NATURAL RESOURCE MODELING
Volume 26, Number 4, November 2013

EVALUATING THE PROSPECTS OF BENEFIT SHARING SCHEMES IN PROTECTING MOUNTAIN GORILLAS IN CENTRAL AFRICA

SAMSON MUKANJARI*
Environmental Economics Policy Research Unit,
School of Economics, University of Cape Town,
Private Bag, Rondebosch 7701, Cape Town, South Africa
E-mail: smukanjari@gmail.com

BIRGIT BEDNAR-FRIEDL
Department of Economics, University of Graz Universitaetsstrasse 15,
A-8010 Graz, Austria
Wegener Center for Climate and Global Change,
University of Graz Brandhofgasse 5, A-8010 Graz, Austria
E-mail: birgit.friedl@uni-graz.at

EDWIN MUCHAPONDWA
Environmental Economics Policy Research Unit,
School of Economics, University of Cape Town,
Private Bag, Rondebosch 7701, Cape Town, South Africa
E-mail: edwin.muchapondwa@uct.ac.za

PRECIOUS ZIKHALI
International Water Management Institute,
Southern Africa Regional Office, Private Bag X813,
Silverton 0127, Pretoria, South Africa
E-mail: p.zikhali@cgiar.org

ABSTRACT. Presently, the mountain gorilla in Rwanda, Uganda, and the Democratic Republic of Congo is endangered mainly by poaching and habitat loss. This paper sets out to investigate the possible resolution of poaching involving the local community by using benefit sharing schemes with local communities. Using a bioeconomic model, the paper demonstrates that the current revenue sharing scheme yields suboptimal conservation outcomes. It is, however, shown that a performance-linked benefit sharing scheme in which the Park Agency makes payment to the local community based on the growth of the gorilla stock can achieve socially optimal conservation. This scheme renders poaching effort by the local community, and therefore poaching fines and antipoaching enforcement toward the local community unnecessary. Given the huge financial outlay requirements for the ideal benefit sharing scheme, the Park Agencies in central Africa could reap more financial benefits for use in conservation if they employ an oligopolistic pricing strategy for gorilla tourism.

KEY WORDS: Benefit sharing, bioeconomic model, conservation, mountain gorilla, performance payment.

1. Introduction.

The need for biodiversity conservation has long been recognized, though it was only formalized with the signing of the Convention of Biological

*Corresponding author. Samson Mukanjari, Environmental Economics Policy Research Unit, School of Economics, University of Cape Town, South Africa, e-mail: smukanjari@gmail.com
Received by the editors on 29th March 2012, and in revised form on 29th August 2012.

Diversity in 1992. In Africa, prominence has been given to the conservation of large individual species, such as the elephant, black rhino, and the gorilla. In Rwanda, Uganda, and the Democratic Republic of Congo (DRC), the gorilla is a key species faced with a range of threats: poaching, war, growing human populations and associated habitat loss, and natural epidemics. The gorilla is presently endangered, and appears in the Appendix of the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

Conservation efforts around the gorilla include the International Gorilla Conservation Programme (IGCP), the Great Ape Survival Project and the Agreement on the Conservation of Gorillas and Their Habitats (Convention on Migratory Species [2008]). Thus, it is clear that global society values endangered species such as the gorilla. However, in the countries in which such species still exist there seem to be inadequate incentives to enable the conservation of optimal populations.

There are two species of gorillas, namely the Western and the Eastern, each with two subspecies. The two subspecies of the Eastern gorilla are the Mountain and the Eastern Lowland Gorilla (UNEP–WCMC [2003]). The Mountain Gorilla (*Gorilla beringei beringei*) is the most endangered, with a total population of 786 individuals (IGCP [2010]) and is therefore the focus of this paper. The relevant gorilla range in Rwanda, Uganda, and the DRC occurs in an area called the Virunga Massif. The annual revenue earned directly from gorilla tourism in these countries is currently estimated to be US$3 million, without taking employment opportunities into consideration (IGCP [2011]). Accounting for first-order multiplier effects, gorilla tourism contributes over US$20 million annually, apportioned between Rwanda, Uganda, and the DRC (IGCP [2011]).

However, even though these countries earn a lot of revenue from gorilla tourism, the trickle-down effect of these revenues to the communities who shoulder the opportunity cost of land not used in agriculture and suffer from crop damage is very limited. The current incentive scheme in the Virunga Massif entails sharing revenue from gorilla tourism with the local community which is then used to finance community projects for enhancing community welfare. The exact proportions shared with the local community range between 5% and 30%, depending on the country. Even though local attitudes toward wildlife are still fairly negative (Adams and Infield [2003]) because in many cases national parks were created by directly displacing rural communities (Schulz and Skonhoft [1996], Adams and Infield [2003]), the flow of revenue has helped win some cooperation from local communities. Nevertheless, the current conservation outcomes could be improved by changing the design of the incentive scheme toward a more holistic benefit sharing scheme which incentivizes local communities to value gorilla populations beyond their revenue generation capabilities, e.g., from sharing tourism revenues to sharing a broader benefit.

The role of benefit sharing schemes has been discussed for similar conservation problems by Schulz and Skonhoft [1996], Skonhoft and Solstad [1996], Skonhoft

[1998], Fischer et al. [2011] and Zabel et al. [2011]. Schulz and Skonhoft [1996] argue against merely compensating local communities for wildlife damages and call for benefit sharing schemes which attract local communities to care about the entire wildlife population. Skonhoft and Solstad [1996] point out that poaching by local communities can be addressed more effectively by granting them property rights to wildlife because without them local communities base their illegal harvesting decisions on short-term considerations.

In a model with a land-use conflict between local agropastoralists and a park authority, Skonhoft [1998] introduces property rights by allowing the agropastoralists to share the profits from wildlife hunting and tourism. Where the agropastoralists receive a profit share from the tourist activity in addition to the hunting benefit, the nuisance from the roaming wildlife will decrease as this scheme provides incentives for the park manager to increase the offtake and thereby decrease the wildlife stock in the long term. There will, therefore, be more livestock and a clear welfare gain for the agropastoralists compared to the situation where they have no property rights. Under certain conditions, the stock sizes will also be closer to what is optimal from a social planner's point of view. Consequently, Skonhoft [1998] supports devolution of ownership rights to the local agropastoralists to incentivize them to develop a long-term view about wildlife conservation.

Using a similar property rights structure, Fischer et al. [2011] shed more light on the welfare implications of such schemes by comparing two benefit sharing schemes involving sharing tourism revenue and shares of hunting licenses in a bioeconomic model incorporating poaching by external agents and community antipoaching enforcement. It turns out that the size of benefits granted and the design of benefit sharing schemes is crucial if resource sharing is to translate into meaningful conservation and welfare improvements. Fischer et al. [2011] argue that directly linking benefits to the actions of locals can result in significant conservation outcomes.

Zabel et al. [2011] evaluate two policy approaches for carnivore conservation: ex-post compensation, and performance payments. While both policies have the capacity to enhance conservation outcomes, unconditional ex-post compensation is shown to have a distortionary effect on incentives to conserve. They argue that performance payments are more effective because of their direct link to specific conservation outcomes. Accordingly, this paper will propose a scheme which is more in line with Zabel et al. [2011]'s performance payment scheme with the difference that in our case the primary motivation is not to compensate for damage inflicted on the local community but generally grow the gorilla population. In addition, we will argue that it is the generation of adequate financial incentives which encourages communities to have a long-term view in their interaction with wildlife besides the mere designation of communities as co-owners of wildlife.

Against the background that the gorilla has remained threatened despite decades of research and many efforts to save it, this paper seeks to analyze how benefit sharing schemes with local communities can help solve the gorilla poaching problem. Using a bioeconomic model, the paper investigates the conservation and welfare outcomes in the Virunga Massif of the revenue sharing scheme in place and proposes a performance-linked benefit sharing scheme in which the Park Agency makes payment to the local community based on the growth of the gorilla stock. The paper is organized as follows: section 2 gives a detailed background of the mountain gorillas' ecology, the key threats and current conservation efforts found in the Virunga Massif. Section 3 outlines the bioeconomic model. Section 4 discusses the market equilibrium. Section 5 presents the social planner's solution, compares it with the market equilibrium, and discusses the current and alternative benefit-sharing schemes. Section 6 discusses the design of benefit sharing schemes while section 7 concludes the paper.

