Institute for Economic Studies, Keio University

Keio-IES Discussion Paper Series

Trophy Hunting Restrictions and Land Use in Private Land Conservation Areas: A Bioeconomic Analysis

Zijin Xie

22 March, 2023
DP2023-007
https://ies.keio.ac.jp/en/publications/22464/

Institute for Economic Studies, Keio University
2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan
ies-office@adst.keio.ac.jp
22 March, 2023

Trophy Hunting Restrictions and Land Use in Private Land Conservation Areas: A Bioeconomic Analysis

Zijin Xie

Keio-IES DP2023-007
22 March, 2023
JEL Classification: Q57, Q2, Q26
Keywords: Bioeconomic modeling, Lion hunting; PLCA, Tourism, Trophy hunting, Wildlife conservation

Abstract

This study investigated how bans/restrictions on trophy hunting affect wildlife conservation in private land conservation areas (PLCAs). We developed a bioeconomic model to examine wildlife and land utilization in a fixed-size PLCA with a land manager. We calibrated the model for the lion-hunting industry in PLCAs in South Africa. The model simulates the impact of trophy-hunting restrictions on the lion population under different management scenarios. We demonstrated that restrictions on trophy hunting would be effective if wildlife-based tourism is an alternative land use to trophy hunting. However, the restrictions on trophy hunting will negatively affect the wildlife (lion) population if alternative land use is not wildlife-based. Although wildlife-based tourism is considered a positive alternative to trophy hunting, it is more vulnerable to external shocks than trophy hunting. Our results suggest that international bans/restrictions on trophy hunting should be cautiously imposed, particularly in the context of the global pandemic, which has had a devastating effect on wildlife-based tourism.

Zijin Xie
Faculty of Economics, Keio University
2-15-45, Mita, Minato-ku, Tokyo 108-8345, Japan
xiezijin@keio.jp

Acknowledgement : This research was supported by the JST SPRING (grant number JPMJSP2123). The author also appreciates the support of the 2020 SEEPS Research Fund for Graduate Students. This study was presented at the 2021 Annual Conference of the Society for Environmental Economics and Policy Studies.

Trophy Hunting Restrictions and Land Use in Private Land Conservation Areas: A Bioeconomic Analysis

Zijin Xie*

Faculty of Economics, Keio University

Abstract

This study investigates how bans/restrictions on trophy hunting affect wildlife conservation in private land conservation areas (PLCAs). We develop a bioeconomic model to examine wildlife and land utilization in a fixed-size PLCA with a land manager. We calibrate the model for the lion-hunting industry in PLCAs in South Africa. The model simulates the impact of trophy-hunting restrictions on the lion population under different management scenarios. We demonstrate that restrictions on trophy hunting would be effective if wildlife-based tourism is an alternative land use to trophy hunting. However, the restrictions on trophy hunting will negatively affect the wildlife (lion) population if alternative land use is not wildlife-based. Although wildlife-based tourism is considered a positive alternative to trophy hunting, it is more vulnerable to external shocks than trophy hunting. Our results suggest that international bans/restrictions on trophy hunting should be cautiously imposed, particularly in the context of the global pandemic, which has had a devastating effect on wildlife-based tourism.

Keywords: Bioeconomic modeling; Lion hunting; PLCA; Tourism; Trophy hunting; Wildlife conservation

---

*Faculty of Economics, Keio University, 2-15-45, Mita, Minato-ku, Tokyo 108-8345, Japan. E-mail: xiezijin@keio.jp

1 Introduction

The debate over whether trophy hunting should be banned gained momentum after the iconic animal—Cecil the lion—was hunted by an American trophy hunter in 2015. The incident was widely reported and sparked international outrage over trophy hunting on social media, which led to campaigns against trophy hunting. Under public pressure, some developed countries that are the main markets of the trophy-hunting industry have implemented several bans or restrictions on the import of wildlife trophies[1].

However, scientists have consistently expressed concerns regarding bans or restrictions on trophy hunting and their transportation. The trophy-hunting industry has been a significant financial stimulant for Sub-Saharan countries and has contributed to the conservation of large areas of natural habitats (Lindsey et al., 2007). Several studies have highlighted that an outright ban on trophy hunting will accelerate the loss of biodiversity due to the loss of the main financial resource for conservation[2].

Trophy hunting remains vital for private land conservation areas (PLCAs) as the primary source of financial income (Parker et al., 2020; Taylor et al., 2020). In South Africa, the area classified as PLCA is twice that of state-owned protected areas (Parker et al., 2020). The trophy-hunting industry incentivizes careful wildlife management in PLCAs because high-quality wildlife trophies are extremely profitable. Although the contribution of trophy hunting toward wildlife conservation remains controversial, Lindsey et al. (2007) and Cooney et al. (2017) documented several successful conservation cases under PLCAs in South Africa, which were attributed to the trophy-hunting

---

[1] France and Australia immediately stopped importing and exporting lion trophies in 2015, and the UK imposed a strict ban on trophy-hunting imports in 2021 (Manning, 2021).

[2] See for example Di Minin et al. (2016) and Sills et al. (2019).

industry.

Therefore, it is believed that a ban or restrictions on trophy hunting may impede wildlife conservation in PLCAs. For PLCAs that do not receive government grants, any forms of ban or restriction on trophy hunting would eliminate the landowner's financial incentive for wildlife management, which increases the risk of extensive habitat loss and poaching.

Consequently, it is essential to understand how bans and restrictions on trophy hunting affect wildlife conservation in PLCAs. Notably, Parker et al. (2020) interviewed PLCA landowners about their attitude toward a potential ban on trophy hunting. They found that 90% of the interviewees claimed that a blanket ban on trophy hunting would negatively impact their livelihood, and 63% would change their wildlife-based land use (i.e., trophy-hunting area) to other non-wildlife-based land uses (e.g., livestock farming or cultivation). Naidoo et al. (2016) demonstrated that a blanket ban on trophy hunting will render a large conservation area unprofitable and decrease the number of communal conservancies in Namibia. However, these studies only discussed the effect of a potential outright ban on trophy hunting. However, research on the impact of external restrictions on trophy hunting, such as restricting the import and export of wildlife trophies, on wildlife conservation in PLCA remains scarce. Although some African countries—such as Kenya—have imposed a complete ban on trophy hunting, external restrictions on trophy hunting led to a significant loss of profits for other countries that rely on revenue from trophy hunting—such as South Africa (Ngounou, 2022). Therefore, this study focuses on the effects of exogenous restrictions instead of a blanket ban.

