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Analysis

The ghost of extinction: Preservation values and minimum viable population in wildlife models

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ABSTRACT

The inclusion of a minimum viable population in bioeconomic modeling creates at least two complications that are not resolved by using a modified logistic growth function. The first complication can be dealt with by choosing a different depensational growth function. The second complication relates to the inclusion of the *in situ* benefits of wildlife into the analysis. Knowledge about the magnitude of the *in situ* benefits provides no guide for policy about conservation management. Simply knowing that people are willing to pay a large amount each year to protect a species says nothing about whether one should manage habitat to protect or enhance the species' numbers, unless the species is in imminent danger of extinction. If willingness to pay is to be a guide, it needs to be better tied to population numbers, especially the minimum viable population.

1. Introduction

Economists have adopted Colin Clark's (1990) general framework for analyzing optimal wildlife populations and harvest levels, with one twist: they have explicitly introduced preservation benefits to say something about socially optimal populations. The logistic growth function has become the mainstay of such analyses, although when there is a threat of extinction (or more appropriately extirpation) a depensatory logistic growth function that explicitly includes a minimum viable population may be employed (Conrad, 1999). While mathematical models with the modified logistic growth function improve the richness of the policy insights, there are two problems with its use in practice. The modified logistic growth function encourages overharvesting that could lead to extinction. Further, its use in determining the socially optimal population of a species becomes exceedingly complex if *in situ* benefits of wildlife are included.

With regard to the latter, the main argument used by economists and others for preserving wildlife species is that they provide significant non-use benefits, as demonstrated by peoples' apparent willingness to pay (WTP) to preserve a variety of species (Loomis and White, 1996), and that these benefits tip most cost–benefit analyses in favor of programs that protect species. Indeed, preservation value is often the foremost determinant of an economically optimal population. However, as demonstrated in this paper, assumptions about how preservation benefits are allocated between maintaining a safe minimum viable population and increasing numbers above this minimum have a profound effect on the policy choice (Bulte and van Kooten, 1999). Although contingent valuation studies have estimated high values for preserving species and ecosystems (Costanza et al., 1997), such information by itself may be meaningless for guiding policy related to the issue of 'how many' wildlife. Rather, one needs to know how peoples' willingness to pay to protect species is allocated between preventing extinction and enhancing numbers above some 'safe' minimum viable population required to keep the species from going extinct. As shown in this paper, knowledge is needed not only about peoples' *marginal* WTP, information which is generally unavailable, but also about how marginal WTP changes as the population size increases (i.e., about the functional form of marginal WTP). The informational requirements are quite demanding, and this has implications for the questions asked in contingent valuation surveys.

The objective of this paper is to improve research and policy related to wildlife management by highlighting these two problems. The focus is on wildlife species that are subject to hunting and have charismatic appeal. First, we specify a population growth function that accommodates a minimum viable population and results in realistic

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rates of growth. This growth function is then incorporated in an optimal control model that includes both harvest and *in situ* (non-use) benefits. Second, we develop the mathematics for modeling non-use benefits of preventing extinction by maintaining a stock just at the minimum viable population (MVP) or augmenting the stock size above MVP. Third, we derive the steady-state conditions for the optimal population size under two alternative assumptions regarding the functional form of marginal non-use benefits. Finally, we develop a numerical application of the models to the conservation of sage grouse, a harvested bird that is a species of concern in several western U.S. states, and present solutions to the models. We conclude by discussing implications of our contribution for valuation research related to the management of charismatic wildlife species.

2. Modeling growth of wildlife species

We begin by postulating the popular Verhulst logistic function that is most-often used to describe the fecundity, mortality and growth characteristics of a fishery or charismatic wildlife population:

$$G(x(t)) = \gamma x(t)\left(1 - \frac{x(t)}{K}\right), \tag{1}$$

where x refers to fish biomass or wildlife numbers at time t, γ is the intrinsic growth rate, and K is the carrying capacity of the ecosystem. Growth function (1) is a quadratic polynomial with the characteristic that, in the absence of intervention, the population will always tend toward the ecosystem carrying capacity K, even if it is very close to zero. This is unrealistic because, for numbers below some minimum level, a species will eventually go extinct, perhaps despite intervention to prevent this.

