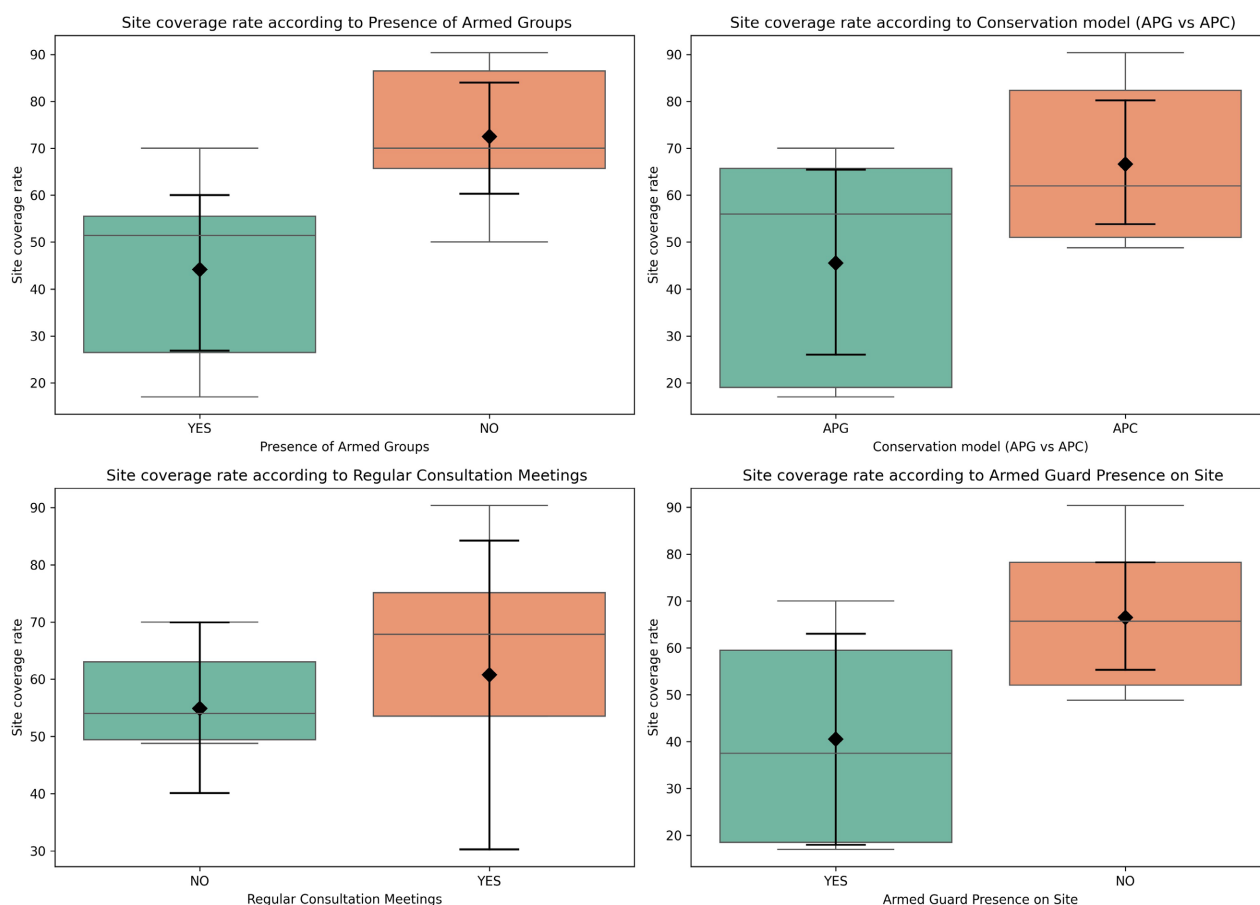


**Figure 2.** Area patrolled per rangers across sites, with: the presence of armed groups (upper left), conservation models (upper right) consultation meetings with local communities, and guards carrying weapons (lower right). The line in the center of the box represents the median, and the extreme points show individual values (or outliers). The dark black horizontal line represents the confidence interval around the mean in the ellipse. Legend: **Figure 2** illustrates the variation in guard capacity in relation to socio-security and institutional factors. The box plot illustrates the distribution of guard capacity according to several contextual variables, including (i) in the top left, the presence or absence of armed groups; (ii) in the top right, the type of conservation model implemented in the PA (APG, APC); (iii) bottom left, represents the presence or absence of regular consultation meetings with local communities; and finally, bottom right, illustrates whether or not guards carry firearms. Each box represents the interquartile range (IQR), with the horizontal line indicating the median. The black diamond corresponds to the average guard capacity, while the black vertical bar in the centre of the diamond represents the 95% confidence interval of this average. This graph highlights the potential influence of security conditions, the conservation model, local consultation and the carrying of weapons on operational guard capacity.

Thirdly, consultation meetings between the PAs and local communities are associated with a higher mean area per ranger ( $35.94 \text{ km}^2/\text{ranger}$ ) compared to sites without these meetings ( $12.89 \text{ km}^2/\text{ranger}$ ).

The means (and medians) vary between groups, but the standard deviations are large, and the sample sizes are small, which explains the lack of significance in the previous tests.

The mean SCR across the Grauer's gorillas' range is 47.3% (**Table 1**). However, comparisons across groups of sites suggest that factors such as the presence of armed groups, the conservation model, consultation meetings with local communities, and the carrying of weapons by rangers may be associated with variation in SCR (**Figure 3**).



**Figure 3.** Graphical representations of the different average ROIR under the influence of external factors: presence of groups, weapons, guards carrying weapons, conservation models, and consultation meetings with local communities. Legend: **Figure 3**, variation in coverage rates under the influence of socio-security and institutional factors. The box plots illustrate the distribution of site coverage rates (%) according to various contextual factors, including (i) in the top left, the presence or absence of armed groups; (ii) top right, the type of conservation model implemented in the PA (APG, APC); (iii) bottom left, the presence or absence of regular consultation meetings with local communities; and finally, bottom right, whether or not guards carry firearms.

Firstly, the mean ROIR-based SCR across sites characterized by the presence of armed groups is 44%, compared to 72% in the absence of armed groups.