2. Background to the problem. The mountain gorilla exists naturally in two small, isolated populations, found in two locations which form their last remaining natural habitat. The Virunga Massif—situated on the slopes of extinct volcanoes along the borders of the DRC (the Mikeno sector of the Virunga National Park, 7900 km^2), Rwanda (Volcanoes National Park, 160 km^2), and Uganda (Mgahinga Gorilla National Park, 33.7 km^2)—is home to about two-thirds of the total gorilla population. The other population is found in Bwindi Impenetrable National Park (BINP) in south-west Uganda, on the border with the DRC (331 km^2) (UNEP–WCMC [2003], UNEP [Undated]).[2] The mountain gorillas of the Virunga occupy an area of approximately 450 km^2, while the Bwindi gorillas occupy about 215 km^2 (UNEP–WCMC [2003]). The Virunga population was estimated to be 480 in 2010; the Bwindi population totaled 302 according to the 2006 census (IGCP [2010], Nellemann et al. [2010]). The mountain gorillas' home range in the Virunga is small, between 5 and 30 km^2; therefore, daily foraging movements may involve crossing national borders. The Bwindi population is relatively stable and even increasing, according to the 2006 census (McNeilage et al. [2006]). Moreover, the Bwindi gorillas have not been disturbed by humans as much as the Virunga population has (Robbins et al. [2009]). The distribution of the mountain gorillas is shown in Figure A1.

At present, all mountain gorillas and their respective habitats are found in "protected" areas. However, such protection is undermined by political and institutional instability, habitat loss, and illegal hunting. Recent concerns include poaching for the bushmeat trade and for the capture of infant gorillas, and the impact of civil conflict within the gorillas' range (UNEP [Undated], Plumptre and Williamson [2001], Kalpers et al. [2003], IUCN [2010]).[3]

Despite the recent recovery of the population, current threats of extinction are as real as they were in the 1950s.[4] While previous studies on the mountain gorilla in the Virunga region have indicated population viability for the next 100 years in the absence of external environmental perturbations (Harcourt [1995], Miller et al. [1998], Durant [2000] cited in Kalpers et al. [2003]), conservative projections by UNEP in 2002 forecasted that the mountain gorillas' natural habitat will have shrunk to only 10% of its original range by 2032.

One of the reasons for habitat loss is the competition for land-uses in the Virunga region, most notably agriculture. Subsistence agriculture is the primary livelihood strategy for communities located around the parks (>90% of the population) (Plumptre and Williamson [2001]). Consequently, high human population densities (between 400 and 600 people per km^2) are a common feature (Plumptre and Williamson [2001], Kalpers et al. [2003]).[5] In addition, the national parks do not have buffer zones between the local communities and the parks' resource base. Periodical refugees have set up temporary structures in the Virunga National Park, putting further pressure on the habitat. The current gorilla habitat and range is considered to be only a fraction of what it used to be; losing more habitat, therefore, will greatly endanger the survival of the remaining gorilla population (Plumptre and Williamson [2001]).

A second major threat to gorilla conservation is posed by poaching. Binyeri et al. [2002] have documented instances of gorilla poaching driven by the increasing demand for baby gorillas from private foreign zoos in the DRC. Williamson and Fawcett [2008] have reported similar incidents for Rwanda. An infant can yield up to £86 000 on the black market (Vesperini [2002] cited in UNEP–WCMC [2003]), and in most cases infants can only be captured after killing the adults in the group who are meant to protect them (UNEP–WCMC [2003]). Moreover, there are social consequences—often associated with the killing of a key member of a group, for example a silverback. This could cause the disintegration of an entire group; and infanticides, as nursing mothers join a new male, thereby triggering population regression (UNEP [Undated], Kalpers et al. [2003]). Because of these social dependencies, poaching may have a much larger impact on the viability of the entire population and hence gorilla conservation.

As habitat loss and poaching endanger gorilla conservation, gorilla tourism could be a remedy against both, in the hope that if gorillas can "pay their way," then this could increase the opportunity cost of their natural habitat. Where gorilla tourism has developed, mountain gorillas have become an economic asset of national importance. Gorilla tourism dates back to 1979 and 1984 in Rwanda and the DRC respectively, while official gorilla tourism in Uganda was established in 1991. The strong demand for gorilla tracking offers the possibility for sustained wealth generation from wildlife. To consolidate the benefits of tourism, institutions need to be devised such that the gorilla "pays its way" to the satisfaction of all parties (Adams and Infield [2003]). However, gorilla tourism is not without challenges; it exposes gorillas to humans and hence to any diseases that humans may be carrying, thereby greatly exposing immunologically naïve populations (Plumptre and Williamson [2001]).[6] In addition to possible stress during the habituation process,[7] habituation increases risks to the gorillas from poachers and military rebels in the forest (Plumptre and Williamson [2001]). Ultimately, the future sustainability and success of gorilla tourism hinges on the ability to attract high-end, low-impact tourist visitors.

Protected areas, regional collaboration and community involvement currently offer the main formal tools that (in theory) will protect the mountain gorillas and preserve biodiversity in the Virunga region (Johannesen and Skonhoft [2005], Nellemann et al. [2010]). Regional collaboration in the form of community initiatives have included revenue sharing schemes and provided alternative livelihoods which do not threaten wildlife. These arise from the recognition that when traditional rights and access shift in a way which disadvantages local communities, little incentive is created to exploit resources in a sustainable manner (Damania et al. [2003], Johannesen and Skonhoft [2005]). However, lack of institutional capacity is proving an obstacle (Adams and Infield [2003]). In addition, given the insignificant magnitude of the benefits per person from revenue sharing—about US$0.36 per year in Rwanda (Nielsen and Spenceley [2011])—there is a need for careful design of the scheme so that it has a more pronounced first-order impact on the local community.

3. The Bioeconomic model. As noted above, there are several actors operating in the Virunga region: park agencies for each of the three countries, local communities in the vicinity of the national parks, and military rebels. In this section, this paper builds a simple bioeconomic model to capture the interaction between broad groups of the different actors. To ensure tractability and allow us to only deal with poaching involving the local community, it considers only two key economic agents[8]: the Park Agency and a local community living adjacent to the park; and three possible activities: gorilla conservation/tourism, gorilla poaching, and agricultural production. To keep the model tractable, we do not consider questions of habitat loss and hence we assume that land allocation has already been decided.[9]

The Park Agency has the mandate to care for the gorillas, manage tourism, and collect tourism revenues from gorilla tracking, mountain climbing, and other related activities. We assume that there is no harvesting by the Park Agency even though there is poaching by the local community.

The local community engages in agricultural production, as well as poaching especially of infant gorillas for sale on the international market to private foreign zoos. The local community allocates its fixed endowment of labor effort ($\bar{N}$) between the two activities, namely agricultural production (N_a) and gorilla poaching (N_g). (See Table 1 for a summary of definitions of symbols used). Therefore total labor effort is given as

$$N_a + N_g = \overline{N}. \tag{1}$$

TABLE 1. Model notation.

G	Gorilla stock	h	Harvesting function of gorillas
$F(G)$	Gorilla natural growth dynamics	s	Poacher's remuneration for each gorilla caught
p_a	Price of agricultural products	w	Cost per unit of effort of labor
$Q(N_a)$	Total agricultural production function	$R(G)$	Revenue from gorilla tourism
N_a	Labor effort devoted to agricultural production	π	Profit function
N_g	Labor effort devoted to gorilla poaching	α	Fixed share of revenue going to locals
θ	Probability of being caught poaching gorillas	β	Fixed share of profits accruing to locals
E	Park Agency's antipoaching effort	$c(G,E)$	Total cost of managing the park
Ω	Fixed fine per unit poached if caught	K	Park land carrying capacity
$Z(G)$	Public good externality	r	Social Planner's discount rate
κ	Fraction of infants in the removed population	ψ	Payment for the growth of the gorilla stock

Enforcement against poaching is done by the Park Agency, to whom fines levied on poachers accrue. Thus, gorilla poaching involves the risk or probability of being caught, (θ). The probability of detection is affected by the level of the Park Agency's antipoaching effort, (E), and the local community's harvesting effort, (N_g)

$$\theta = \theta(E, N_g). \tag{2}$$

We assume that $\theta(0, N_g) = 0$, $\partial\theta/\partial E > 0$ and $\partial\theta/\partial N_g > 0$, implying θ is an increasing function of the level of antipoaching effort, and time spent on poaching gorillas, respectively. In addition, $\theta_{EN_g} > 0$, implying that as the level of antipoaching effort increases, the probability of being detected increases at the margin.