This study addresses the effect of an external ban or restrictions on trophy hunting (hereafter referred to as trophy-hunting restrictions) on the imports of wildlife trophies and wildlife conservation in PLCAs. We examine a fixed-size PLCA with any of the following land-use types: (1) land used for wildlife-based tourism and trophy hunting and (2) land divided for agriculture and trophy hunting. First, we develop a theoretical model to describe the management of PLCA for each land-use type. In addition, the PLCA managers may or may not share property rights with wildlife populations[3]. Thus, we consider two property rights regimes. Then, we compare the effect of trophy-hunting restrictions on the lion trophy-hunting industry in PLCAs in South Africa, considering the above-mentioned land-use types and property rights regimes.

The numerical analysis reveals that the impact of trophy-hunting restrictions on wildlife conservation depends on alternative land use. Particularly for the second land-use type, external trophy-hunting restrictions are expected to decrease wildlife (lion) populations in the long term because it can be optimal for land managers to reduce the hunting area's size under such restrictions, irrespective of whether they share property rights. Therefore, if alternative land use is not wildlife-based, reducing hunting area causes habitat loss, decreasing wildlife populations.

Our work contributes to the bio-economic literature on trophy hunting and protected area management. While we focus on the effect of trophy-hunting restrictions, previous studies have modeled protected area management with trophy hunting and/or poaching behaviors of locals. For example, Skonhoft and Solstad (1998) suggested that giving property rights to locals can reduce their poaching behavior, which increases wildlife populations. In a series of related studies, Johannesen and Skonhoft (2005), Johannesen (2006), Fischer et al. (2010), and Winkler (2011) focused on introducing economic incentives to prevent locals from poaching. In particular, they explore the ef-

---

[3] The owners and managers of a PLCA could be different (Stolton et al., 2014).

fect of a benefit-sharing protected area management scheme that transfers a part of the profits from tourism and/or trophy hunting to locals[4]. Although Winkler (2011) and Rondeau and Bulte (2007) considered hunting as land use for wildlife habitats, their main focus was on promoting wildlife conservation by preventing wildlife poaching. In this study, we do not explicitly include the poaching behavior of locals but focused on managing a PLCA under trophy-hunting restrictions.

The remainder of this paper is organized as follows. Section 2 discusses a theoretical model that describes management in a PLCA. Section 3 describes the model's application to the lion trophy-hunting industry in PLCAs in South Africa. Section 4 discusses the results and concludes the study.

2 The Model

Let us consider a fixed-size PLCA with a land manager. This PLCA has two types of land uses: (1) land used for trophy hunting and tourism and (2) land used for trophy hunting and agricultural activities[5]. Regardless of the land-use type, the manager optimizes profits by delimiting the area for trophy hunting and tourism/agriculture.

2.1 Land-use type 1: PLCAs with trophy hunting and tourism

We first consider the case wherein the fixed-size area is split into regions for hunting and tourism. The manager delimits the size of the hunting and tourism area, which directly affects the corresponding revenue. In addition, we assume that tourism and

---

[4] Such a management scheme is called integrated conservation development projects (ICDPs) or community-based natural resource management (CBNRM).

[5] According to Parker et al. (2020), trophy hunting is not the only source of income for PLCAs. Revenue from trophy hunting accounts for an average of 36% of the total revenue. Other income resources include eco-tourism and agriculture.

hunting activities are limited to their respective areas, even though wildlife can roam freely across the two regions[6].

The land manager, who maximizes the present value of the net profits from trophy hunting and tourism, has the following objective function:

$$\begin{aligned} \max_{\{H_t\}_0^\infty} \quad \pi &= \sum_{t=0}^{\infty} \rho^t [(1-c)R(h_t) + W(V_t, X_t)] \\ &= \sum_{t=0}^{\infty} \rho^t [(1-c)R(\alpha H_t) + W(L-H_t, X_t)] \end{aligned} \tag{1}$$

$$\text{s.t.} \quad X_{t+1} - X_t = F(X_t) - \alpha H_t, X_0 > 0 \text{ given}, R_h > 0, R_{hh} < 0, h_t \equiv \alpha H_t,$$

$$V_t \equiv L - H_t, W_V > 0, W_{VV} < 0, W_X > 0, W_{XX} < 0, F_X \gtreqless 0, F_{XX} < 0$$

$(1-c)R(h_t)$ refers to the benefit from trophy hunting during period t; $h_t \equiv \alpha H_t$ is the offtake for wildlife quota, and H_t is the size of the hunting area[7]. Trophy-hunting restrictions are modeled by assuming that restrictions can decrease the benefit of trophy hunting (increased c) or offtake rate of the hunting quota (decreased α)[8]. Furthermore, $W(V_t, X_t)$ is the income from tourism, which is a function of the size of the area for tourism denoted by $V_t \equiv L - H_t$ and wildlife populations in the PLCA denoted by X_t[9]. The profits from trophy hunting and tourism change according to the change in wildlife stock $X_{t+1} - X_t$—the difference between bio-growth $F(X_t)$ and the hunting quotas αH_t. Additionally, ρ represents the discount factor, and $\rho \equiv 1/(1+\delta)$, where δ denotes the capital interest rate.

---

[6] We assume that although wildlife can migrate freely between the two regions, they are evenly distributed throughout the conservation area. There are studies on wildlife migration between management borders (e.g., Johannesen (2007)).

[7] Quota-setting methodology remains problematic for the trophy-hunting industry due to the lack of transparency (Lindsey et al., 2013). Hurt and Ravn (2000) mentioned that hunting quotas are usually based on the following: "(i) size of the area, (ii) type of habitat, (iii) density of species, and (iv) offtake in the previous year" (p. 308). For simplicity, we assume that the hunting quota h_t is based on the size of the hunting area H_t.

[8] Trophy import restrictions affect wildlife species profitability. Limiting the offtake rate of hunting quota is also a form of restriction (IUCN, 2016).

[9] In period t, wildlife population in the tourism area is $X_t/L * V_t$.

The Lagrangian for this problem is as follows:

$$\mathscr{L} = \sum_{t=0}^{\infty} \rho^t \{(1-c)R(\alpha H_t) + W(L - H_t, X_t) + \rho\lambda_{t+1}[X_t + F(X_t) - \alpha H_t - X_{t+1}]\} \quad (2)$$

The first-order conditions for the manager are as follows:

$$\frac{\partial \mathscr{L}}{\partial H_t} = \rho^t\{(1-c)\alpha R_{h_t} - W_{V_t} - \alpha\rho\lambda_{t+1}\} = 0 \quad (3)$$

$$\frac{\partial \mathscr{L}}{\partial X_t} = \rho^t\{W_{X_t} + \rho\lambda_{t+1}(1 + F_{X_t})\} - \rho^t\lambda_t = 0 \quad (4)$$

$$\frac{\partial \mathscr{L}}{\partial \rho\lambda_{t+1}} = \rho^t\{X_t + F(X_t) - \alpha H_t - X_{t+1}\} = 0 \quad (5)$$

(3) implies that a profit-maximizing manager expands hunting land until the marginal net benefit of hunting $(1-c)\alpha R_{h_t} - W_{V_t}$ equals the discounted shadow price of the wildlife stock in period $t+1$ for trophy hunting. (4) reveals that for optimal management, the shadow price λ_t equals the marginal net benefit W_{X_t} with the discounted marginal benefit of an unharvested unit of stock in the next period $\rho\lambda_{t+1}(1 + F_{X_t})$.