The carrying of firearms by rangers on patrol is not associated with an increase in the area patrolled by rangers; in fact, we observe the opposite pattern. With firearms, the mean SCR is 40%, whereas without weapons, it is 66%. Meanwhile, it shows that the presence of armed groups accounts for 14.76% of the causes of unorganized patrols on the site or the lack of deployment in specific site compartments, which decreases rangers' capacity by 30.77% (**Figure 3**).

Secondly, the conservation model may also be associated with variation in SCR; the mean SCR across GPA sites is 45%, compared to a mean of 66% across CPA sites. The same applies to collaboration with local communities. Across sites where consultation meetings with communities are held, the mean SCR is 60%. In contrast, at sites where these meetings are not held, the mean SCR is 54%.

Each box represents the interquartile range (IQR), with the horizontal line in-

dicating the median coverage rate for the site. The black diamond corresponds to the mean, and the black vertical bar crossing the diamond indicates the 95% confidence interval of this mean. This graph highlights the differences in coverage levels based on the influence of the presence of armed groups, the conservation model, consultation with local communities and the carrying of weapons on the operational capacity of the guard.

In each graph in **Figure 3**, the line in the center of the box represents the median, and the extreme points show individual values (or outliers). The dark black horizontal line represents the confidence interval around the mean in the ellipse.

The means (and medians) vary between groups, but the standard deviations are large, and the sample sizes are small, which explains the lack of significance in the previous tests.

#### ***Required number and density of rangers to control/cover the Grauer's gorilla range***

**Based on the** observed area patrolled per ranger across sites, we estimate that covering the entire Grauer's gorilla area using the GPA model would require significantly more rangers (966 rangers) than under the CPA model (768 rangers). Furthermore, the PPP mode of governance requires the largest number of rangers to control the entire Grauer gorilla range, with 1,705.63 rangers. In contrast, the government governance mode requires the fewest in the area (616.97 rangers).

## **4. Discussion**

This study assessed the return on ranger investment across the Grauer's gorilla range, as it may vary with conservation models, modes of governance, the presence of armed groups, and other related factors. While this is a preliminary study based on a limited number of sites for which data were available, it is a valuable step towards determining the most effective strategies for expanding conservation efforts throughout Grauer's gorilla range.

#### **Ranger investment in the GG range**

While many factors influence ranger capacity (e.g., including available training, equipment, and funding), we determined the current number and density of rangers, and site area patrolled per ranger, across protected area sites to estimate additional investment in rangers that would be required to expand coverage of protection efforts across the Grauer's gorilla distribution area.

With a mean ranger density of one ranger per 77 km<sup>2</sup> across all protected area sites considered here, ranger density was low throughout the Grauer's gorilla range compared to the standard average range density in global forest landscapes of 25 km<sup>2</sup> per ranger (Bruner et al., 2001; Chomba et al., 2021; Appleton et al., 2022). There was substantial variation in ranger density across sites, and overlap in this measure between GPA and CPA sites, except in the two GPAs with PPP governance mode, which had a higher ranger density than the average ranger density of global forest landscapes (25 Km<sup>2</sup>/ranger) (Bruner et al., 2001; Chomba et al., 2021; Appleton et al., 2022); All the other governance modes had a lower rang-

ers' density.

All sites examined here had ranger densities below the 5 km<sup>2</sup>/ranger density recommended by the 2016 World Conservation Congress of the International Union for Conservation of Nature (IUCN) (IUCN, 2016). The ranger density in Grauer's gorilla range reveals that there is a lack of rangers in this area, but also an ineffective distribution throughout PAs; some have more than needed, while others have insufficient numbers. However, ranger insufficiency is not exclusive to the Grauer gorilla range; other research has shown the insufficiency of ranger numbers in protected areas worldwide (Belecky, Parry Jones, & Singh, 2021; Wyatt, Singh, & Belecky, 2022). In Africa, the average density of rangers is 76 km<sup>2</sup>/ranger, i.e., 51 km<sup>2</sup> more than is recommended for effective control (Appleton et al., 2022).

Therefore, in many countries, the limited number of rangers has been identified as a main factor contributing to insufficient site coverage and control. If not addressed, this will undermine the Aichi goals of protecting 30% of the planet with protected areas (PAs) and OECMs (Appleton et al., 2022). It has already been recognized as the reason for the failure of the parallel Aichi Objective 11 (Bruner et al., 2001; Mathys, 2017; Coad et al., 2019).

The results indicate a relationship between ranger density and ROIR; sites with low ranger density tended to have a low SCR ( $R = -0.024$ ) and higher rates of poaching. This relationship between ranger density and ROIR in Grauer's gorilla range confirms other results indicating that rangers play a crucial role in site coverage and addressing poaching in APs (Gray & Kalpers, 2005; Kuiper et al., 2021; Singh et al., 2021; Anagnostou et al., 2022). Therefore, insufficient ranger density can prevent the drive from expanding APs in the Grauer's gorilla range from being achieved.

However, despite this relationship between ranger density and ROIR, some PAs have an exceptionally high (e.g., NCA) or low (e.g., MNP and RGU) SCR relative to their rangers' density.

In Grauer's gorilla range, some sites have higher coverage rates, and others have lower coverage rates than the predicted rate based on their ranger density. This confirms that the high or very low ROIR could be due to multiple cumulative effects (Lonn et al., 2018; Ngobobo et al., 2025).

The average ranger capacity of the Grauer's gorilla range, specifically in the GPA (fortress conservation model), is lower than that of forest landscapes (25 km<sup>2</sup> per ranger). In contrast, the rangers' capacity in CPA (community-based forestry) is almost equal to the average rangers' capacity in the global forest landscape (Table 1). To assess the capacity of rangers in the Grauer's gorilla distribution area in relation to the global average rangers' capacity in forest landscapes, this study referred to the international standard average coverage capacity of a ranger in a forest landscape, which is 25 km<sup>2</sup>/ranger (Bruner et al., 2001; Chomba et al., 2021; Appleton et al., 2022).