While the intention of poachers is mainly to capture infant gorillas for sale to foreign zoos, in reality the capture of infants involves killing adult group members, as they normally protect the infants (Nellemann et al. [2010]).[10] Poaching therefore affects the entire gorilla population, motivating modeling the total gorilla stock rather than a sub-population. Assuming that the poacher's remuneration for each infant gorilla caught is s and that the harvest/offtake function of gorillas is $h = h(G, E, N_g)$, the payoff function from gorilla poaching is given by

$$\pi_g = s\kappa h - wN_g - \theta(\cdot)\Omega\kappa h = (s - \theta(\cdot)\Omega)\kappa h(G, E, N_g) - wN_g, \tag{3}$$

where N_g is the effort expended on poaching, w is the cost per unit of effort, Ω is the fixed fine per unit poached when detected, and κ is the fraction of infants in the gorilla offtake. It should be noted that the local community does not directly decide on the amount of gorilla offtake. Instead, it decides on the amount of labor to allocate to poaching, N_g which alongside other variables determines the level of gorilla offtake. In addition, even though h is the ultimate gorilla offtake by poachers, revenue is derived from infants (κh) only.[11] It is assumed that $\partial h/\partial G > 0$ implying that a higher stock induces a higher illegal offtake, and $\partial h/\partial E < 0$ meaning that an increase in antipoaching effort gives rise to reduced illegal offtake through increasing the probability of detection. Furthermore, $\partial^2 h/\partial E^2 \geq 0$: as antipoaching effort increases, poaching will decline—at an increasing rate. Therefore the function h is convex in E.

There is revenue sharing between the locals and the Park Agency with regard to the gross revenues from tourism. The locals are assumed to get a share α of the revenues from gorilla tourism, implying that the Park Agency gets the rest, $(1 - \alpha)$, where $0 \leq \alpha \leq 1$. It is assumed further that these shares are fixed through a legal system.[12] Denoting the revenue from gorilla tourism at time t by $R(G)$ implies that the amount of revenue going to the community is $\alpha R(G)$.[13]

It is assumed that the local community's agricultural production is affected by the labor used in agricultural production, N_a. Therefore the agricultural profit function is given by

$$\pi_a = p_a Q(N_a) - wN_a, \tag{4}$$

where w is the imputed wage rate (price of labor) which is assumed to be predetermined because of the general possibility of off-farm employment; p_a is the fixed market price of agricultural output which is assumed to be exogenously determined for the local community since there exists a national market for agricultural output; $Q(N_a)$ is the total agricultural production function, and is assumed to be characterized by constant returns to scale. It is assumed that $Q'(N_a) \geq 0$, and $Q''(N_a) < 0$.

Thus the local community's net benefit from agricultural and wildlife activities is given by

$$\pi_{LOC} = \pi_a + \pi_g + \alpha R(G) = p_a Q(N_a) - wN_a + (s - \theta(\cdot)\Omega)\kappa h(\cdot) - wN_g + \alpha R(G). \tag{5}$$

Equation (6) gives the Park Agency's net benefit from wildlife activities in the presence of a revenue sharing scheme with the local community

$$\pi_{PAR} = (1-\alpha)R(G) + \theta(\cdot)\Omega\kappa h(\cdot) + Z(G) - c(G,E). \tag{6}$$

The total cost of managing the park and the gorillas in each time period is $c(G,E)$, which is assumed to depend on the gorilla stock as well as the antipoaching effort in the following way $\partial c(G,E)/\partial G > 0$, $\partial^2 c(G,E)/\partial G^2 < 0$, $\partial c(G,E)/\partial E > 0$, $\partial^2 c(G,E)/\partial E^2 < 0$ and $c(G,0) = 0$. The Park Agency therefore faces costs associated with controlling and securing the benefits from the gorillas and their habitat by exerting antipoaching effort (E). Such costs could be in the form of equipping and paying an antipoaching unit. In return, the Park Agency receives three types of benefits: (i) share of revenue from gorilla tourism, $(1-\alpha)R(G)$, (ii) proceeds from poaching fines, $\theta(\cdot)\Omega\kappa h(\cdot)$, and (iii) the public good value of the gorilla stock, $Z(G)$, taking the form of existence value, bequest value or option value.[14] It is assumed that $Z(G) > 0$, $Z(0) = 0$, $Z'(G) > 0$ and $Z''(G) \leq 0$.

The production activities taking place inside the park (namely tourism and poaching of gorillas) are constrained by the gorilla stock dynamics. The change in the gorilla stock over time will be equal to the natural growth of the gorillas, less the illegal offtake

$$\frac{dG}{dt} = F(G) - h(G,E,N_g), \tag{7}$$

where $F(G)$captures the natural growth, which can take the form of a logistic growth function and is represented by $F(G) = \eta G^{\phi}(1-\frac{G}{K})$, where η is the intrinsic rate of growth of the gorilla stock and K is the carrying capacity of the park, which is the gorilla habitat.[15] It is also assumed that $F'(G) > 0$ and $F''(G) < 0$ in the domain $0 < G < K$. The natural growth of the gorilla $F(G)$ incorporates several factors, including the size of the habitat, the current structure of land use and gorilla mortality from disease and war.

4. Market equilibrium. In the market equilibrium, both the local community and Park Agency legally benefit from revenue from gorilla tourism. However, the local community and the Park Agency pursue individual interests and consequently act uncooperatively. The local community is involved in poaching and ignores the public good value of the gorilla stock. The Park Agency takes the public good value of the gorilla stock into account and exerts antipoaching enforcement to protect the gorilla. The local community makes decisions about labor allocation between its two livelihood activities while the Park Agency makes a decision about the level of antipoaching enforcement. The local community takes the anti-poaching enforcement E as given while the Park Agency takes the local community's poaching effort N_g as given until equilibrium poaching effort and antipoaching enforcement values are attained.[16]

4.1. The local community's problem. The decisions to be made by the local community relate to how much labor to allocate to gorilla poaching, N_g, and how much to allocate to agriculture, N_a. Given the existence of a labor constraint shown in equation (1), a decision on how much effort to allocate to one activity already implies a certain allocation to the other activity. Thus, the local community is confronted by the following maximization problem, where the labor constraint has already been substituted

$$\max_{N_g} \pi_{LOC} = p_a Q(\bar{N} - N_g) - w(\bar{N} - N_g) + [s - \theta(E, N_g)\Omega]\kappa h(G, E, N_g) - wN_g + \alpha R(G). \tag{8}$$

As shown in Skonhoft and Solstad [1998], the local community does not base its poaching decision on intertemporal considerations, since it does not have property rights over the gorilla and effective enforcement in subsequent periods might completely curtail its poaching. Uncertainty regarding the local community's ability to expropriate from the park in the future motivates it to disregard sustainable use of the gorilla.

The first-order condition with respect to poaching effort is

$$p_a Q'(\bar{N} - N_g) = s\kappa \frac{\partial h(\cdot)}{\partial N_g} - \theta(\cdot)\Omega\kappa \frac{\partial h(\cdot)}{\partial N_g} - \Omega\kappa h(\cdot)\frac{\partial \theta(\cdot)}{\partial N_g}. \tag{9}$$

Thus, the local community will allocate labor to gorilla poaching according to the optimality condition given by equation (9). The marginal benefit of poaching effort consists of three components. The term $s\kappa\partial h(\cdot)/\partial N_g$ is the marginal (financial) value of poaching effort to the local community in terms of the value of the infants captured and sold. The term $-\theta(\cdot)\Omega\kappa\partial h(\cdot)/\partial N_g$ shows the marginal value (loss) to the local community in terms of the expected value of fines upon being apprehended and fined because of additional investment in poaching effort. The term $-\Omega\kappa h(\cdot)\partial\theta(\cdot)/\partial N_g$ shows the marginal value (loss) to the local community in terms of the value of fines upon being apprehended and fined when the risk of detection increases because of additional investment in poaching effort.