(3)∼(5) imply a steady state where $X_{t+1} = X_t = X^*$, $H_{t+1} = H_t = H^*$, and $\lambda_{t+1} = \lambda_t = \lambda^*$. Consequently, in steady-state equilibrium, (3)∼(5) can be written as follows:

$$(1-c)\alpha R_h - W_V = \alpha\rho\lambda \quad (6)$$

$$\rho\lambda(\delta - F_X) = W_X \quad (7)$$

$$F(X) = \alpha H \quad (8)$$

Rearranging (6)∼(8) and using the definition of the discount factor $\rho \equiv 1/(1+\delta)$, we derive the *fundamental equation of renewable resources*

$$\frac{W_X}{(1-c)\alpha R_h - W_V/\alpha} + F_X = \delta. \tag{9}$$

The LHS of (9) is referred to as the *resource's rate of return*, which is the sum of the marginal stock effect (the ratio of marginal net hunting revenue to marginal tourism revenue) and marginal growth rate (Conrad, 2010). (9) indicates that the resource's rate of return should be equal to the interest rate under optimal management. Furthermore, (6)∼(8) imply that $dX/dc > 0$ and $dX/d\alpha < 0$ if $F_X < 0$ and W_{XV} are sufficiently small, ceteris paribus. See Appendix.

2.2 Land-use type 2: PLCAs with trophy hunting and agriculture

In cases where land is used for trophy hunting and agriculture, the manager maximizes the sum of the revenue by determining the size of the area for hunting and agriculture. Thus, the following defines the problem for the manager:

$$\begin{aligned} \max_{\{H_t\}_0^\infty} \quad & \pi = \sum_{t=0}^{\infty} \rho^t [(1-c)R(h_t) + Q(A_t, X_t)] \\ & \quad = \sum_{t=0}^{\infty} \rho^t [(1-c)R(\alpha H_t) + Q(L - H_t, X_t)] \\ \text{s.t.} \quad & X_{t+1} - X_t = F(X_t, H_t) - \alpha H_t, X_0 > 0 \text{ given}, R_h > 0, R_{hh} < 0, \\ & A_t \equiv L - H_t, Q_A > 0, Q_{AA} < 0, Q_X < 0, Q_{XX} < 0, \\ & F_X \gtreqless 0, F_{XX} < 0, F_H > 0 \end{aligned} \tag{10}$$

$Q(A_t, X_t)$ is the revenue from agricultural production, which is a function of the size of the agricultural land A_t and wildlife stock X_t. We consider that $Q_{X_t} < 0$ because wildlife stock causes damage to agricultural production in farms near the predator's habitat. The wildlife stock changes according to the bio-growth function $F(X_t, H_t)$ and the hunting quotas αH_t. Notably, the bio-growth function depends on the wildlife stock X_t and size of the hunting land H_t[10]. This implies that the expansion of agricultural land reduces the ability of the land to support wildlife. In addition, we suppose that the land used for hunting can be converted into farmland immediately without cost (and vice versa).

The Lagrangian for this problem is as follows:

$$\mathscr{L} = \sum_{t=0}^{\infty} \rho^t \{(1-c)R(\alpha H_t) + Q(L - H_t, X_t) + \rho\lambda_{t+1}[X_t + F(X_t, H_t) - \alpha H_t - X_{t+1}]\} \quad (11)$$

The first-order conditions are as follows:

$$\frac{\partial \mathscr{L}}{\partial H_t} = \rho^t \{(1-c)\alpha R_{h_t} - Q_{A_t} - \rho\lambda_{t+1}(\alpha - F_{H_t})\} = 0 \quad (12)$$

$$\frac{\partial \mathscr{L}}{\partial X_t} = \rho^t \{Q_{X_t} + \rho\lambda_{t+1}(1 + F_{X_t})\} - \rho^t \lambda_t = 0 \quad (13)$$

$$\frac{\partial \mathscr{L}}{\partial \rho\lambda_{t+1}} = \rho^t \{X_t + F(X_t, H_t) - \alpha H_t - X_{t+1}\} = 0 \quad (14)$$

(12) implies that under conditions of optimum management, the marginal net benefit of trophy hunting equals the discounted shadow price of the wildlife stock in the next period multiplied by the net marginal effect of hunting land on the dynamics of the wildlife stock. According to (13), the shadow price of the wildlife stock in period t

---

[10] We assume that the bio-growth function F is a logistic function, which depends on X_t, the intrinsic growth rate of wildlife, and carrying capacity. Since the carrying capacity of wildlife is positively associated with the size of wildlife habitat (Griffen and Drake, 2008), the size of the agricultural area negatively affects the carrying capacity.

equals the marginal wildlife damage on agricultural production Q_{X_t} along with the discounted marginal benefit of an unharvested unit of the stock in the next period $\rho\lambda_{t+1}(1 + F_{X_t})$.

(12)∼(14) imply a steady state, where $X_{t+1} = X_t = X^*$, $H_{t+1} = H_t = H^*$, and $\lambda_{t+1} = \lambda_t = \lambda^*$, solving

$$(1 - c)\alpha R_h - Q_A = \rho\lambda(\alpha - F_H) \tag{15}$$

$$\rho\lambda(\delta - F_X) = Q_X \tag{16}$$

$$F(X, H) = \alpha H \tag{17}$$

Thus, we can derive the *fundamental equation of renewable resources*:

$$\frac{Q_X}{(1 - c)\alpha R_h - Q_A/(\alpha - F_H)} + F_X = \delta. \tag{18}$$

Ceteris paribus reveals that the impact of hunting restrictions on steady-state wildlife populations can be ambiguous. The comparative static results and derivations are presented in the appendix. In the next section, we numerically show the asymmetric path of how X_0 converges with X^* under trophy-hunting restrictions[11].

3 Numerical Application

This section applies the theoretical model with specific function forms to a numerical simulation of lion trophy hunting in South Africa.