Our analysis also shows that rangers' capacity influences ROIR in Grauer's go-

rilla range, particularly at the level of the conservation model. The global low ranger capacity of the Grauer's gorilla range and the fortress model may explain its low ROIR (coverage rate and poaching level, range, and trend); therefore, the high ranger capacity in community conservation forestry may explain its high ROIR (coverage rate). The results confirm our assumption of the relationship between rangers' capacity and ROIR in the Grauer gorilla range ( $P = 0.052$ ). Previous studies conducted outside Grauer's gorilla range have already established this relationship, confirming that low ranger capacity is a major limiting factor in site control capacity (Coad et al., 2019; Belecky, Parry Jones, & Singh, 2021; Wyatt, Singh, & Belecky, 2022).

However, rangers' capacity is affected by several other factors. Among those analyzed in this study, the presence of armed groups is the factor that most affects rangers' capacity in Grauer's gorilla distribution area. It reduces rangers' capacity to 28.85 km<sup>2</sup>/ranger (Figure 2). The presence of armed groups makes the site control strategy ineffective in the APGs, where rangers carry firearms during their patrols. Instead of contributing to improving rangers' capacity, it further reduces it to a range of 20.12 km<sup>2</sup> per ranger (Figure 2). This is why, even among the factors influencing the ability to carry weapons analyzed in this study, holding a gun is the one with the smallest difference in mean values.

In a context of militarization, any armed man is considered a target by others armed group which like to neutralize them to have control of the area that they curb in the AP, while unarmed guards, as is the case in community forestry conservation CPAs, go about their activities without being direct targets of other armed groups in their PAs.

In addition to the presence of armed groups, the conservation model also plays a role in rangers' capacity. The results of this study show that in the Grauer gorilla range, the influence of the fortress on rangers' capacity is negative compared to that of community forestry conservation, which lifts the rangers' capacity. This can be explained by the fact that rangers in CPAs of community conservation forestry seem to be a continuation of customary rangers or community conservation, which protected their forests based on customary principles. With the advent of the conservation model known as community conservation forestry, a dose of modern conservation principles and wildlife management rules, along with adequate means and techniques, has been introduced. However, the advent of the fortress is still poorly perceived and opposed by local communities. Although the conservation model generally plays a role in retention capacity, the specifics depend on the governance mode. In the Grauer's gorilla range, two modes of governance from two different conservation models have rangers' capacities higher than the average ranger's capacity of the forest landscape, including the government governance mode under fortress (31.93 km<sup>2</sup> per ranger) and the SEM governance mode under community forestry of conservation (27.47 km<sup>2</sup> per ranger). In contrast, two other different governance modes form two different conservation models, have a rangers' capacity below the average rangers' capacity of the

forest landscape, including the PPP governance mode in the fortress (11.55 km<sup>2</sup> per ranger) and the community governance mode in the community forestry of conservation (23.59 km<sup>2</sup> per ranger). However, the rangers' capacity for community governance is closer to the average capacity of rangers in the forest landscape.

Additionally, the involvement of local communities is crucial to enhancing conservation capacity. PAs that organize consultation meetings between sites and local communities tend to have higher conservation capacity than sites that do not (Figure 3). However, there are significant disparities in the rangers' capacity for governance modes within the same conservation model. For example, in the GPA (fortress), the rangers' capacity of the PPP is lower than that of the GPA (fortress) managed directly by the government. It is also the weakest of the Grauer's gorilla range, whereas GPA is managed directly by the government and has the highest rangers' capacity of the Grauer's gorilla range. Therefore, we find the lowest and highest ranger's capacity in the same conservation model (fortress).

Similarly, in community forestry for conservation, the rangers' capacity of CPAs under the community governance mode is lower than that of the SEM governance mode, even though they share the same conservation model. We observed that rangers' capacity results from a combination of several factors.

The ranger capacity varies enormously within both fortress GPA and community forestry of conservation CPA conservation models and governance modes. However, the highest ranger capacities were found in CPA sites. SCR averages 47.3% across the Grauer's gorilla range, with the highest SCRs found in CPAs (90.4%, range = 19.7% - 90.4%) compared to GPAs (17.0%, range = 17.0% - 65.7%). These differences are one of the reasons why APGs under PPP, despite having the lowest rangers' capacity of the Grauer's gorilla range, have a good ROIR compared to some APs that exceed them in gross rangers' capacity. We found that some sites with low ranger capacity, which have high ROIR (e.g., VNP and KBNP), while other sites (e.g., RNI, RCO, and RGMB) had high ranger capacity but low site coverage. This difference is not an anomaly but rather highlights the difference between theoretical capacity and practical capacity, with the latter influencing ROIR.

The weaknesses in rangers' capacity are widely acknowledged to be a key factor undermining the ROIR (Coad et al., 2019; Minang et al., 2019; Belecky, Parry Jones, & Singh, 2021; Graham et al., 2021; Remme et al., 2021; Wyatt, Singh, & Belecky, 2022; Smith et al., 2023).

#### ***ROIR and other influencing factors in Grauer's gorilla range***

Ranger capacity plays a key role in ROIR. However, it is subject to the influence of several factors.

The rangers' capacity alone cannot explain or generate a high or low ROIR. Unlike ROIL (Ngobobo et al., 2025), ROIR is more influenced by several factors that are not addressed in this chapter. This is why there are differences in rangers' capacity when they analyze integrated other factors, such as the presence of armed groups, the conservation model, the collaboration of the local community, and the

carrying of weapons by the rangers during their patrols. This finding aligns with the results of previous research. (Laudari, Aryal, & Maraseni, 2020; Smith et al., 2023) which shows that, in some context, gross rangers' capacity is not the only factor influencing ROIR. Many other factors can positively or negatively affect the effect of rangers' capacity to deliver high ROIR, including security factors, funding factors, site size factors, management factors (Bruner et al., 2001; Mathys, 2017; Coad et al., 2019; Geldmann et al., 2019; Graham et al., 2021).