To determine whether a species has a good chance of survival, it is necessary to take into account the possibility (as opposed to probability[1]) of a population surviving under various assumptions about its habitat, reproduction, predation, legal and perhaps illegal harvests (including incidental take while hunting other species, referred to as by-catch in the fishery), genetic deterioration, and so on. To do so, we specify a growth function that includes the notion of a minimum viable population (MVP), denoted by M. The modified logistics growth function most commonly used to take into account extinction is (Clark, 1990, p.23; Conrad, 1999, p.33):[2]

$$G(x(t)) = \gamma x(t)\left(\frac{x(t)}{M} - 1\right)\left(1 - \frac{x(t)}{K}\right). \tag{2}$$

Despite its use in theoretical and empirical applications (e.g., Bulte and van Kooten, 1999, 2001), this specification has some undesirable properties. We illustrate this with the aid of Fig. 1, which gives the growth (panel a) and population response (panel b) of a slow-growing mammal species. As long as population exceeds MVP, harvests set equal to growth will leave the population intact.

Fig. 1 highlights the first problem with the modified logistics growth function (2): if used as a basis for policy recommendations, harvest levels will be too high, perhaps dangerously so if actual growth is closer to the standard logistics growth function (1) than the modified function (2). Further, starting with a population of 15,000 animals, say, the depensatory growth function (2) results in a too rapid approach to carrying capacity of 100,000 compared to the standard logistics function. For the same intrinsic growth rate and carrying capacity, maximum growth (and thus harvest) with the logistics functional form is 2000 animals per year, while it is 18,000 animals with function (2)!

To address such ‘unrealistic’ growth, we specify the following growth function due to Boukal and Berec (2002):[3]

$$G(x(t)) = \gamma x(t)\left(\frac{x(t) - M}{x(t) + M}\right)\left(1 - \frac{x(t)}{K}\right). \tag{3}$$

The population response for this specification is much closer to that of standard logistic growth, with annual growth peaking at 1636 animals (Fig. 1a). Policy based on growth function (3) is less likely to lead to potential overharvesting.

To address the second problem, that of determining optimal population and harvest levels when *in situ* benefits are included and there exists the possibility of extinction, a model of wildlife management and exploitation is first required.

3. An optimal control model for wildlife species

The benefits that society gets from protecting a wildlife species can be grouped into two general categories. Some receive benefits from harvesting, and these may exceed the costs of purchasing a hunting permit, harvesting the animal (viz., expenditures on firearms, ammunition, fishing gear, boats, specialized clothing, accommodation), and getting to the hunting location. However, wildlife also provide benefits to those who observe them in the wild (non-consumptive use benefits), to citizens who benefit simply from knowing that they exist, and to society as a whole because a species contributes to overall biodiversity. Although such benefits are difficult to measure, economists can employ a variety of techniques to determine their magnitude (Loomis and White, 1996).

Assume that the authority wishes to maximize the discounted sum of net use and non-use benefits of a wildlife species over time. This is expressed mathematically as:

$$\int_0^\infty [p(h(t))h(t) - c(h(t)) + B(x(t))]e^{-rt}dt, \tag{4}$$

where $p(h)h - c(h)$ is the net benefit of harvesting and/or consuming h animals at time t, and $B(x(t))>0$ are total non-use benefits as a function of the *in situ* population at time t. The demand function is downward sloping if harvesters can influence price, $p'(h)<0$, while it is perfectly elastic if price is constant. Further, $c'(h)>0$, with marginal cost upward sloping if $c''(h)>0$ and constant if $c''(h)=0$, both of which are possible. It is assumed that $B'(x)>0$ and $B''(x)<0$, implying that non-use benefits increase as the wildlife population increases, with marginal benefits positive but declining as numbers increase. Finally, r is the social discount rate.

The economic problem is to maximize Eq. (4) subject to the population dynamics:

$$\dot{x} = G(x(t)) - h(t), \tag{5}$$

where $G(x)$ is the growth function (2) or (3) if there exists a MVP. From the maximum principle, the respective optimality condition and co-state equation are (suppressing t):

$$\lambda = [p(h) + p'(h)h] - c'(h). \tag{6}$$

$$\dot{\lambda} = [r - G'(x)]\lambda - B'(x). \tag{7}$$

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[1] It is beyond the scope of the current paper to model uncertainty and meta-populations (local extinction and ‘replenishment’ from elsewhere). See van Kooten and Bulte (2000, pp. 211–215) for a discussion of these issues.

[2] This function exhibits what in fisheries is referred to as depensational growth. It is a population-level phenomenon related to spawner-recruitment, unlike the Allee effect that shows up as a lower per capita growth rate at low population levels (Boukal and Berec, 2002).

[3] Boukal and Berec (2002) also demonstrate that the discrete-time and continuous-time versions of growth models can exhibit quite different population dynamics.