Trophy hunting generates enormous revenue for the conservation of wildlife and corresponding habitat in Southern African countries. Lion trophies, one of the most

---

[11] Also known as the optimal path approach method (Conrad, 2010).

valuable wildlife trophies, are significantly profitable for South Africa—the world's largest exporter of lion trophies (Lindsey et al., 2012). However, the global public condemned the lion trophy-hunting industry, especially after Cecil the lion was killed. Importing lion trophies has been banned in some developed countries, including Australia, France, and the UK. PLCA managers turn to ecotourism and livestock farming as alternative land uses in the face of a ban on trophy hunting (Parker et al., 2020). The lion trophy-hunting situation is similar to the problem of PLCA management discussed in the previous section.

3.1 Functional forms and parameterization

The revenue from trophy hunting, that is, $R(h_t)$, depends on selling the hunting quotas represented by $h_t = \alpha H_t$. We assume that the hunting revenue under the restriction on the trophy price during period t is given by:

$$(1-c)R(\alpha H_t) = (1-c)P_H(\alpha H_t)^{\gamma} \tag{19}$$

where P_H is the per-unit price of the hunting quota, c represents the exogenous restrictions on the trophy price, and γ is the production elasticity of hunting quotas in generating revenue.

For revenue from tourism, extant literature suggests that increasing the density of the lion population X_t/L and tourism area $V_t = L - H_t$ increases tourism revenue $W(L-H_t, X_t)$ for PLCAs (Clements et al., 2016; Naidoo et al., 2011). Thus, we assume that tourism revenue takes the following form:

$$W(L - H_t, X_t) = P_W(L - H_t)^{\theta}(X_t/L)^{1-\theta} \tag{20}$$

where P_W is a scaling factor, and θ is the production elasticity of the land area that generates tourism revenue.

In cases where the land is unsuitable for tourism, we postulate that livestock farming is the alternative land use to hunting. Since agricultural production $Q(A_t, X_t)$ depends on the size of the farmland $A_t = L - H_t$, its proportion $D(X_t, A_t)$ will be destroyed by predators X_t. For simplicity, we postulate that the proportion of agricultural products damaged by wildlife D is a linear function of X_t and A_t, which is $D(X_t, A_t) = dX_tA_t$. Thus, we define revenue from agricultural production as follows:

$$Q(A_t, X_t) = P_A(1 - dX_tA_t)(A_t)^{\mu}, \text{ with } A_t = L - H_t \tag{21}$$

where P_A is the price of agricultural products (i.e., a scaling factor for farming productivity), d denotes the proportion of agricultural products destroyed by wildlife, and μ is the production elasticity of farmland.

The lion population has grown according to a logistical growth function.

$$F(X_t) = rX_t(K - X_t) \tag{22}$$

where r refers to the intrinsic growth rate, and K represents the carrying capacity. Since the carrying capacity is associated with habitat size, we define K as a linear function of habitat size. In other words, for land-use type 1, the bio-growth function can be written as $F(X_t) = rX_t(\phi L - X_t)$ and for land-use type 2, it becomes $F(X_t, H_t) = rX_t(\phi H_t - X_t)$, where ϕ is the size of the lion population per unit of land can support.

Subsequently, we can apply the model to lion trophy hunting in PLCAs, with plausible parameter values. In South Africa, lion hunts are generally sold as all-inclusive hunt packages with a mid-price of US\$ 30542 ± 3523 (Lindsey et al., 2012). Thus, we established the trophy price of $P_H = 3.3$ (10 thousand US\$). Lion trophy exports from South Africa averaged 758 trophies in 2009–2010 (Lindsey et al., 2012), and the size of the hunting land was estimated at 160,000 km^2 (Lindsey et al., 2007). Accordingly, we estimate an offset rate of $\alpha = 758/16000 \approx 0.004$ lions/km^2.

For revenue generated from lion tourism, Clements et al. (2016) estimated the relationship between tourism income and lion density using survey data from 71 PLCAs managers in South Africa. Following this empirical study, the elasticity of lion density for generating tourism revenue is $1 - \theta = 0.55$, and the scaling factor for tourism productivity is $P_W = 1$ (10 thousand US\$).

Compared with the wildlife-based revenue from hunting and tourism, income from agricultural production constitutes a relatively small portion of PLCAs' total revenue (Parker et al., 2020). Even though economic data for agricultural production in PLCAs are challenging to find, an estimate of the impact of several factors on agricultural production in sub-Saharan countries is provided by Barrios et al. (2008). They show that the production elasticity of land is 0.539∼0.576; therefore, we set $\mu = 0.558$. We assume a scaling factor for agriculture of $P_A = 0.2$ and a wildlife damage rate of $d = 0.00001$.

Finally, Miller and Funston (2014) reported that the lion population in South Africa's small reserves grew at a rate of 1∼2. Thus, we set the lion growth rate as

Table 1: Parameter values

Economic parameters	Source	Biological and harvest parameters	Source
$P_H = 3.3$	Lindsey et al. (2012)	$L = 300$	Parker et al. (2020)
$\gamma = 0.9$	-	$r = 0.015$	Miller and Funston (2014)
$P_W = 1$	Clements et al. (2016)	$\phi = 0.12$	Hayward et al. (2007)
$1 - \theta = 0.55$	Naidoo et al. (2011)	$X_0 = 15$	Clements et al. (2016)
$P_A = 0.2$	-	$\delta = 0.01$	-
$\mu = 0.558$	Barrios et al. (2008)	$\alpha = 0.004$	Lindsey et al. (2012)
$d = 0.00001$	-		

$r = 0.015$. Hayward et al. (2007) estimated the carrying capacity of large carnivores in South Africa as 0.12 lions /km^2, so $\phi = 0.12$. Moreover, the size of the PLCA land ranged from 0.1$\sim$543.8 km^2 in South Africa (Parker et al., 2020); thus, we assume that the PLCA's land area is $L = 300$ km^2. The density of the lion population in different PLCAs vary according to the available prey, with an average value of 0.048 million /km^2 (Clements et al., 2016). Accordingly, we assume $X_0 = 0.05 * 300 = 15$ lions. Table 1 summarizes the parameter values.

3.2 Results

3.2.1 Land-use type 1

We first consider the case wherein the manager has property rights over lions under land-use type 1. Here, the land manager determines H_t while considering the lion population's dynamics. Substituting the parameter values in Table 1 into (1), we use Solver to numerically derive the approach paths of X_t under different scenarios. For tractability, we assume that trophy-hunting restrictions decrease the offtake rate α or the price of hunting quota P_H (i.e., increase c).

Figure 1 depicts the approach paths for different scenarios. In the absence of trophy-hunting restrictions, we observe that $X_t \to 33.72$ as $t \to 19$ (grey line). However, after imposing restrictions, $X_t \to 33.79$ as $t \to 21$ if P_H is reduced by 30% (dashed line), and $X_t \to 34.97$ as $t \to 17$ if $\alpha = 0.002$ (dotted line). This implies that trophy-hunting restrictions positively affect the lion population.