Firstly, the presence of armed groups has a significantly negative impact on the ROIR in Grauer's gorilla range (Figure 3). The presence of armed groups limits the ROIR in Grauer's gorilla range by undermining the rangers' ability to effectively patrol and control the site and address the poaching by restricting their deployment capacity. This negative impact of the presence of armed groups on the ROIR has already been noticed by other studies outside Grauer's gorilla range (Plumptre et al., 2015; Mathys, 2017). This result is confirmed by the (correlation [ $p = 0.026$ ], dependency [ $\phi = 3.813$ ], and even a strong dependency [Gramer's  $V = 0.813$ ]). The GPAs are more affected by the presence of armed groups than the CPAs. (Mcclanahan et al., 2008; Ervin et al., 2010; Allan et al., 2015; Lonn et al., 2018). In the Grauer's gorilla range, the PPP governance mode is the most vulnerable to the presence of armed groups (Walker, 2020). Most of the GPAs under the PPP governance mode in the fortress have several areas that have become virtual and exist only on paper (also depicted as "paper parks") (Chardonnet, 2019). This is the case of Virunga National Park, where areas are occupied by various armed groups, including the most famous, the M23, and several factions of the Mai-Mai armed group. Like the Kahuzi Biega National Park, farmers obstructed the ecological corridor, and other armed groups associated with the Pygmies controlled and cut down trees in many park areas. Apart from RPKI, other GPA under government management is also affected by the presence of armed groups; However, in the Maiko National Park, areas were, initially occupied by the Simba rebels before other armed group invested some area of the site for different purposes as is the case for RNI which was occupied by local communities before seeing armed group came. The presence of the armed group decreases the rangers' capacity to control the site and address the poaching there. This led to the almost total collapse of control of the APs, with the slowing down or even cessation of control activities in some PAs. Therefore, the presence of an armed group negatively impacts the ROIR of the site (site coverage rate and addressing poaching). All sites where wildlife populations are stable or increasing do not harbor armed groups (Ngobobo et al., 2025).

The results of the current study are consistent with other studies, which show that the presence of the armed groups in an AP limits the capacity of rangers to fulfill their mission, then its negatively impacted on their capacity to deliver good ROIR differently (Mcclanahan et al., 2008; Ervin et al., 2010; Allan et al., 2015; Lonn et al., 2018). The presence of armed groups in the PAs prevents rangers from covering the entire area of the PA with patrols, because they create inaccessible

zones within the PAs and/or cause the cancellation of already scheduled patrols. This makes it difficult for rangers to achieve a good ROIR, as they will not be able to ensure a good SCR and reduce the level, extent, and trend of poaching or hunting, which is necessary to allow for the restoration of wildlife and its ecosystem.

Furthermore, carrying weapons has proven ineffective in increasing the ROIR in Grauer's gorilla range (**Figure 3**). It does not enable rangers to increase site coverage in the area or change poaching trends. In contrast, it exacerbates the problem because carrying weapons makes rangers direct targets for armed groups in the sites. This is most evident in Virunga National Park, which for a long time had a well-trained, well-equipped, and well-paid elite ranger unit called the Quick Response Force (QRF), which was transformed into the Mobile Support Unit (UMA in french), with a permanent paramilitary training center, but which stands by helplessly as large parts of the site are occupied by the local and foreigner communities and armed group such as M23 which deteriorated of its flora and fauna. The same is true of Kahuzi-Biega National Park, where some part of its lowland sector is inaccessible, occupied by an armed group, while the highland sector is the epicenter of charcoal despite the presence of armed rangers (Yamagiwa, 2003; Simpson & Pellegrini, 2023), whereas the sites where rangers do not carry weapons have nevertheless managed to expand the conservation coverage of their sites exponentially, convince armed groups to leave the site, and maintain patrols there. This is the case, for example, in the Nkuba Conservation Area, where the local community has set itself up as guardian of the facilities (base, stations, and patrol posts) of the Dian Fossey Gorilla Fund and maintains community patrols in the forests during the installation of riverside communities in the NCA, where they have taken refuge to flee the recent takeover of Walikale by the M23.

This study shows that the most vulnerable and least resilient mode of governance is governance through the PPP.

Secondly, the conservation model affects the ROIR in Grauer's gorilla range. This influence is positive in CPAs and negative in the GPAs. CPAs seem to have a positive effect on the ROIR than the GPAs. One of the reason of that is most of the GPAs already had conflictual relations with the local communities for several reasons, including the feeling that the creation of GPAs led to land expropriation without adequate compensation, exclusion, non-respect of ancestral rights and human rights, and the restriction of access to natural resources, all of which created frustrations and led to numerous conflicts (Poisson, 2009). Taking advantage of the proliferation of guns and weakening of the DRC state over the last 20 years, some local community members have turned into armed groups pretexting the protection of their forests and lands against spoliators, who pretend to be GPAs' rangers and other GPAs staff members, who have looted their forests turned into parks. Therefore, local communities often obstruct or take action to hinder rangers' efforts to control the site and address illegal activities, such as poaching. Whereas, in community forestry for conservation, communities consider CPAs as their forest, and the rangers recruited from their community are considered their

representatives in the organization that manages their forest in case of SEM. In CPA, as is the case in the NCA, most rangers are recruited from the local community and are considered by armed group members as their relatives. Their work in the forest is regarded as a continuous form of customary forest conservation. This gives rangers in ForesCom the advantage of increasing their control capacity and site ROIR while undermining the ranger capacity and the ROIR in the fortress.

In addition, in the fortress, as is an under government control model, the armed groups take on the role of public authority, creating confusion to the point where it is difficult to distinguish between state, non-state, and extra-state actors and issuing rules that sometimes offend the management principles of certain entities such as PAs, as is the case for the Virunga National Park in the DRC (Marijnen, 2018). Thus, despite the goodwill and competence of rangers, the situation is becoming increasingly complicated in this context of militarization, which transnational actors have long supported. (Daskin & Pringle, 2018; Marijnen, 2018), to implement conservation planning (Réginas Ndayiragije, Sahawal Alidou, & Geenen, 2021).

Thirdly, community engagement can mitigate the negative impact of other factors on the ROIR, reducing it from 0 to 6% (Table 2, Figure 3). Community engagement is a crucial factor in ROIR, as it empowers local communities to take ownership of conservation actions. This is crucial in the context of the militarization of the civilian population and mistrust between specific conservation models and local communities, who feel excluded from the management of PAs and their access to them, given that these forests belonged to them before being expropriated by governments to create exclusive PAs.