4.2. The Park Agency's problem. The decision to be made by the Park Agency is how much antipoaching enforcement E to invest in. As the Park Agency has a legal right to exploit the gorilla for tourism and its public good value, it has a long-term view, and therefore takes the dynamics of the gorilla stock into account. However, the Park Agency is likely to use a discount rate γ which may be different from that used by the social planner (see section 5). The Park Agency therefore faces the following problem, subject to the dynamics of the gorilla stock (7)[17]

$$\max_{E} \pi_{PAR} = \int_0^\infty [(1-\alpha)R(G) - c(G,E) + \theta(\cdot)\Omega\kappa h(\cdot) + Z(G)]e^{-\gamma t}\,dt. \tag{10}$$

The current-value Hamiltonian function is therefore given in equation (11) where the superscript PAR denotes the Park Agency

$$H^{PAR} = [(1-\alpha)R(G) - c(G,E) + \theta(\cdot)\Omega\kappa h(\cdot) + Z(G)] + \lambda\left[\eta G^{\phi}\left(1 - \frac{G}{K}\right) - h(\cdot)\right], \tag{11}$$

where λ is the costate variable, and the current value of the shadow price of a gorilla at any time t. The shadow price measures the approximate decrease in the present value of net benefits resulting from a unit decrease in the gorilla stock. The following expression can be obtained from the first-order

$$\frac{\partial c(\cdot)}{\partial E} = \Omega\kappa h(\cdot)\frac{\partial\theta(\cdot)}{\partial E} - \lambda\frac{\partial h(\cdot)}{\partial E} + \theta(\cdot)\Omega\kappa\frac{\partial h(\cdot)}{\partial E}. \tag{12}$$

The Park Agency will deploy antipoaching effort up to the point where the marginal cost of the antipoaching effort $\partial c(\cdot)/\partial E$ is equal to its marginal benefit. The marginal benefit of antipoaching enforcement consists of three components. The term $\Omega\kappa h(\cdot)\partial\theta(\cdot)/\partial E$ shows the marginal (financial) value to the Park Agency in terms of the value of fines receivable upon apprehension of poachers when the risk of detection increases due to increased antipoaching enforcement. The term $-\lambda\partial h(\cdot)/\partial E$ is the marginal (shadow) value to the Parks Agency of gorillas saved from poaching because of increased antipoaching enforcement while the term $\theta(\cdot)\Omega\kappa\partial h(\cdot)/\partial E$ shows the marginal (financial) valuation by the Park Agency of fines forgone because of decreased offtake following additional investment in antipoaching enforcement.

The costate equation $\dot{\lambda} - \gamma\lambda = -\partial H^{PAR}/\partial G$ reads as

$$\begin{aligned}\frac{\dot{\lambda}}{\lambda} &+ \left[\frac{(1-\alpha)R'(G) - \partial c(\cdot)/\partial G + \theta(\cdot)\Omega\kappa\partial h(\cdot)/\partial G + Z'(G)}{\lambda}\right] \\ &+ \eta\left(\phi G^{\phi-1} - \frac{(\phi+1)G^{\phi}}{K}\right) - \frac{\partial h(\cdot)}{\partial G} = \gamma.\end{aligned} \tag{13}$$

The Park Agency would maintain the gorilla stock at a level that equates the return from the gorilla with the return from alternative assets. The marginal revenue from gorilla tourism is weighted by the share of such revenue accruing to the Park Agency. In steady state, $\dot{\lambda} = \dot{G} = 0$. Therefore, it can be shown from the costate equation (13) and the equation for the dynamics of the gorilla stock that the optimal shadow value of the gorilla stock is:

$$\lambda^* = \frac{(1-\alpha)R'(G) - \partial c(\cdot)/\partial G + \theta(\cdot)\Omega\kappa\partial h(\cdot)/\partial G}{\frac{\partial h(\cdot)}{\partial G} - \eta\left(\phi G^{\phi-1} - \frac{(\phi+1)G^{\phi}}{K}\right) + \gamma}. \tag{14}$$

The market equilibrium levels of poaching effort N_g^*, antipoaching effort E^* and the stock of the gorilla G^*, can be computed from equations (7), (9) and (12). The steady-state offtake of the gorilla by the local community can be solved for by substituting these values into the harvesting function $h^* = h(G^*, E^*, N_g^*)$.

5. The social planner's problem. The social planner chooses poaching effort and antipoaching enforcement to maximize the present value of net benefits from agricultural and gorilla activities, including the public good value of the gorilla stock. Therefore, subject to the labor constraint (1) and the dynamics of the gorilla stock (7), the social planner is confronted with the following maximization problem[18]

$$\begin{aligned} \max_{E,N_g} PVNB = \int_0^{\infty} & [(1-\alpha)R(G) - c(G,E) + \theta(\cdot)\Omega\kappa h(\cdot) + p_a Q(N_a) - wN_a\,. \\ & + (s - \theta(\cdot)\Omega)\kappa h(G,E,N_g) - wN_g + \alpha R(G) + Z(G)]\, e^{-rt} dt \end{aligned} \tag{15}$$

The current-value Hamiltonian function is therefore given in equation (16) where the superscript *sp* denotes the social planner

$$\begin{aligned} H^{sp} &= R(G) - c(G,E) + p_a Q(\overline{N} - N_g) - w(\overline{N} - N_g) + s\kappa h(\cdot) - wN_g \\ &\quad + Z(G) + \lambda\left[\eta G^{\phi}\left(1 - \frac{G}{K}\right) - h(\cdot)\right], \end{aligned} \tag{16}$$

The first-order condition with respect to poaching effort is given by

$$p_a Q'(\bar{N} - N_g) = s\kappa\frac{\partial h(\cdot)}{\partial N_g} - \lambda\frac{\partial h(\cdot)}{\partial N_g}. \tag{9'}$$

The social planner will allocate labor between agriculture and gorilla poaching until the value of the marginal product of labor allocated to each activity is equalized. The marginal benefit of labor allocated to poaching consists of two components related to the valuations by the two agents for whom the social planner decides: the term $s\kappa\partial h(\cdot)/\partial N_g$ shows the marginal (financial) value of poaching effort to the local community in terms of the value of the infants captured and sold while the term $-\lambda\partial h(\cdot)/\partial N_g$ shows the marginal (shadow) loss of poaching effort to the Parks Agency in terms of its effect on the gorilla stock.

The first-order condition with respect to antipoaching effort can be stated as

$$\frac{\partial c(\cdot)}{\partial E} = -\lambda\frac{\partial h(\cdot)}{\partial E} + s\kappa\frac{\partial h(\cdot)}{\partial E}. \tag{12'}$$

Equation (12′) states that the social planner should deploy antipoaching effort up to the point where the marginal (financial) cost of the anti-poaching effort $\partial c(\cdot)/\partial E$ is equal to its marginal benefit. The marginal benefit consists of two components related to the valuations by the two agents for whom the social planner decides: the term $-\lambda\partial h(\cdot)/\partial E$ is the marginal (shadow) valuation by the Parks Agency of gorillas saved from poaching through marginal antipoaching enforcement while the term $s\kappa\partial h(\cdot)/\partial E$ is the marginal (financial) valuation by the local community of poaching income lost because of marginal antipoaching enforcement.

The costate equation $\dot{\lambda} - r\lambda = -\partial H^{sp}/\partial G$ reads as

$$\begin{aligned}\frac{\dot{\lambda}}{\lambda} &+ \left[\frac{R'(G) - \partial c(\cdot)/\partial G + s\kappa\partial h(\cdot)/\partial G + Z'(G)}{\lambda}\right] \\ &+ \eta\left(\phi G^{\phi-1} - \frac{(\phi+1)G^{\phi}}{K}\right) - \frac{\partial h(\cdot)}{\partial G} = r.\end{aligned} \tag{13'}$$

The social planner would therefore maintain the gorilla stock at a level that equates the return from gorillas with the return from alternative assets. The return from the gorilla stock is in terms of the change in the marginal valuation of the gorilla stock and stock effects on revenue from gorilla tourism, cost of antipoaching enforcement, revenue from sale of infant gorilla by the local community, natural growth of the gorilla including offtake. In steady state, $\dot{\lambda} = \dot{G} = 0$. From the costate equation (13′) and the stock dynamics equation (7), it can be shown that the steady-state shadow value of the gorilla stock is

$$\lambda^{sp^*} = \frac{R'(G) - \partial c(\cdot)/\partial G + s\kappa\partial h(\cdot)/\partial G + Z'(G)}{\frac{\partial h(\cdot)}{\partial G} - \eta\left(\phi G^{\phi-1} - \frac{(\phi+1)G^{\phi}}{K}\right) + r}. \tag{14'}$$

The steady state equilibrium levels of poaching effort $N_g^{sp^*}$, antipoaching effort E^{sp^*} and the stock of the gorilla G^{sp^*}, can be computed from equations (7), (9′) and (12′). Subsequently, one can solve for the steady state offtake of the gorilla by the local community by substituting these values into the harvesting function $h^{sp^*} = h(G^{sp^*}, E^{sp^*}, N_g^{sp^*})$.

