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Optimization of wildlife management in a large game reserve through waterpoints manipulation: A bio-economic analysis

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ABSTRACT

Surface water is one of the constraining resources for herbivore populations in semi-arid regions. Artificial waterpoints are constructed by wildlife managers to supplement natural water supplies, to support herbivore populations. The aim of this paper is to analyse how a landowner may realize his ecological and economic goals by manipulating waterpoints for the management of an elephant population, a water-dependent species in the presence of water-independent species. We develop a theoretical bio-economic framework to analyse the optimization of wildlife management objectives (in this case revenue generation from both consumptive and non-consumptive use and biodiversity conservation), using waterpoint construction as a control variable. The model provides a bio-economic framework for analysing optimization problems where a control has direct effects on one herbivore species but indirect effects on the other. A landowner may be interested only in maximization of profits either from elephant offtake and/or tourism revenue, ignoring the negative effects that could be brought about by elephants to biodiversity. If the landowner does not take the indirect effects of waterpoints into consideration, then the game reserve management, as the authority entrusted with the sustainable management of the game reserve, might use economic instruments such as subsidies or taxes to the landowners to enforce sound waterpoint management.

1. Introduction

In South Africa private landowners play a crucial role in wildlife conservation, and often aim to conserve wildlife (Jordi and Peddie, 1988; APNR, 2005). Some private landowners have agreed to remove fences between their properties to allow wildlife to roam between their properties. A private nature reserve is one of the types of private land ownership for wildlife management in South Africa. A nature reserve also referred to as game reserve consists of several landowners who have often removed fences amongst their landholdings. They generally employ a management team to run the reserve and ensure that sustainable wildlife management actions are practiced by the landowners, although the individuals retain their individual property ownership rights (APNR, 2005). Management objectives of private nature reserves vary from preservation to the sustainable use of wildlife. Some nature reserves have formed associations whereby adjoining reserves pooled their resources and removed fences to create even larger units. One of such associations is the Associated Private Nature Reserves (APNR) which is the focus of this paper. The APNR is located to the west of the Kruger National Park and consists of the Timbavati, Klaserie, Umbabat and Balule Private Nature Reserves and has a combined total area of approximately 1850 km^2 (APNR, 2005). Furthermore, the APNR has entered into an agreement with the state-owned

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Kruger National Park which led to the removal of fences between the Kruger National Park and the APNR in 1994 to create a very large game reserve (APNR, 2005).

The APNR generates income from e.g., eco-tourism, fees paid by landowners, and hunting (APNR, 2005). Some commercial and trophy hunting is conducted in the APNR (2005). Hunting quotas are based on existing wildlife populations and are set by the province administration (APNR, 2005). Since the reserves within the APNR are "associations-not-for-gain", the proceeds generated by hunting activities are used exclusively for biodiversity conservation (APNR, 2005). However, the state has the ultimate say on hunting activities. For instance, to promote the growth of the elephant population, the South African government banned elephant culling and hunting in 1995, which resulted in a substantial increase in the elephant population (Grant et al., 2008). However, the ban was lifted in 2008 to improve management of the flourishing elephant populations (Nature, 2008).

Surface water provision, fire management, fencing and animal population manipulation by culling, translocation or introducing predators, are some of the most common interventions used by landowners in wildlife protected areas to achieve their objectives (Perrings and Walker, 1997; Slotow et al., 2005; de Boer et al., 2007; Grant et al., 2008; Ripple and Beschta, 2011). Surface water is one of the main constraining resources for herbivore populations in semi-arid regions (Western, 1975; Redfern et al., 2003). Artificial waterpoints are therefore constructed by game managers to supplement natural water supplies, to support the existing populations, and to distribute the impacts of herbivores more evenly over the area (Owen-Smith, 1996; Grant et al., 2008).