**Table 2.** Current Grauer's gorilla the ranger situation and estimates of rangers needed to control site area in different scenarios.

Category	STS (km <sup>2</sup> )	Number of rangers	Current situation			Prediction for the whole GG range (19700 km <sup>2</sup> )	
			Site size covered (km <sup>2</sup> )	Ranger density (rangers per km <sup>2</sup> )	Area patrolled per ranger (km <sup>2</sup> )	Current deficit in ranger	predicted ranger number
GG range	3817.24	122	1442.57	77	22.6	46.90	871.68
GPA	6394.4	228	2249.4	82.55	20.4	85.45	965.69
CPA	1669.61	33	803.55	72.47	25.66	32.07	767.73
GM/ICCN	8301	62	1468.49	173.77	31.93	197.97	616.97
PPP	7000	477	3680	14.75	11.55	129.06	1705.63
CM	1488.29	30	583.19	71.22	23.59	33.09	835.10
SEM	2457	81	2222.19	30.34	27.43	8.57	718.19

Legend **Table 2:** STS is the total size of the site, GG is Grauer's gorilla, GPA is government-based protected area, CPA is community forestry, GM is government Management, ICCN is Institut Congolais pour la Conservation de la Nature, PPP is a public-private partnership, CM is community Management, SEM is a separate Entity Management.

### ***Prediction of the number and density of rangers required to control/cover the GG range***

The analysis results indicate that the ranger deficit tends to be more significant in the conservation model and governance mode, where the ROIR is low. It can also be seen that ranger density does not influence the state of ranging at the site (ranger sufficiency or ranger insufficiency) but rather the ROIR.

The estimated ranger deficit and the prediction made for each conservation model and governance mode mask wide variations within sites.

This estimate is close to most published recommendations for rangers' densities in forest landscape protected areas (**Table 2**) and suggests that most national protected area systems are severely understaffed (**Table 1**). Using these densities, we can calculate the number of forest rangers needed if the area's coverage increases from its current coverage rate (**Table 2**) to 100% coverage. We anticipate a need for approximately 872 rangers across the entire region, based on the average ROIR of the GG range. However, this requirement varies according to the ROIR of each conservation model and governance mode.

## **5. Conclusion**

This chapter examines the return on investment in rangers in Grauer's gorilla range. Preliminary analyses of rangers' density and capacity, the ROIR (site coverage rate, level, extent, and trend of poaching/hunting, and the trends of wildlife) in Grauer's gorilla range.

In conclusion, rangers' density is very low in Grauer's gorilla range (77 km<sup>2</sup> per ranger). This weakness is not related to the conservation model, but rather to the mode of governance. PPP AGPs have a high rangers' density (14.75 Km<sup>2</sup>/ranger) and SEM APCs have relatively good density (30.34 Km<sup>2</sup>/ranger). Meanwhile, APGs managed by the state itself (173.77 km<sup>2</sup> per ranger) and APCs managed by communities (71.22 km<sup>2</sup> per ranger) have low densities. The same is true for rangers' capacity, which is lower (22.60 km<sup>2</sup>/ranger) than the average rangers' capacity in the forest landscape (25 km<sup>2</sup>/ranger). However, rangers' capacity is influenced by several factors, including those studied in this article, namely the presence of armed groups negatively affects the rangers' capacity, conservation models, the fortress doesn't improve the rangers' capacity; in contrast, community forestry does, and community commitment improves the rangers' capacity. The carrying of weapons by rangers during their patrol doesn't help them to improve their capacity; it undermines it.

In addition, ROIR is higher in community conservation forestry than in the fortress. The presence of armed groups hurts the ROIR, the fortress conservation model and the carrying of weapons by rangers during patrol do not help to improve the ROIR. However, it improves with community engagement. Nevertheless, we must avoid generalizations. These conclusions apply only to the Grauer gorilla ranger. Further studies with slightly larger samples are needed to reach extrapolatable conclusions.

## Authors' Contributions

- Urbain NGOBOBO, designed the questionnaire, collected and analyzed the data and wrote the article,
- Professor Zo Hasina Rabemananjara supervised all stages of the article,
- Professors Augustin Basabose and Bruno Ramamonjisoa contributed to all stages of the article.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- Albuquerque, U. P., & Oliveira, R. F. (2007). Is the Use-Impact on Native Caatinga Species in Brazil Reduced by the High Species Richness of Medicinal Plants? *Journal of Ethnopharmacology*, *113*, 156-170.  
<https://doi.org/10.1016/j.jep.2007.05.025>
- Allan, E., Manning, P., Alt, F., Binkenstein, J., Blaser, S., Blüthgen, N. et al. (2015). Land Use Intensification Alters Ecosystem Multifunctionality via Loss of Biodiversity and Changes to Functional Composition. *Ecology Letters*, *18*, 834-843.  
<https://doi.org/10.1111/ele.12469>
- Anagnostou, M., Gunn, V., Nibbs, O., Muntaner, C., & Doberstein, B. (2022). An International Scoping Review of Rangers' Precarious Employment Conditions. *Environment Systems and Decisions*, *42*, 479-503.  
<https://doi.org/10.1007/s10669-022-09845-3>
- Anthony, N. M., Atteke, C., Bruford, M. W., Dallmeier, F., Freedman, A., Hardy, O. et al. (2015). Evolution and Conservation of Central African Biodiversity: Priorities for Future Research and Education in the Congo Basin and Gulf of Guinea. *Biotropica*, *47*, 6-17.  
<https://doi.org/10.1111/btp.12188>
- Appleton, M. R., Courtiol, A., Emerton, L., Slade, J. L., Tilker, A., Warr, L. C. et al. (2022). Protected Area Personnel and Ranger Numbers Are Insufficient to Deliver Global Expectations. *Nature Sustainability*, *5*, 1100-1110.  
<https://doi.org/10.1038/s41893-022-00970-0>
- Armenteras, D., Rodríguez, N., & Retana, J. (2009). Are Conservation Strategies Effective in Avoiding the Deforestation of the Colombian Guyana Shield? *Biological Conservation*, *142*, 1411-1419. <https://doi.org/10.1016/j.biocon.2009.02.002>
- Armsworth, P. R., Jackson, H. B., Cho, S., Clark, M., Fargione, J. E., Iacona, G. D. et al. (2018). Is Conservation Right to Go Big? Protected Area Size and Conservation Return-on-investment. *Biological Conservation*, *225*, 229-236.  
<https://doi.org/10.1016/j.biocon.2018.07.005>