5.1. Comparison with the market equilibrium. The market equilibrium and social optimal levels of poaching effort, antipoaching effort and the stock of the gorilla can be assessed by comparing equations (9) and (12) to (9′) and (12′) respectively. From equations (9) and (9′), the value of marginal product of labor allocated to agriculture is lower and the return from poaching effort is higher in the market equilibrium than in the social planner's solution. Consequently, the value of N_g will be higher in the market equilibrium and lower in the social planner's solution.

Comparing the optimality conditions (12) and (12′) for antipoaching enforcement reveals that $E^* > E^{sp^*}$, i.e., antipoaching enforcement will be higher in the market equilibrium and lower in the social planner's solution.

From the above comparisons, it is therefore clear that the gorilla stock is larger for the social planner, i.e., $G^{sp^*} > G^*$. Comparing equations (14) and (14′), it may be noted that the optimal shadow value of the gorilla stock is higher in the social planner's scenario. This is because the marginal returns in the social planner's solution are higher than in the market equilibrium, since the social planner also takes into account the marginal valuations of the gorilla stock by the local community (i.e., the local community's marginal revenue from poaching and the local community's share of marginal revenue from gorilla tourism).

From the above analysis we can conclude that the market equilibrium gorilla stock in central Africa is suboptimal in the presence of the current revenue sharing scheme. In fact, the gorilla stock will not reach its socially optimal level in the market equilibrium, with or without a revenue sharing scheme. In the case where all tourism-related income accrues to the Park Agency (i.e., $\alpha = 0$), equations (9) and (12) reveal that the market equilibrium amounts of poaching effort and antipoaching enforcement would not be materially different from those in the presence of revenue sharing. Thus, the revenue sharing scheme has no effect on conservation outcomes because it is not internalized by the local community. However, revenue sharing obviously has an effect on community welfare in as far as it provides additional incomes.[19] In order to align market equilibrium with the social planner's solution, a different intervention will be needed.

5.2. Increasing the productivity of agriculture. One of the policies which could be used is to make the agricultural activity more valuable in order to redistribute effort from poaching to agriculture. However, this is only likely to work if the human population does not exceed the carrying capacity of the available agricultural land. If the population is already excessive for the agricultural land available then more valuable agricultural activity would lead to the opening up of parklands for agriculture. In fact, Schulz and Skonhoft [1996] show that policies to conserve wildlife by increasing agricultural productivity in areas neighboring protected areas might be inappropriate because increasing agricultural product prices in an area with massive population pressure will lead to a lower wildlife stock size in the long run. As the area in question is under severe population pressure which is one of the reasons why the local community tolerates poaching so as to free up more land for their agricultural activities rather than gorilla conservation, we will focus on policies such as benefit sharing schemes which do not necessarily increase the scale of agriculture.

5.3. Imposition of optimal poaching fines. On the side of the local community, a market equilibrium outcome similar to the social planner's solution can be achieved by setting the fine in such a way that equations (9) and (9′) are equalized. Starting with equalized marginal benefits of poaching effort, $\lambda\partial h(\cdot)/\partial N_g = \theta(\cdot)\Omega\kappa\partial h(\cdot)/\partial N_g + \Omega\kappa h(\cdot)\partial\theta(\cdot)/\partial N_g$, further manipulation and rearrangement yields for the optimal fine:

$$\Omega^* = \lambda/\kappa[\theta(\cdot) + h(\cdot)\partial\theta(\cdot)/\partial h(\cdot)]. \tag{17}$$

Therefore, instead of setting the fine arbitrarily, the poaching fine has to cover the full cost of poaching actions, which disincentivizes poaching. However, obtaining the necessary information about some of the arguments required to compute the optimal fine is a challenge.[20] Furthermore, an optimal fine does not incentivize the local community to take a long-term view of its interaction with the gorilla stock. As a result, an optimal fine alone will not bring convergence between the market equilibrium and the social planner's solution.

5.4. Assignment of property rights over wildlife to local communities. The devolution of wildlife property rights has been suggested as a solution in literature (see Skonhoft and Solstad [1998] and Songorwa [1999], for example). However, the mere designation of the local community as co-owners of wildlife has not brought sustained conservation practices for some communities (for example, CAMPFIRE communities in Zimbabwe as studied by Fischer et al. [2011]). Such participatory schemes rely heavily on active community involvement in areas such as problem identification, planning, implementation, monitoring and evaluation, (Songorwa [1999]) and the community expects an adequate payoff for their continued engagement. In order for devolution of property rights to positively affect conservation practices, it needs to simultaneously bring tangible benefits to the local communities.

5.5. Instituting a performance-linked benefit sharing scheme. In this section, we analyze a performance-linked benefit sharing scheme in which the Park Agency pays the local community a payment directly linked to the growth in the gorilla stock. Zabel et al. [2011] have also suggested a similar scheme for tiger conservation in India where predation incidents greatly impact households' income and retaliatory killing threatens endangered carnivore species' survival. This alternative benefit sharing scheme has two advantages over the current revenue sharing scheme: the local community's welfare is enhanced as it earns more from the gorilla and the local community is incentivized to take a long-term view of its interaction with the gorilla stock as payments are based on the dynamics of its stock.

To assess its impacts, the proposed alternative benefit sharing scheme can now be incorporated into the local community and Park Agency's maximization problems, where the payment for the growth in the gorilla stock ($\dot{G}$ as defined in equation 7) is denoted by ψ. The local community is now confronted by the following maximization problem, subject to the labor constraint (1)

$$\max_{N_g} \pi_{LOC} = p_a Q(N_a) - wN_a + [s - \theta(E, N_g)\Omega]\kappa h(G, E, N_g) - wN_g + \psi\dot{G}. \tag{18}$$

The first-order condition with respect to poaching effort is given as

$$p_a Q'(\bar{N} - N_g) = s\kappa \frac{\partial h(\cdot)}{\partial N_g} - \theta(\cdot)\Omega\kappa \frac{\partial h(\cdot)}{\partial N_g} - \Omega\kappa h(\cdot) \frac{\partial \theta(\cdot)}{\partial N_g} - \psi \frac{\partial h(\cdot)}{\partial N_g}. \tag{19}$$

Here, the marginal benefit from poaching effort differs from its counterpart in the social planner's solution.[21] However, the comparison between equations (19) and (9′) shows that setting $\Omega = 0$ and $\psi = \lambda$ would align the current expression for the marginal benefit from poaching effort with its counterpart in the social planner's solution. It is thus necessary that the poaching fine is abolished and that the compensation for conservation is equal to the gorilla's shadow price. The aligned expression from the local community's problem would consist of two terms showing marginal valuations by the same agent (unlike two agents in the social planner's solution): the term $s\kappa\partial h(\cdot)/\partial N_g$ shows the marginal (financial) value of poaching effort to the local community in terms of the value of the infants captured and sold while the term $-\lambda\partial h(\cdot)/\partial N_g$ shows the marginal (financial) loss to the local community due to poaching effort displacing payments receivable had there been no additional offtake which could have added to the gorilla stock. Consequently, the local community will desist from poaching as it can earn more from an intact gorilla stock than from poached gorilla, i.e., $\lambda > s\kappa$ and therefore $\psi > s\kappa$.[22]