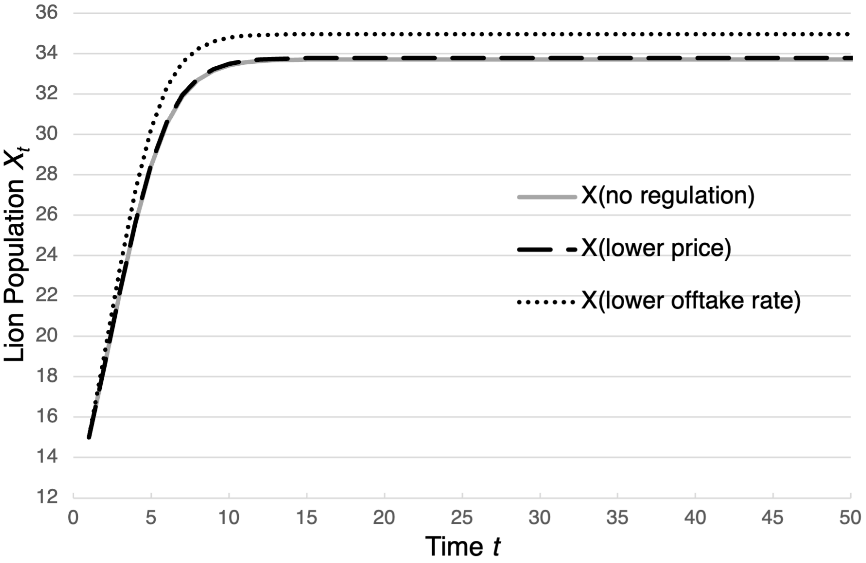

Figure 1: Approach paths of X_t under land-use type 1, wherein the manager has property rights over lions

We also consider the case wherein the manager does not have property rights over lions. In this case, the manager is a myopic harvester who does not consider the lion population's dynamics while determining H_t. In other words, a myopic manager's problem can be stated as follows:

$$\begin{aligned} \max_{H_t} \quad \pi &= (1-c)R(h_t) + W(V_t, X_t) \\ &= (1-c)R(\alpha H_t) + W(L - H_t, X_t) \end{aligned} \tag{23}$$

This myopic manager determines H_t based on the first-order condition of (23), which is $(1-c)\alpha R_{h_t} = W_{V_t}$. Given that $X_0 = 15$, we can solve for H_0 by substituting the parameter values in Table 1 into this first-order condition. Subsequently, X_1 can be derived from the interactive map $X_1 = F(X_0) - \alpha H_0$. We repeat this process $t = T$ times to derive the lion population's dynamics.

Figure 2 depicts the approach paths of X_t. The gray line represents the approach path of X_t in the absence of trophy-hunting restrictions. In Figure 2, we observe that the gray line is below the dashed line (the approach path of X_t when the quota price P_H is reduced by 30%) and the dotted line (the approach path of X_t when the offset rate α becomes 0.002). This implies that any decrease in the value of α or P_H will also increase the value of X_t.

The effect of trophy-hunting restrictions when property rights are taken away from the manager is the same as in the previous case. In the presence of trophy-hunting restrictions, it is optimal for a manager to convert hunting land into land for tourism activities. Thus, the number of hunting quotas decreases with the size of hunting land, consequently increasing the lion population.

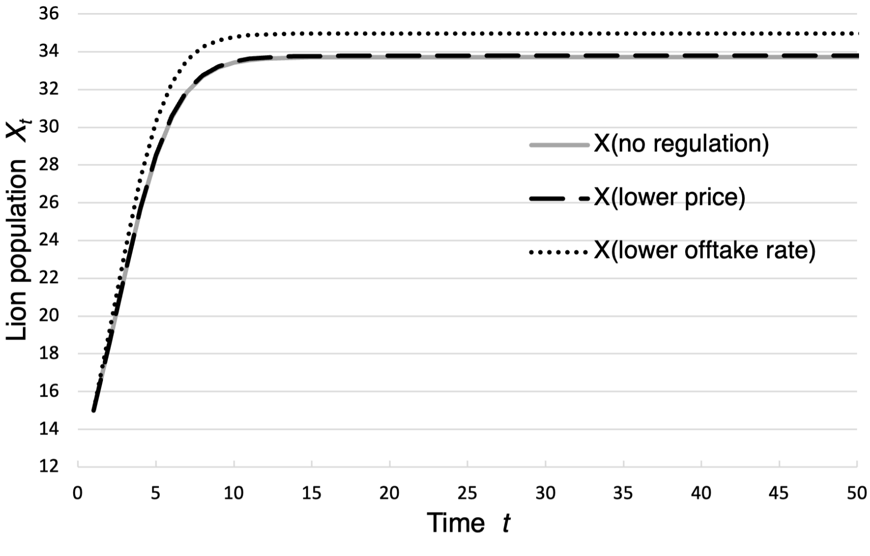

Figure 2: Approach paths of X_t under land-use type 1, wherein the manager has no property rights over lions

3.2.2 Land-use type 2

Here, we consider land-use type 2, wherein the land is divided into areas for hunting and agricultural activities. The management problem when the manager has property rights over lions is denoted by (10). The parameter values in Table 1 are substituted into (10) to numerically solve the problem and derive the approach path of X_t. Figure 3 depicts the approach paths of the lion population X_t. With an initial lion population $X_0 = 15$, figure 3 shows that $X_t \to 28.88$ as $t \to 21$ in the absence of hunting restrictions (gray line). However, $X_t \to 25.96$ as $t \to 30$ when the price of quotas P_H decreases (dashed line) and $X_t \to 24$ as $t \to 34$ if the offset rate is reduced to $\alpha = 0.002$ (dotted line).

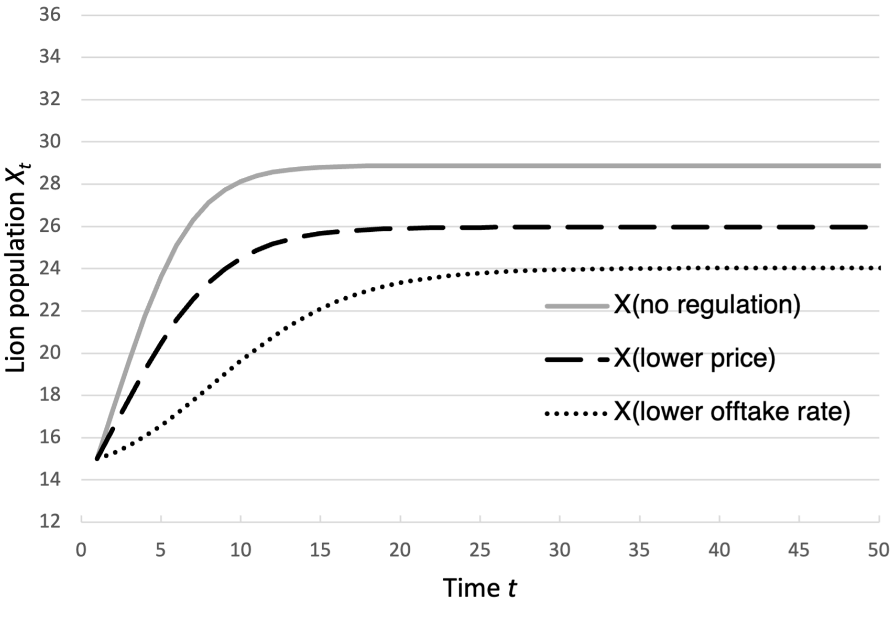

Figure 3: Approach paths of X_t under land-use type 2, wherein the manager has property rights over lions