- Baghai, M., Miller, J. R. B., Blanken, L. J., Dublin, H. T., Fitzgerald, K. H., Gandiwa, P. et al. (2018). Models for the Collaborative Management of Africa's Protected Areas. *Biological Conservation*, 218, 73-82. <https://doi.org/10.1016/j.biocon.2017.11.025>
- Belecky, M., Parry Jones, R., & Singh, R. (2021). Employment Conditions of Public Sector Rangers: A Major Underaddressed Problem. *Parks Stewardship Forum*, 37, 1-13. <https://doi.org/10.5070/p537151749>
- Belecky, M., Singh, R., & Moreto, W. D. (2019). *Life on the Frontline 2019: A Global Survey of the Working Conditions of Rangers*. WWF Report.
- Bingham, H. C. et al. (2021). *Protected Planet Report Coverage and Connectivity*.
- Brugière, D., Chardonnet, B., & Scholte, P. (2015). Large-Scale Extinction of Large Carnivores (Lion *Panthera leo*, Cheetah *Acinonyx jubatus* and Wild Dog *Lycaon pictus*) in Protected Areas of West and Central Africa. *Tropical Conservation Science*, 8, 513-527. <https://doi.org/10.1177/194008291500800215>
- Bruner, A. G., Gullison, R. E., Rice, R. E., & da Fonseca, G. A. B. (2001). Effectiveness of Parks in Protecting Tropical Biodiversity. *Science*, 291, 125-128. <https://doi.org/10.1126/science.291.5501.125>
- Buchanan, G. M., Donald, P. F., & Butchart, S. H. M. (2011). Identifying Priority Areas for Conservation: A Global Assessment for Forest-Dependent Birds. *PLOS ONE*, 6, e29080. <https://doi.org/10.1371/journal.pone.0029080>
- Butchart, S. H. M., Di Marco, M., & Watson, J. E. M. (2016). Formulating Smart Commitments on Biodiversity: Lessons from the Aichi Targets. *Conservation Letters*, 9, 457-468. <https://doi.org/10.1111/conl.12278>
- Chardonnet, B. (2019) *L'Afrique Change: Ses Aires Protégées Doivent-Elles Évoluer? Reconfigurer Les Aires Protégées en Afrique*.
- Chomba, C., Simpamba, T., Kampamba, G., & Nyirenda, V. (2021). A Detailed Study: Does the Luangwa Hippo Population Size and Density Distribution Vary between Upper and Lower Study Blocks? What Are the Management Implications of Such Distribution Pattern? In *International Research in Environment, Geography and Earth Science Vol. 9* (pp. 40-60). Book Publisher International. <https://doi.org/10.9734/bpi/ireges/v9/4295d>
- Coad, L., Watson, J. E., Geldmann, J., Burgess, N. D., Leverington, F., Hockings, M. et al. (2019). Widespread Shortfalls in Protected Area Resourcing Undermine Efforts to Conserve Biodiversity. *Frontiers in Ecology and the Environment*, 17, 259-264. <https://doi.org/10.1002/fee.2042>
- Critchlow, R., Plumptre, A. J., Alidria, B., Nsubuga, M., Driciru, M., Rwetsiba, A. et al. (2016). Improving Law-Enforcement Effectiveness and Efficiency in Protected Areas Using Ranger-Collected Monitoring Data. *Conservation Letters*, 10, 572-580. <https://doi.org/10.1111/conl.12288>
- Daskin, J. H., & Pringle, R. M. (2018). Warfare and Wildlife Declines in Africa's Protected Areas. *Nature*, 553, 328-332. <https://doi.org/10.1038/nature25194>
- Dinerstein, E., Vynne, C., Sala, E., Joshi, A. R., Fernando, S., Lovejoy, T. E. et al. (2019). A Global Deal for Nature: Guiding Principles, Milestones, and Targets. *Science Advances*, 5, 1-18. <https://doi.org/10.1126/sciadv.aaw2869>
- Doumenge, C. et al. (2015). *Protégées D'Afrique Centrale*.
- Ervin, J., Game, E., Bos, P. et al. (2010) *Making Protected Areas Relevant: A Guide to Integrating Protected Areas into Wider Landscapes, Seascapes and Sectoral Plans and Strategies*. CBD Technical Series No. 44. Convention on Biological Diversity.
- Fischer, A., Naiman, L. C., Lowassa, A., Randall, D., & Rentsch, D. (2014). Explanatory Factors for Household Involvement in Illegal Bushmeat Hunting around Serengeti, Tan-