The Park Agency maximizes the following problem, subject to the dynamics of the gorilla stock in equation (7)

$$\max_{E} \pi_{PAR} = \int_0^\infty [R(G) - c(G, E) + \theta(\cdot)\Omega\kappa h(\cdot) - \psi\dot{G} + Z(G)]e^{-\gamma t} dt. \tag{20}$$

The first-order condition can be expressed as

$$\frac{\partial c(\cdot)}{\partial E} = \Omega\kappa h(\cdot)\frac{\partial \theta(\cdot)}{\partial E} - \lambda\frac{\partial h(\cdot)}{\partial E} + \theta(\cdot)\Omega\kappa\frac{\partial h(\cdot)}{\partial E} + \psi\frac{\partial h(\cdot)}{\partial E}.$$

Given that $\Omega = 0$ and $\psi = \lambda$ for a socially optimal outcome on the local community's side, we would therefore have $\partial c(\cdot)/\partial E = 0$ on the Park Agency's side. Due to the assumption of a convex cost function, this implies that the Park Agency would choose zero antipoaching enforcement. This is a plausible result in that once the local community is adequately incentivized through payment linked to the growth in the gorilla stock it will stop poaching and, therefore, the Park Agency does not need to invest in any antipoaching enforcement. Thus, under the performance-linked benefit sharing scheme we have $E^{pps^*} = 0$. Given that the new equilibrium levels of poaching effort N_g^* and antipoaching effort E^* are zero, the steady-state offtake of the gorilla by the local community also becomes zero, i.e., $h^* = h(G^*, E^* = 0, N_g^* = 0) = 0$. The stock of the gorilla G^* rises to a level consistent with social optimality with no offtake.[23]

To summarize, the proposed benefit sharing scheme involves the Park Agency paying the local community an amount of money directly linked to the growth in the gorilla stock. This scheme would simultaneously require that the fine for poaching the gorilla is set to zero while setting the payment to the local community at ψ, which is equal to the shadow price of gorillas. The performance-linked benefit sharing scheme would guarantee the growth in the gorilla stock to a level consistent with social optimality with no offtake. Since the incentives going to the local community are linked to the gorilla stock, an increase in the stock of the gorilla directly translates into an increase in income going to the local community and therefore enhanced community welfare.

5.6. The Potential for extracting surplus rents. While the above scheme guarantees social optimality, the implementation of such a scheme requires significant financial resources. The payment of ψ (which should equal the shadow value of the gorilla) to the local community implies that the local community receives an amount made up of both the financial and the nonfinancial benefits associated with the gorilla since the shadow value also embodies nonuse values of the gorilla, e.g., existence, bequest, and option values. This poses challenges to the viability of the scheme since the gorilla tourism revenue accruing to the Park Agency is only with respect to the use value of the gorilla.

As a starting point, additional financial resources could be generated by reforming the pricing of gorilla tracking (tourism) permits. Because of ecological considerations, visitors are currently limited to about eight people per group per day (Moyini and Uwimbabazi [2000], Fawcett et al. [2004], ORTPN/IGCP and Homesy [1999] cited in Nielsen and Spenceley [2011]). What are the implications of having a small population of the gorilla such that visitation must be rationed? Since the mountain gorilla is only found in central Africa (i.e., the Virunga Massif and Bwindi Impenetrable National Park), the interdependence between the three Park Agencies controlling these areas has oligopolistic features. The provision of gorilla tourism is therefore characterized by natural barriers to entry, implying that the risk of losing customers to potential entrants or competitors is nonexistent. Therefore the Park Agencies could generate higher revenues by charging prices consistent with their oligopoly nature.

In addition, the international community must have an interest to support conservation financially beyond tourism visits since the price for gorilla tracking permits only equates to the private benefit and not the public benefit associated with the gorilla. External financial support for benefit sharing schemes around gorilla conservation could therefore be the financial expression of $Z(G)$. One practical way for raising external financial support might be to impose a gorilla conservation levy on all international visitors at the ports of entry into the gorilla states. The resultant revenues would then be earmarked for the gorilla benefit sharing scheme. This could therefore help address the potential financial shortfall associated with a performance-linked benefit sharing scheme.

6. Discussion. Local communities will engage in poaching as long as the return from such activities exceeds the returns from alternative activities. This is partly fuelled by the high incidence of poverty in these areas. Therefore, in order to persuade communities living in the vicinity of the gorilla habitat to be partners in gorilla conservation, a stable flow of financial resources linked to their cooperation in gorilla conservation is required. It is important that disbursements are linked to the attainment of specific conservation goals (Ferraro and Simpson [2002], Zabel et al. [2011]) e.g. the growth in the stock of the gorilla. Moreover, it is important to ensure that benefits are shared among all members of the local community to avoid that some reap the benefits while others still have an incentive to poach. This requirement is critical particularly in politically unstable areas.

The proposed performance-linked benefit sharing scheme also requires the Park Agency to do a regular census and thereafter make payments accordingly thereby reducing burden on the regulator and encouraging self-monitoring by the local community. However, conducting gorilla censuses is already the mandate of the Park Agency. In addition, the Park Agency does not need to know anything about the local poaching community's behavior since the proposed scheme is incentive compatible with an inbuilt driver of permanency of good behavior by the local community. Moreover, locals face an implicit fine should they decide to poach as their hidden actions are revealed in the next gorilla census and thus penalized accordingly. With a performance-linked benefit sharing scheme, the local community is effectively locked into a binding contract with the Park Agency and therefore assumes full responsibility for the stock dynamics. Since any action that enhances the gorilla stock directly translates into increased transfers to the local community, the local community might become proactive in resource conservation.

If the importance of tourism in supporting gorilla conservation and the proposed alternative benefit scheme is recognized, then there is a need to consolidate the current tourism gains through the "harmonization" of rules and regulations, as this would reduce costly competition and strengthen collaboration. Since the benefit sharing scheme is mainly about sharing tourism gains, integrating activities would reduce costs and ultimately increase the amount available for gorilla conservation. It would allow the exploitation of country-specific attractions such as active and inactive volcanoes, lakes, bird viewing, and the fascination of different cultures, which could all enrich the tourism experience and boost revenue. At the same time this calls for the implementation of an optimal pricing strategy. The attractiveness of a regional transboundary initiative lies in its possible ability to insulate the economic activities in the area from political instability. Though not addressed directly by this study, this is an area ripe for further investigation.

Another important consideration not directly deriving from this model is the need for the benefit sharing scheme to incorporate the heterogeneity of the Virunga Massif in terms of tourism revenue generation capacity. Some areas are likely to generate less revenue because of infrastructure differences and political instability, in addition to having fewer habituated gorillas. In such instances, Muchapondwa and Ngwaru [2010] argue that benefit sharing will help to solve transboundary environmental conservation problems if there is substantial cross-subsidisation in the short to medium term. It follows that the equalization of benefits across the three countries would assume prominence, since unequal benefit sharing schemes might give rise to unequal cooperation.[24] This is important, given the current variation in the proportions going to local communities in the three countries. Therefore, the focus should be on effectively managing the entire Virunga Massif, rather than portions thereof, in order to consolidate the current gains in gorilla conservation.

7. Conclusion. Conserving the endangered gorilla in Rwanda, Uganda, and the DRC which is characterized by slow population growth and facing a multitude of threats is a daunting task. This paper sets out to investigate the possible resolution of the poaching problem using benefit sharing schemes with local communities. Using a bioeconomic model, the paper demonstrates that the current revenue sharing scheme with the local communities yields suboptimal conservation outcomes. To this end, the paper also considers an alternative benefit sharing scheme which involves the Park Agency paying the local community an amount of money directly linked to the growth in the gorilla stock. It is shown that a performance-linked benefit sharing scheme can achieve socially optimal conservation. Through linking payments to the stock growth, the local community explicitly takes into account the gorilla stock dynamics. The scheme renders poaching effort by the local community, poaching fines on the local community and antipoaching enforcement against the local community unnecessary.

The oligopolistic interdependence between the only three countries offering gorilla tourism offers the prospect of extracting surplus rents which could be channeled toward more gorilla conservation. Given the huge financial outlay requirements for the ideal benefit sharing scheme, the Park Agencies in central Africa could reap more financial benefits for use in conservation if they employ an oligopolistic pricing strategy for gorilla tourism. The dynamic nature and severity of the threats to the gorillas mean that there is need for ongoing, active involvement of all stakeholders. Equal benefit sharing among the three countries could significantly enhance the effectiveness of the benefit sharing scheme. It is therefore important to manage the area as a single park with a common objective.