For the case in which the manager has no property rights over lions, the optimal problem becomes as follows:

$$\begin{aligned} \max_{H_t} \quad \pi &= (1-c)R(h_t) + Q(A_t, X_t) \\ &= (1-c)R(\alpha H_t) + Q(L - H_t, X_t) \end{aligned} \tag{24}$$

The first-order condition implies that the optimal hunting area size at time t satisfies $(1-c)\alpha R_{h_t} = Q_{A_t}$. The approach paths for X_t are shown in Figure 4. This implies that if the price of hunting quota or offtake rate decreases, X_t corresponds with a lower lion population ($X_t \to 26.97$ as $t \to 27$ if P_H is reduced by 30% (dashed line); $X_t \to 26.69$ as $t \to 24$ for $\alpha = 0.002$ (dashed line) compared to when there are no hunting restrictions ($X_t \to 29.13$ as $t \to 20$, grey line). Furthermore, a comparison of Figure 3 and Figure 4 shows that the manager's possession of the property rights over lions does not necessarily ensure a higher lion population under land-use type 2. A summary of the steady-state values of the lion population for different cases is presented in Table 2.

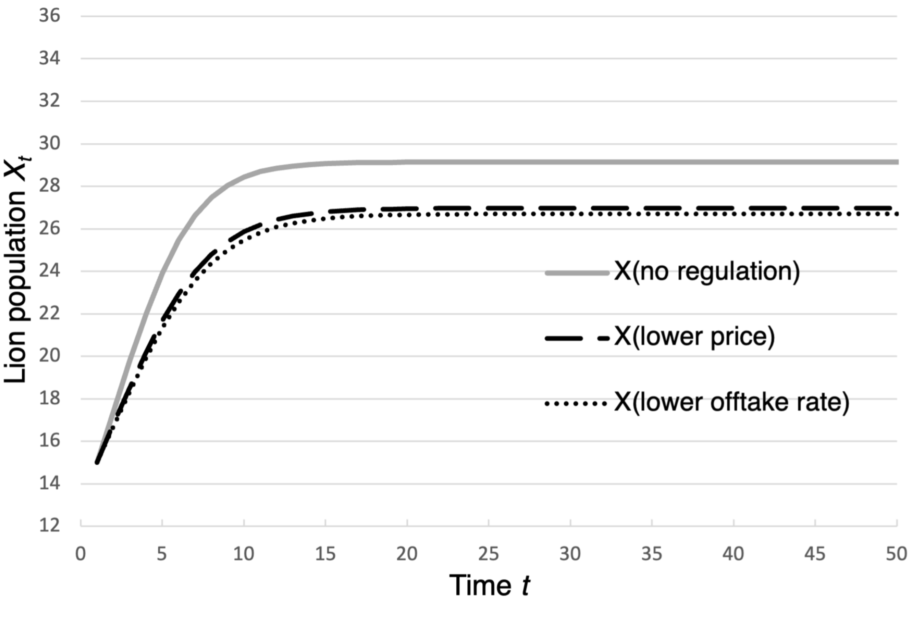

Figure 4: Approach paths of X_t under land-use type 2, wherein the manager has no property rights over lions

Table 2: Summary of the results

Land-use type	Manager with property rights?	Steady-state lion population X^*			Figure references
		No restrictions[a]	Lower P_H[b]	Lower α[c]	
1. Trophy hunting	Yes	33.719	33.79	34.97	Fig 1
& tourism	No	33.718	33.78	34.96	Fig 2
2. Trophy hunting &	Yes	28.88	25.96	24.03	Fig 3
livestock farming	No	29.13	26.97	26.69	Fig 4

[a] $P_H = 3.3$ and $\alpha = 0.004$.
[b] The value of P_H is reduced by 30%.
[c] The value of α is reduced by 50%.

4 Conclusion and Discussion

Whether trophy hunting should be banned remains a matter of controversy. In this study, we developed a bioeconomic model to explore the impact of trophy-hunting restrictions on wildlife populations in the context of a fixed-size PLCA and two land-use types. The land is divided into areas for hunting and tourism activities in the first land-use type. In the presence of trophy-hunting restrictions, managers can turn hunting areas into tourism areas, which still serve as wildlife habitats. In land-use type 2, we consider agricultural production (livestock farming) as an alternative land use to trophy hunting. In other words, the manager may convert the hunting area into an area for agricultural activities in the presence of trophy-hunting restrictions. The numerical simulation results suggest that if alternative land use is not wildlife-based, then any restriction on trophy hunting can negatively affect wildlife populations.

Our results reveal that trophy-hunting restrictions improve wildlife conservation when the hunting area is converted into an area for tourism activities; however, tourism is particularly sensitive to external conditions (Lindsey et al., 2007), such as travel restrictions due to the COVID-19 pandemic. Travel restrictions due to the pandemic have caused massive shocks to wildlife-based tourism, which is one of the principal sources of revenue for protected areas in African countries. For example, protected areas in South Africa experienced a 90% reduction in tourism revenue during 2020 (Gibbons et al., 2021). Owing to the decrease in income, the budget for conservation has declined, causing a reduction in anti-poaching efforts, increasing human-wildlife conflicts, and bushmeat hunting (Gibbons et al., 2021). This problem has been further exacerbated for private conservation areas owing to the need for more government grants.

The COVID-19 pandemic induced financial losses of up to USD 58 million in the private wildlife industry of South Africa in 2020 (van der Merwe et al., 2021). The cancellation of ecotourism and trophy-hunting tours has negatively affected privately owned reserves. Researchers believe that PLCA landowners are more likely to sell or convert wildlife habitats into other land uses in the face of an uncertain future of wildlife-based tourism (Spenceley, 2021).