- zania. *Journal for Nature Conservation*, 22, 491-496.  
<https://doi.org/10.1016/j.jnc.2014.08.002>
- Gavin, M. C., Solomon, J. N., & Blank, S. G. (2010). Measuring and Monitoring Illegal Use of Natural Resources. *Conservation Biology*, 24, 89-100.  
<https://doi.org/10.1111/j.1523-1739.2009.01387.x>
- Geldmann, J., Barnes, M., Coad, L., Craigie, I. D., Hockings, M., & Burgess, N. D. (2013). Effectiveness of Terrestrial Protected Areas in Reducing Habitat Loss and Population Declines. *Biological Conservation*, 161, 230-238.  
<https://doi.org/10.1016/j.biocon.2013.02.018>
- Geldmann, J., Manica, A., Burgess, N. D., Coad, L., & Balmford, A. (2019). A Global-Level Assessment of the Effectiveness of Protected Areas at Resisting Anthropogenic Pressures. *Proceedings of the National Academy of Sciences*, 116, 23209-23215.  
<https://doi.org/10.1073/pnas.1908221116>
- Gibbons, J. D., & Chakraborti, S. (2010). *Nonparametric Statistical Inference*. Chapman and Hall/CRC.
- Graham, V., Geldmann, J., Adams, V. M., Grech, A., Deinet, S., & Chang, H. (2021). Management Resourcing and Government Transparency Are Key Drivers of Biodiversity Outcomes in Southeast Asian Protected Areas. *Biological Conservation*, 253, Article 108875. <https://doi.org/10.1016/j.biocon.2020.108875>
- Gray, M., & Kalpers, J. (2005). Ranger Based Monitoring in the Virunga–Bwindi Region of East-Central Africa: A Simple Data Collection Tool for Park Management. *Biodiversity and Conservation*, 14, 2723-2741. <https://doi.org/10.1007/s10531-005-8406-x>
- Hannah, L., Roehrdanz, P. R., Marquet, P. A., Enquist, B. J., Midgley, G., Foden, W. et al. (2020). 30% Land Conservation and Climate Action Reduces Tropical Extinction Risk by More than 50%. *Ecography*, 43, 943-953. <https://doi.org/10.1111/ecog.05166>
- Hollander, M., Wolfe, D. A., & Chicken, E. (2015). *Nonparametric Statistical Methods*. Wiley. <https://doi.org/10.1002/9781119196037>
- IPBES (2019). *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services*. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. <https://zenodo.org/record/3553579#.YfmYTerMl2w>
- IUCN (2016). *WCC-2016-REC-103-EN: Establishment, Recognition and Regulation of the Career of Park Ranger*.  
[https://portals.iucn.org/library/sites/library/files/resrec-files/WCC\\_2016\\_REC\\_103\\_EN.pdf](https://portals.iucn.org/library/sites/library/files/resrec-files/WCC_2016_REC_103_EN.pdf)
- Jones, K. R., Venter, O., Fuller, R. A., Allan, J. R., Maxwell, S. L., Negret, P. J. et al. (2018). One-Third of Global Protected Land Is under Intense Human Pressure. *Science*, 360, 788-791. <https://doi.org/10.1126/science.aap9565>
- Juffe-Bignoli, D., Burgess, N. D., Belle, E. M. S. et al. (2014). *Protected Planet Report 2014*.
- Kettunen, M. (2021). *Building on Nature: Area-Based Conservation as a Key Tool for Delivering SDGs*. IEEP, IUCN WCPA, The Nature Conservancy, The World Bank, UNDP, Wildlife Conservation Society and WWF.
- Kristen, S. C., Paul, T., & Bijay, R. A. (2019). Effects of Protected Area Size on Conservation Return on Investment. *Environmental Management*, 63, 777-788.
- Krosby, M., Bridge, G., Asinas, E. T., & Hall, S. (2023). Moving Transboundary Conservation from Indigenous Engagement to Indigenous Leadership: Working across Borders for a Resilient Cascadia. *Parks Stewardship Forum*, 39, 47-60.  
<https://doi.org/10.5070/p539159903>

- Kuiper, T., Massé, F., Ngwenya, N. A., Kavhu, B., Mandisodza-Chikerema, R. L., & Milner-Gulland, E. J. (2021). Ranger Perceptions of, and Engagement with, Monitoring of Elephant Poaching. *People and Nature*, 3, 148-161. <https://doi.org/10.1002/pan3.10154>
- Laudari, H. K., Aryal, K., & Maraseni, T. (2020). A Postmortem of Forest Policy Dynamics of Nepal. *Land Use Policy*, 91, Article 104338. <https://doi.org/10.1016/j.landusepol.2019.104338>
- Leader-Williams, N., & Milner-Gulland, E. J. (1993). Policies for the Enforcement of Wildlife Laws: The Balance between Detection and Penalties in Luangwa Valley, Zambia. *Conservation Biology*, 7, 611-617. <https://doi.org/10.1046/j.1523-1739.1993.07030611.x>
- Lonn, P., Mizoue, N., Ota, T., Kajisa, T., & Yoshida, S. (2018). Biophysical Factors Affecting Forest Cover Changes in Community Forestry: A Country Scale Analysis in Cambodia. *Forests*, 9, Article 273. <https://doi.org/10.3390/f9050273>
- Marijnen, E. (2018). Public Authority and Conservation in Areas of Armed Conflict: Virunga National Park as a 'State within a State' in Eastern Congo. *Development and Change*, 49, 790-814. <https://doi.org/10.1111/dech.12380>
- Mathys, G. (2017). Bringing History Back in: Past, Present, and Conflict in Rwanda and the Eastern Democratic Republic of Congo. *The Journal of African History*, 58, 465-487. <https://doi.org/10.1017/s0021853717000391>
- Maxwell, S. L., Cazalis, V., Dudley, N., Hoffmann, M., Rodrigues, A. S. L., Stolton, S. et al. (2020). Area-Based Conservation in the Twenty-First Century. *Nature*, 586, 217-227. <https://doi.org/10.1038/s41586-020-2773-z>
- McClanahan, T. R. et al. (2008). Cover Caption. *Conservation Letters*, 1, 53.
- Milner-Gulland, E. J., & Leader-Williams, N. (1992). A Model of Incentives for the Illegal Exploitation of Black Rhinos and Elephants: Poaching Pays in Luangwa Valley, Zambia. *The Journal of Applied Ecology*, 29, 388-401. <https://doi.org/10.2307/2404508>
- Minang, P. A., Duguma, L. A., Bernard, F., Foundjem-Tita, D., & Tchoundjeu, Z. (2019). Evolution of Community Forestry in Cameroon: An Innovation Ecosystems Perspective. *Ecology and Society*, 24, Article 1. <https://doi.org/10.5751/es-10573-240101>
- Naidoo, R., Gerkey, D., Hole, D., Pfaff, A., Ellis, A. M., Golden, C. D. et al. (2019). Evaluating the Impacts of Protected Areas on Human Well-Being across the Developing World. *Science Advances*, 5, 1-8. <https://doi.org/10.1126/sciadv.aav3006>
- Ngobobo, U., Rabemananjara, Z. H., Ramamonjisoa, B., & Basabose, A. (2025). Effect of Site Size, Armed Group Presence, Conservation Model and Governance Mode on the Conservation Return on Investment across Selected Conservation Areas in the Grauer's Gorilla (*Gorilla beringei graueri*) Range in Eastern Democratic Republic of the Congo. *Journal of Geoscience and Environment Protection*, 13, 60-73. <https://doi.org/10.4236/gep.2025.135005>
- Nuno, A. N. A., Bunnefeld, N., & Milner-Gulland, E. J. (2017). Using Management Strategy Evaluation as a Framework for Improving Conservation under Uncertainty: The Case of the Serengeti Ecosystem. In *Decision-Making in Conservation and Natural Resource Management* (pp. 156-181). Cambridge University Press. <https://doi.org/10.1017/9781316135938.007>
- Plumptre, A. et al. (2017) *Gorilla Beringei ssp. Graueri (Errata Version)*. *The IUCN Red List of Threatened Species 2016: e.T39995A102328430*. <http://dx.doi.org/10.2305/IUCN.UK.2016-2.RLTS.T39995A17989838.en>
- Plumptre, A. J. et al. (2015) Statut du Gorille de Grauer et des Chimpanzes a L'Est de la Republique Democratique du Congo Distribution et Abondance Historique et Actuelle. <https://www.albertinerift.org>