ENDNOTES

1. Funding from Economic Research Southern Africa (ERSA), FORMAS and Swedish International Development Cooperation Agency (SIDA) is gratefully acknowledged. An earlier version of this paper appears as ERSA Discussion Paper No. 321 and Resources for Future Discussion Paper EfD 12–16.

2. The Virunga National Park was designated a World Heritage Site in 1979 and a World Heritage Site in Danger in 1994. The Volcanoes National Park was created in 1929 and designated a Biosphere Reserve. The Bwindi Impenetrable National Park is also a World Heritage Site in Danger (Lanjouw et al. [2004]).

3. The Virunga region remains largely politically unstable, further increasing threats to gorillas (Kalpers et al. [2003], IUCN [2010]). Bringing an end to the activities of the militia through minimizing the profits from illegal activities could stop the destruction of rain forests and mountain gorillas. In addition, isolation and low population numbers raise concerns about inbreeding (Kalpers et al. [2003], UNEP–WCMC [2003]).

4. Historically, the mountain gorilla has been at risk of extinction from various pressures at different times and in different areas. Threats have encompassed poaching, loss of habitat due to agricultural expansion, illegal cattle grazing, growing human population, destruction and fragmentation of habitat due to logging, mining and charcoal production, climate change, war, and natural epidemics (e.g., Ebola) and the risk of diseases passed from humans to gorillas (a threat to habituated gorillas in areas of gorilla tourism) (Plumptre and Williamson [2001], Robbins et al. [2009], IUCN [2010]).

5. A proposal in 2000 to resettle refugees in the Volcano National Park, and the subsequent deforestation (in 2004) of 15 km^2 in just 1 week for conversion to farmland in the Mikeno sector (NASA [2005]), as well as the sharp increase in timber extraction for the illegal production of charcoal, clearly demonstrate the extent of the threat of habitat loss for gorillas.

6. Currently there are strict rules to regulate tourist visiting times and number of tourists per group, and limiting observation distance to 7 m. A recent contribution by Klailova et al. [2010] argues that among other measures, a minimum observation distance >10 m might be desirable, as humans might alter the behavior of gorillas.

7. Habituation involves the loss of fear of humans before gorillas can be considered suitable for visiting by tourists.

8. As a reviewer pointed out, there are other agents besides the local community who are involved in poaching. However, we only focus on poaching by the local community for two reasons. First, poaching by agents such as the militia require a policy response from national government rather than the parks agency, e.g., deployment of the army. Second, poaching by external agents such as commercial gangs usually gets aided by locals who are more knowledgeable about the area. Once the incentives of the local collaborators have been removed, poaching by external agents will likely subside. In fact, Fischer et al. [2011] show that linking benefits of conversation to the actions of locals can result in significant conservation outcomes even after incorporating poaching by external agents.

9. In reality, even though property rights are well defined, lack of enforcement results in encroachment; but that does not entail legally owning any additional land. Encroachment is a costless process. Since land is fixed, there is direct competition between the two agents. Encroachment of agricultural activities benefits the local communities but at the expense of the Park Agency, as it entails a significant reduction in gorilla habitat.

10. Whenever a key member of a group called a silverback is killed, nursing mothers join a new one. Silverbacks often kill the infants after gaining control (following fights called "interactions") of the group to establish dominance and to induce the females to start bearing infants again.

11. Poaching effort has two effects: infant gorillas are captured and adult gorillas are killed while protecting their infants. Dead adult gorillas can be sold for bushmeat or trophy. However, there is a very small market for this in the Congo Basin (Nellemann et al. [2010]) hence we assume that dead adult gorillas have no value in our model to keep the analysis tractable. Of course, the implicit assumption is that poachers can only be effectively apprehended and fined if found in possession of evidence, i.e., infant gorillas (rather than just a gun even when they have killed an adult gorilla).

12. All the above assumptions are in line with reality: the local community in Rwanda currently gets about 5% of the net revenue; in Uganda 20% of park revenues go the same way (Andersson et al. [2005]); and in the DRC, 30% of the cost of the gorilla tracking permit goes to the local community (Virunga National Park [2010]).

13. Production activities such as actual tourist numbers are not explicitly modeled in the revenue function. Revenue is assumed to be related to the gorilla biomass, and $R(0) = 0$. In addition, $R'(G) > 0$ and $R''(G) \leq 0$, implying that (all other factors remaining constant) a large biomass induces increased tourist visits but at a decreasing rate, as there will be more habituated gorillas to be visited. In reality, the number of visitors allowed depends on both the size of the gorilla group and the number of habituated groups. For example, in the Virunga National Park, six tourists are allowed to visit a gorilla family consisting of 10 or more individuals while only four tourists are permitted to visit a gorilla family with fewer than 10 individuals. While the total number of tourists visiting the gorilla families depends on the number of habituated gorilla families, at present a maximum of 30 tourists are permitted per day (Virunga National Park [2010]).

14. On the one hand, where the public good is national, government incentives are necessary. On the other hand, where the public good is global, trade or international transfers are often needed.

15. The parameter ϕ controls for depensation. If $\phi = 1$, there is no depensation. Depensation dynamics are therefore characterized by $\phi > 1$. The presence of depensatory dynamics affects the potential for recovery (Myers et al. [1995]).

16. One form in which the interaction between the two agents might take is sequential. The local community first chooses poaching effort N_g, based on what it perceives as the likely response from the Park Agency. In the second stage, the Park Agency chooses enforcement effort E after observing the poaching effort by the local community. Such iterations continue until equilibrium values are attained.

17. In reality, Park Agencies may not really be expected to optimize (in the sense of maximizing the present value of net benefits); they may only care about certain ecological outcomes, for example maintaining the stock of gorillas at a specific level. However, in reality they may also have to optimize (in the sense of maximizing the present value of net benefits), given that they need resources for conservation, which is not adequately supported in Africa.

18. It should be noted that by including revenues from poaching we are not judging it as a social good; in fact revenue from poaching is only considered good by certain groups of society not everyone. However, the role of the social planner is to balance the revenues (i.e., goods) and costs (i.e., bads) faced by different groups in society. Accordingly, as long as certain groups find revenue from poaching good (i.e., receive this revenue) then it will necessarily feature positively in the social planner's problem. The inclusion of the benefits of poaching in the social planner's problem is in line with existing literature and reflects the fact that these benefits accrue to a group that is part of the society (see for example Johannesen and Skonhoft [2005]). Excluding revenue from poaching will underestimate the total benefits associated with gorillas and will underestimate the level of incentives required to reduce poaching.

19. In central Africa, the local community's share of proceeds from gorilla tourism is invested in social infrastructure such as schools and water tanks (Nielsen and Spenceley [2011]).

20. While reforming the current revenue sharing scheme by moving toward the optimal fine might move the gorilla conservation toward social optimality, the policy imposes a huge regulatory burden on the Park Agency due to its enormous information requirements. Regulators often do not possess the superior information possessed by poachers who however have no incentive to share it with the regulators. Not only does the Park Agency have to decide how huge the optimal fine (Ω^*) should be, the Agency also has to define the optimal enforcement effort (here the Agency would have to grapple with evaluating the effect of an increase in enforcement officers against initiatives such as giving them additional hi-tech enforcement equipment or upgrading their skills levels). This is further compounded by the fact that the Park Agency interacts with the local community in a dynamic set up and hence an optimal policy could be rendered suboptimal in the next period of interaction.

21. The marginal benefit from poaching effort is also lower than the market equilibrium one shown in equation ($9'$) by the term $\psi\partial h(\cdot)/\partial N_g$.

22. It should be noted that in some ways it seems that the proposed benefit sharing scheme could be quantitatively similar to a high fine policy. However, the truth is that the fine policy is reactive and only affects the local community with a probability of θ while the proposed benefit-sharing scheme is proactive and always affects the local community as long as there is stock growth.

23. As pointed out by one of the reviewers, this result will only emerge when the group of local people is fully homogeneous. If in contrast people would pursue different interests and have different objectives, such that, e.g., only a subgroup receives the conservation payments while the others do not, poaching would not become zero.