Although the recovery of the ecotourism industry remains elusive in the short run, some sub-Saharan countries, such as Botswana and South Africa, announced re-opening the trophy-hunting season in 2021. Compared with photographic tourism, the trophy-hunting industry can generate massive profits from fewer visitors (Lindsey et al., 2007). In addition, Biggs et al. (2020) mentioned that trophy hunters may be more willing to visit reserve areas because they are more resilient to risk circumstances. Consequently, trophy hunting is significant for solving the immediate financial difficulties private reserve areas faced during the pandemic. Therefore, international trophy-hunting bans and restrictions should be cautiously issued, especially during/after the pandemic.

While several people continue to believe that trophy hunting is brutal and unnecessary, they do not recognize it as a conservation tool for wildlife habitats in low-income countries. Opponents of trophy hunting argue that it should be replaced by photographic tourism, which can generate sustainable revenue and conserve wildlife habitats. Indeed, photographic tourism does generate higher total benefits compared to trophy hunting. However, many visitors have caused over-tourism, negatively impacting the local culture and ecosystem in sub-Saharan countries (Séraphin et al., 2020). Furthermore, as mentioned previously, some remote reserve areas are unsuitable for ecotourism. Banning trophy hunting can preserve wildlife from trophy hunters; however, finding alternatives to trophy hunting that can provide revenue for conserving wildlife remains difficult.

Acknowledgements

This research was supported by the JST SPRING (grant number JPMJSP2123). The author also appreciates the support of the 2020 SEEPS Research Fund for Graduate Students. This study was presented at the 2021 Annual Conference of the Society for Environmental Economics and Policy Studies.

Appendix

In the case where land is used for hunting and tourism, comparative static results are derived by taking the total differential of (6), (7), and (8). The total differentiation yields

$$\underbrace{\begin{bmatrix} 0 & -\alpha & F_X \\ -\alpha & \mathscr{L}_{HH} & \mathscr{L}_{HX} \\ F_X-\delta & \mathscr{L}_{XH} & \mathscr{L}_{XX} \end{bmatrix}}_{[J]} \begin{bmatrix} d\rho\lambda \\ dH \\ dX \end{bmatrix} = \begin{bmatrix} 0 \\ \alpha R_h \\ 0 \end{bmatrix} dc + \begin{bmatrix} H^* \\ \psi_1 \\ 0 \end{bmatrix} d\alpha \tag{A1}$$

where

$$\mathscr{L}_{HH} = \alpha^2(1-c)R_{hh} + W_{VV} < 0 \tag{A2}$$
$$\mathscr{L}_{HX} = -W_{XV} \tag{A3}$$
$$\mathscr{L}_{XX} = W_{XX} + \rho\lambda F_{XX} < 0 \text{ for } F_X - \delta < 0 \tag{A4}$$
$$\psi_1 \equiv -(1-c)R_h - (1-c)\alpha H R_{hh} + \rho\lambda \tag{A5}$$

at steady state. We define the first term of (A1) as the matrix $[J]$; then, the determinant of $[J]$ must be positive if $F_X(F_X - \delta) > 0$ and W_{XV} is sufficiently small. If we assume that $|J| > 0$ and $F_X - \delta < 0$, then (A1) implies that $dX/dc > 0$ and $dX/d\alpha < 0$ (otherwise, the signs of dX/dc and $dX/d\alpha$ could be ambiguous).

For land-use type 2, the steady-state value was obtained from (15)∼(17). The total differentiation yields

$$\underbrace{\begin{bmatrix} 0 & F_H - \alpha & F_X \\ F_H - \alpha & \mathscr{L}_{HH} & \mathscr{L}_{HX} \\ F_X - \delta & \mathscr{L}_{XH} & \mathscr{L}_{XX} \end{bmatrix}}_{[R]} \begin{bmatrix} d\rho\lambda \\ dH \\ dX \end{bmatrix} = \begin{bmatrix} 0 \\ \alpha R_h \\ 0 \end{bmatrix} dc + \begin{bmatrix} H^* \\ \psi_2 \\ 0 \end{bmatrix} d\alpha \tag{A6}$$

where

$$\mathscr{L}_{HH} = (1-c)\alpha^2 R_{hh} + Q_{AA} + \rho\lambda F_{HH} \tag{A7}$$
$$\mathscr{L}_{LX} = -Q_{XA} + \rho\lambda F_{XH} \tag{A8}$$
$$\mathscr{L}_{XX} = Q_{XX} + \rho\lambda F_{XX} > 0 \text{ for } F_X - \delta < 0 \tag{A9}$$
$$\psi_2 \equiv -(1-c)R_h - (1-c)\alpha H R_{hh} + \rho\lambda \tag{A10}$$

We set the first term of (A6) to $[R]$. However, the sign of $|R|$ is ambiguous. If we assume that $|R| > 0$ and $F_X - \delta < 0$, then $dX/dc < (>)0$ and $dX/d\alpha \gtreqless (<)0$ if $F_H - \alpha > (<)0$.

References

Barrios, Salvador, Bazoumana Ouattara, and Eric Strobl (2008) "The impact of climatic change on agricultural production: Is it different for Africa?" *Food Policy*, 33 (4), 287–298, https://doi.org/10.1016/j.foodpol.2008.01.003.

Biggs, Duan, Alexander Richard Braczkowski, Alta De Vos, and Hayley Clements (2020) "COVID-19, Africa's conservation and trophy hunting dilemma," `https://theconversation.com/covid-19-africas-conservation-and-trophy-hunting-dilemma-140029`.

Clements, Hayley S., Graeme S. Cumming, and Graham I. H. Kerley (2016) "Predators on private land: broad-scale socioeconomic interactions influence large predator management," *Ecology and Society*, 21 (2), 10.5751/ES-08607-210245.

Conrad, Jon M (2010) *Resource economics*: Cambridge university press.

Cooney, Rosie, Curtis Freese, Holly Dublin, Dilys Roe, David Mallon, Michael Knight, Richard Emslie, M. Pani, V. Booth, S. Mahoney, C. baby, and conservati hunting (2017) "The baby and the bathwater: Trophy hunting, conservation and rural livelihoods," *Unasylva*, 249, 3.

Di Minin, Enrico, Nigel Leader-Williams, and Corey J.A. Bradshaw (2016) "Banning Trophy Hunting Will Exacerbate Biodiversity Loss," *Trends in Ecology & Evolution*, 31 (2), 99–102, https://doi.org/10.1016/j.tree.2015.12.006.

Fischer, Carolyn, Edwin Muchapondwa, and Thomas Sterner (2010) "A Bio-Economic Model of Community Incentives for Wildlife Management Under CAMPFIRE," *Environmental and Resource Economics*, 48 (2), 303–319, 10.1007/s10640-010-9409-y.