- Plumptre, A. J., Fuller, R. A., Rwetsiba, A., Wanyama, F., Kujirakwinja, D., Driciru, M. et al. (2014). Efficiently Targeting Resources to Deter Illegal Activities in Protected Areas. *Journal of Applied Ecology*, *51*, 714-725. <https://doi.org/10.1111/1365-2664.12227>
- Plumptre, A. J., Kirkby, A., Spira, C., Kivono, J., Mitamba, G., Ngoy, E. et al. (2021). Changes in Grauer's Gorilla (*Gorilla beringei graueri*) and Other Primate Populations in the Kahuzi-Biega National Park and Oku Community Reserve, the Heart of Grauer's Gorilla Global Range. *American Journal of Primatology*, *83*, 1-15. <https://doi.org/10.1002/ajp.23288>
- Plumptre, A. J., Nixon, S., Kujirakwinja, D. K., Vieilledent, G., Critchlow, R., Williamson, E. A. et al. (2016). Catastrophic Decline of World's Largest Primate: 80% Loss of Grauer's Gorilla (*Gorilla beringei graueri*) Population Justifies Critically Endangered Status. *PLOS ONE*, *11*, e0162697. <https://doi.org/10.1371/journal.pone.0162697>
- Poisson, J. (2009). *Impact de la gestion participative sur l'efficacité de conservation dans les parcs nationaux des pays sous-développés*. <https://core.ac.uk/download/pdf/51340205.pdf>
- Pörtner, H. O. (2021). *Scientific Outcome of the IPBES-IPCC Co-Sponsored Workshop on Biodiversity and Climate Change*. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.
- Réginas, N., Alidou, S. et al. (2021). *Conjonctures de l'Afrique Centrale*. Musée royal de l'Afrique centrale et L'Harmattan.
- Remme, R. P., Frumkin, H., Guerry, A. D., King, A. C., Mandle, L., Sarabu, C. et al. (2021). An Ecosystem Service Perspective on Urban Nature, Physical Activity, and Health. *Proceedings of the National Academy of Sciences*, *118*, 1-10. <https://doi.org/10.1073/pnas.2018472118>
- Ruxton, G. D. (2006). The Unequal Variance T-Test Is an Underused Alternative to Student's T-Test and the Mann-Whitney U-Test. *Behavioral Ecology*, *17*, 688-690. <https://doi.org/10.1093/beheco/ark016>
- Simpson, F. O. L., & Pellegrini, L. (2023). Agency and Structure in Militarized Conservation and Armed Mobilization: Evidence from Eastern DRC's Kahuzi-Biega National Park. *Development and Change*, *54*, 601-640. <https://doi.org/10.1111/dech.12764>
- Singh, R., Galliers, C., Appleton, M., Hoffmann, M., Long, B., Cary-Elwes, J. et al. (2021). The Vital Role of Rangers in Conservation. *Parks Stewardship Forum*, *37*, 1-11. <https://doi.org/10.5070/p537151745>
- Smith, A. C., Hurni, K., Fox, J., & Van Den Hoek, J. (2023). Community Forest Management Led to Rapid Local Forest Gain in Nepal: A 29 Year Mixed Methods Retrospective Case Study. *Land Use Policy*, *126*, Article 106526. <https://doi.org/10.1016/j.landusepol.2022.106526>
- Stolton, S. (2015). *Protected Area Governance and Management*. ANU Press.
- Trigg, M. A., & Tshimanga, R. M. (2020). Capacity Building in the Congo Basin: Rich Resources Requiring Sustainable Development. *One Earth*, *2*, 207-210. <https://doi.org/10.1016/j.oneear.2020.02.008>
- Walker, B. H. (2020). Resilience: What It Is and Is Not. *Ecology and Society*, *25*, 1-3. <https://doi.org/10.5751/es-11647-250211>
- Watson, J. E. M., Dudley, N., Segan, D. B., & Hockings, M. (2014). The Performance and Potential of Protected Areas. *Nature*, *515*, 67-73. <https://doi.org/10.1038/nature13947>
- WCPA (2020). *The International Journal of Protected Areas and Conservation Developing Capacity for a Protected Planet*.

- Welch, B. L. (1947). The Generalization of Student's Problem When Several Different Population Variances Are Involved. *Biometrika*, *34*, 28-35. <https://doi.org/10.2307/2332510>
- Wilson, K. A., McBride, M. F., Bode, M., & Possingham, H. P. (2006). Prioritizing Global Conservation Efforts. *Nature*, *440*, 337-340. <https://doi.org/10.1038/nature04366>
- Wyatt, A., Singh, R., & Belecky, M. (2022). Protecting Our Protectors: The Need for Improved Ranger Welfare. *The Ecological Citizen*, *5*, 123-127.
- Yamagiwa, J. (2003). Bushmeat Poaching and the Conservation Crisis in Kahuzi-Biega National Park, Democratic Republic of the Congo. *Journal of Sustainable Forestry*, *16*, 111-130. [https://doi.org/10.1300/j091v16n03\\_06](https://doi.org/10.1300/j091v16n03_06)