24. Due to the high irreplaceability associated with the area, investing in sensitizing the main actors in the Virunga Massif (i.e., local communities, the Park Agency and military rebels) is crucial for gathering support for the benefit sharing scheme.

Appendix

Figure A1 shows the Virunga Conservation Area, which contains the Virunga National Park (Parc National des Virunga) in the Democratic Republic of Congo (DRC), the Mgahinga Gorilla National Park in Uganda, the Volcanoes National Park (Parc National des Volcans) in Rwanda and the Bwindi Impenetrable National Park (BINP) in south-west Uganda, on the border with the DRC.

FIGURE A1. The distribution of the mountain gorilla (*Gorilla beringei beringei*). *Source:* International Gorilla Conservation Programme (IGCP).

REFERENCES

W.M. Adams and M. Infield [2003], *Who is on the Gorilla's Payroll? Claims on Tourist Revenue from a Ugandan National Park*, World Dev. **31**, 177–190.

P. Andersson, S. Croné, J. Stage, and J. Stage [2005], *Potential Monopoly Rents from International Wildlife Tourism: An Example from Uganda's Gorilla Tourism*, Eastern Africa Soc. Sci. Res. Rev. **21**, 1–18.

D.K. Binyeri, D.M. Hibukabake, and C.S. Kiyengo [2002], *The Mikeno Gorillas*, Gorilla J. **25**, 5–7.

Convention on Migratory Species of Wild Animals [2008], *Agreement on the Conservation of Gorillas and their Habitats*, Retrieved 31 January 2010, from http://www.cms.int/species/gorillas/

R. Damania, R. Stringer, K.U. Karanth, and B. Stith [2003], *The Economics of Protecting Tiger Populations: Linking Household Behavior to Poaching and Prey Depletion*, Land Econ. **79**, 119–216.

P.J. Ferraro and R.D. Simpson [2002], *The Cost-Effectiveness of Conservation Payments*, Land Econ. **78**, 339–353.

C. Fischer, E. Muchapondwa, and T. Sterner [2011], *A Bio-Economic Model of Community Incentives for Wildlife Management under CAMPFIRE*, Environ. Res. Econ. **48**(2), 303–319.

International Gorilla Conservation Programme (IGCP) [2010], *Census Confirms Increase in Population of the Critically Endangered Virunga Mountain Gorillas*, Retrieved 17 December 2010, from http://www.igcp.org/2010-mountain-gorilla-census/

International Gorilla Conservation Programme (IGCP) [2011], *Tourism*, Retrieved 3 January 2011, from http://www.igcp.org/gorillas/tourism/

International Union for Conservation of Nature (IUCN) [2010], *IUCN Red List of Threatened Species*, Retrieved 18 December 2010, from http://www.iucnredlist.org

A.B. Johannesen and A. Skonhoft [2005], *Tourism, Poaching and Wildlife Conservation: What Can Integrated Conservation and Development Projects Accomplish?* Res. Energy Econ. **27**, 208–226.

J. Kalpers, E.A. Williamson, M.M. Robbins, A. Mcneilage, A. Nzamurambaho, N. Lola, and G. Mugiri [2003], *Gorillas in the Crossfire: Population Dynamics of the Virunga Mountain Gorillas over the Past Three Decades*, Oryx **37**, 326–337.

M. Klailova, C. Hodgkinson, and P. C. Lee [2010], *Behavioral Responses of One Western Lowland Gorilla (Gorilla gorilla gorilla) Group at Baihokou, Central African Republic to Tourists, Researchers and Trackers*, American J. Primatolo. **72**, 897–906.

A. Lanjouw, A. Kayitare, H. Rainer, E. Rutagarama, M. Sivha, S. Asuma and J. Kalpers [2004], *Beyond Boundaries: Transboundary Natural Resource Management for Mountain Gorillas in the Virunga-Bwindi Region,* Biodiversity Support Program, Washington, DC, USA.

A. McNeilage, M.M. Robbins, M. Gray, W. Olupot, D. Babaasa, R. Bitariho, A. Kasangaki, H. Rainer, S. Asuma, G. Mugiri, and J. Baker [2006], *Census of the Mountain Gorilla Population in Bwindi Impenetrable National Park, Uganda*, Oryx **40**, 419–427.

Y. Moyini and B. Uwimbabazi [2000], *Analysis of the Economic Significance of Gorilla Tourism in Uganda.* International Gorilla Conservation Programme, Kampala, Uganda.

E. Muchapondwa and T. Ngwaru [2010], *Modelling Fugitive Natural Resources in the Context of Transfrontier Parks: Under what Conditions will Conservation be Successful in Africa*? ERSA Working Paper No. 170 (March), Economic Research Southern Africa (ERSA), Cape Town, South Africa.

R.A. Myers, N.J. Barrowman, J.A. Hutchings, and A.A. Rosenberg [1995], *Population Dynamics of Exploited Fish Stocks at Low Population Levels*, Science **269**(5227), 1106–1108.

National Aeronautics and Space Administration (NASA) [2005], *Gorillas in the Midst of Extinction*, Retrieved 3 January 2011, from http://www.nasa.gov/vision/earth/lookingatearth/gorillas.html.

C. Nellemann, I. Redmond, and J. Refisch (Eds.) [2010], *The Last Stand of the Gorilla – Environmental Crime and Conflict in the Congo Basin: A Rapid Response Assessment*, United Nations Environment Programme/GRID-Arendal, Norway.

H. Nielsen and A. Spenceley [2011], *The Success of Tourism in Rwanda – Gorillas and More*, (P. Chuhan-Pole and M. Angwafo, eds.), *Yes Africa Can: Success Stories from a Dynamic Continent*, The International Bank for Reconstruction and Development/The World Bank, Washington DC, pp. 231–249.

A.J. Plumptre and E.A. Williamson [2001], *Conservation Oriented Research in the Virunga Region*, in (M.M. Robbins, P. Sicotte, and K. Stewart, eds.), *Mountain Gorrillas: Three Decades of Research at Karisoke*, Cambridge University Press, Cambridge, pp. 361–390.

M.M. Robbins, M. Gray, E. Kagoda, and A. M. Robbins [2009], *Population Dynamics of the Bwindi Mountain Gorillas*, Biolog. Conserv. **142**, 2886–2895.

C.E. Schulz and A. Skonhoft [1996], *Wildlife Management, Land-Use and Conflicts*, Environ. Dev. Econ. **1**, 265–280.

A. Skonhoft [1998], *Resource Utilisation, Property Rights and Welfare – Wildlife and the Local People*, Ecolog. Econ. **26**, 67–80.

A. Skonhoft and J. T. Solstad [1996], *Wildlife Management, Illegal Hunting and Conflicts. A Bioeconomic Analysis*, Environ. Dev. Econ. **1**, 165–181.

A. Skonhoft and J.T. Solstad [1998], *The Political Economy of Wildlife Exploitation*, Land Econ. **74**, 16–31.

A.N. Songorwa [1999], *Community-Based Wildlife Management (CWM) in Tanzania: Are the Communities Interested?* World Dev. **12**, 2061–2079.

UNEP – WCMC [2003], *Report on the Status and Conservation of the Mountain Gorilla: Gorilla gorilla beringei*, United Nations Environment Programme – World Conservation Monitoring Centre.

UNEP [Undated], *Great Apes Survival Project Fact Sheet*, United Nations Environment Programme. Retrieved 30 November, 2010, from http://www.unep-wcmc.org/species/great_apes/GRASP_5_complete.pdf

Virunga National Park [2010], *Visiting Mountain Gorillas in Virunga. All You Need To Know*. Retrieved 31 January 2010, from http://gorillacd.org/2010/08/20/visiting-mountain-gorillas-in-virunga-all-you-need-to-know/

E.A. Williamson and K.A. Fawcett [2008], *Long-Term Research and Conservation of the Virunga Mountain Gorilla*, in (R. Wrangham and E. Ross, eds.), *Science and Conservation in African Forests: The Benefits of Long-Term Research*, Cambridge University Press, Cambridge, UK, pp. 213–229.

A. Zabel, K. Pittel, G. Bostedt, and S. Engel [2011], *Comparing Conventional and New Policy Approaches for Carnivore Conservation: Theoretical Results and Application to Tiger Conservation*, Environ. Res. Econ. **48**(2), 287–301.