Gibbons, David W et al. (2021) "The relative importance of COVID-19 pandemic impacts on biodiversity conservation globally," *Conservation biology : the journal of the Society for Conservation Biology.*

Griffen, Blaine D and John M Drake (2008) "Effects of habitat quality and size on extinction in experimental populations," *Proceedings of the Royal Society B: Biological Sciences*, 275 (1648), 2251–2256, 10.1098/rspb.2008.0518.

Hayward, Matt W., John O'Brien, and Graham I.H. Kerley (2007) "Carrying capacity of large African predators: Predictions and tests," *Biological Conservation*, 139 (1), 219–229, https://doi.org/10.1016/j.biocon.2007.06.018.

Hurt, Robin and Pauline Ravn (2000) *Hunting and Its Benefits: an Overview of Hunting in Africa with Special Reference to Tanzania*, 295–313, Dordrecht: Springer Netherlands, 10.1007/978-94-011-4012-6_15.

IUCN (2016) "Briefing paper: Informing decisions on trophy hunting," `https://www.iucn.org/sites/dev/files/iucn_sept_briefing_paper_-_informingdecisionstrophyhunting.pdf`.

Johannesen, Anne Borge (2006) "Designing integrated conservation and development projects (ICDPs): illegal hunting, wildlife conservation, and the welfare of the local people," *Environment and Development Economics*, 11 (2), 247–267, 10.1017/S1355770X05002792.

——— (2007) "Protected areas, wildlife conservation, and local welfare," *Ecological Economics*, 62 (1), 126–135, https://doi.org/10.1016/j.ecolecon.2006.05.017.

Johannesen, Anne Borge and Anders Skonhoft (2005) "Tourism, poaching and wildlife conservation: what can integrated conservation and development projects accomplish?" *Resource and Energy Economics*, 27 (3), 208–226, 10.1016/j.reseneeco.2004.10.001.

Lindsey, P., G. Balme, N. Midlane, R. Alexander, and J. Craig (2012) "Possible relationships between the South African captive-bred lion hunting industry and the hunting and conservation of lions elsewhere in Africa : research article," *South African Journal of Wildlife Research - 24-month delayed open access*, 42 (1), 11–22, 10.10520/EJC121989.

Lindsey, P.A., P.A. Roulet, and S.S. Romañach (2007) "Economic and conservation significance of the trophy hunting industry in sub-Saharan Africa," *Biological Conservation*, 134 (4), 455–469, https://doi.org/10.1016/j.biocon.2006.09.005.

Lindsey, Peter Andrew, Guy Andrew Balme, Paul Funston, Philipp Henschel, Luke Hunter, Hilary Madzikanda, Neil Midlane, and Vincent Nyirenda (2013) "The Trophy Hunting of African Lions: Scale, Current Management Practices and Factors Undermining Sustainability," *PLOS ONE*, 8 (9), 1–11, 10.1371/journal.pone.0073808.

Manning, Jonathan (2021) "UK announces ban on trophy hunting imports," Dec, `https://www.nationalgeographic.co.uk/environment-and-conservation/2021/12/uk-announces-ban-on-trophy-hunting-imports`.

Miller, Susan M. and Paul J. Funston (2014) "Rapid growth rates of lion (¡i¿Panthera leo¡/i¿) populations in small, fenced reserves in South Africa : a management dilemma," *South African Journal of Wildlife Research - 24-month delayed open access*, 44 (1), 43–55, 10.10520/EJC151625.

Naidoo, Robin, L. Chris Weaver, Richard W. Diggle, Greenwell Matongo, Greg Stuart-Hill, and Chris Thouless (2016) "Complementary benefits of tourism and hunting to communal conservancies in Namibia," *Conservation Biology*, 30 (3), 628–638, https://doi.org/10.1111/cobi.12643.

Naidoo, Robin, L. Chris Weaver, Greg Stuart-Hill, and Jo Tagg (2011) "Effect of biodiversity on economic benefits from communal lands in Namibia," *Journal of Applied Ecology*, 48 (2), 310–316, https://doi.org/10.1111/j.1365-2664.2010.01955.x.

Ngounou, Boris (2022) "South Africa: Controversy over hunting trophy ban in London," Jan, `https://www.afrik21.africa/en/south-africa-controversy-over-hunting-trophy-ban-in-london/`.

Parker, Kim, Alta De Vos, Hayley S. Clements, Duan Biggs, and Reinette Biggs (2020) "Impacts of a trophy hunting ban on private land conservation in South African biodiversity hotspots," *Conservation Science and Practice*, 2 (7), e214, https://doi.org/10.1111/csp2.214.

Rondeau, Daniel and Erwin Bulte (2007) "Wildlife Damage and Agriculture: A Dynamic Analysis of Compensation Schemes," *American Journal of Agricultural Economics*, 89 (2), 490–507, 10.1111/j.1467-8276.2007.00995.x.

Sills, Jennifer, Amy Dickman, Rosie Cooney, Paul J. Johnson, Maxi Pia Louis, Dilys Roe, and null null (2019) "Trophy hunting bans imperil biodiversity," *Science*, 365 (6456), 874–874, 10.1126/science.aaz0735.

Skonhoft, Anders and Jan Tore Solstad (1998) "The political economy of wildlife exploitation," *Land Economics*, 16–31, 10.2307/3147210.

Spenceley, Anna (2021) "The Future of Nature-Based Tourism: A new report on the impacts of COVID-19 and paths to sustainability," Post-Print hal-03403876, Luc Hoffmann Institute, `https://luchoffmanninstitute.org/future-nature-based-tourism-report/`.

Stolton, Sue, Kent Hubbard Redford, Nigel Dudley, and William Mark Adams (2014) *The futures or privately protected areas: Developing capacity for a protected planet*: IUCN.

Séraphin, Hugues, Tatiana Gladkikh, and Tan Vo-Thanh (2020) "Overtourism: Causes, Implications and Solutions,"Technical report.

Taylor, W. Andrew, Peter A. Lindsey, Samantha K. Nicholson, Claire Relton, and Harriet T. Davies-Mostert (2020) "Jobs, game meat and profits: The benefits of wildlife ranching on marginal lands in South Africa," *Biological Conservation*, 245, 108561, https://doi.org/10.1016/j.biocon.2020.108561.

van der Merwe, Peet, Andrea Saayman, and Chireé Jacobs (2021) "Assessing the economic impact of COVID-19 on the private wildlife industry of South Africa," *Global Ecology and Conservation*, 28, e01633, https://doi.org/10.1016/j.gecco.2021.e01633.

Winkler, Ralph (2011) "Why do ICDPs fail?: The relationship between agriculture, hunting and ecotourism in wildlife conservation," *Resource and Energy Economics*, 33 (1), 55–78, 10.1016/j.reseneeco.2010.01.003.