It has been shown that properties with the 'Big Five', consisting of elephant, buffalo, rhino, lion and leopard, generally attract a high number of tourists (Lindsey et al., 2007; Okello et al., 2008). Investment in the establishment of waterpoints is expected to increase if their construction would increase the number and visibility of such animals (Mabunda et al., 2003; Chamaillé-Jammes et al., 2007; Smit et al., 2007). This led to the assumption that a more extensive network of waterpoints would increase the revenues generated through tourism (Parker and Witkowski, 1999; Mabunda et al., 2003). For example, the number of waterpoints in the Klaserie Private Nature Reserve increased from only six waterpoints in 1965, to 144 by 1980 (Witkowski, 1983; Parker and Witkowski, 1999). Although waterpoints could be beneficial to wildlife viewing, they may compromise biodiversity (Harrington et al., 1999). Additional waterpoints could result in an increased number of herbivores. This could increase revenues in the short term, but in the long term it would adversely affect biodiversity (Thrash et al., 1991; Baxter, 2003).

Hence, the potential increase in animal impact with increasing numbers of artificial waterpoints is an issue of concern. A certain number of waterpoints per given area could be beneficial to the animals in a conservation area. Too few waterpoints could result in severe water shortages for animal populations, increasing animal mortality. On the other hand, too many waterpoints might result in increased environmental costs, such as reduced biodiversity. Too many waterpoints could result in widespread large impacts on the vegetation, an increase in predation, or an over-utilization of the vegetation, resulting in the homogenization of the vegetation composition and structure (Owen-Smith, 1996; Thrash, 1998; Harrington et al., 1999). Moreover, additional waterpoints might lead to an increase in the population of water-dependent species like elephant, zebra, buffalo, wildebeest and waterbuck (Collinson, 1983; Redfern et al., 2003, 2005), at the expense of water-independent (or less water-dependant) species, such as tsessebe, roan antelope, impala, kudu, giraffe, and warthog, which can tolerate limited water consumption and survive for long periods without access to surface water (Martin, 1983; Smithers, 1983; Estes, 1991).

Roan antelope, sable antelope and other antelope species are sensitive to habitat changes and have critical habitat requirements, as they depend on tall grasses (Martin, 1983). So the physiognomic changes to vegetation structure brought about by bulk feeders could result in a decrease of these water-independent species (Martin, 1983). For instance, in the Kruger National Park a severe drop in the roan antelope population was observed between 1986 and 1993 from about 450 to about 45 animals (Harrington et al., 1999; Grant et al., 2002). Some studies have claimed the cause of this decline to be the provision of numerous artificial waterpoints in the roan antelope range, which attracted the large grazers such as zebra and wildebeest, particularly during drought conditions (Harrington et al., 1999; Grant et al., 2002).

Human society often pursues several goals, improving human welfare, increase sustainability of production methods, and conserving biodiversity. A positive feedback loop could emerge if sustainable human activities promote biodiversity, which in turn fosters successful and sustainable human activities. In this context, artificial waterpoints can be thought of as a proxy for human endeavours. However, the ecological impacts of waterpoints on biodiversity are at present not well understood, and there are no economic studies addressing the issue of waterpoint construction from a bio-economic perspective. The intention of this paper is therefore to address this knowledge gap. We aim to analyse how wildlife managers may achieve their objectives of generating returns from wildlife by manipulating the number of waterpoints simultaneously contributing to sustainable wildlife conservation. We develop a theoretical bio-economic framework to analyse the optimization of wildlife management objectives using waterpoint manipulation and herbivore offtake as control variables. The underlying assumption is that surface water availability can be manipulated through provision of artificial waterpoints at relevant scale to influence the distribution of wildlife populations (Redfern et al., 2005). We present a theoretical bio-economic model with various degrees of complexity based on a set of ecological assumptions presented in Table 1.

2. The model

We first consider a single species model without environmental costs. We then consider another single species model with environmental costs. Lastly we consider a two species model – with elephants representing a water-dependent species and roan antelope as proxy for water-independent species. We regard the occurrence of the second species as a proxy for biodiversity which can be justified from the Harrington et al. (1999) study. For simplicity, predation is not included as a controlling mechanism in the model. The model is based on a large closed (fenced) reserve in which immigration and emigration is absent.

2.1. The single species model without environmental costs

Two economic activities were considered *viz.* tourism and hunting. For notational convenience, we suppress the time notation, but time should be understood to be implicit in all variables. The population dynamics of the elephant is given by the following equation:

$$\frac{dX}{dt} = h(X, W) - qX \tag{1}$$

Where: $h(X, W)$ is the growth function of elephant which depends on its own density (X) and is positively affected by the number of