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Adaptive management of the brown bear population in Hokkaido, Japan

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ABSTRACT

In Hokkaido, Japan, recent trends concerning the intrusions of the brown bear (*Ursus arctos*) into crop fields and a subsequent increase in agricultural damage have highlighted the need for new and more effective population management strategies. To devise such strategies, we focused on a well-defined, previously studied brown bear population living in the Oshima Peninsula region of Hokkaido, and constructed a population dynamics model for adult females. The model construction was based on the ecological and physiological characteristics of the Oshima Peninsula population, with particular emphasis on bear behavior (levels of aggressiveness and intrusiveness) and human–bear interactions (bear kills, food conditioning, and aversive conditioning). To predict the future population dynamics, we ran stochastic simulations over a period of 100 years. We used the simulation outputs to estimate the risk of management failure under four plausible scenarios, including the scenario that represents the present management practices. The results of the analysis indicated that the present management practices could not satisfactorily resolve the problem of increasing agricultural damage. However, an adaptive management strategy successfully reduced the risk of management failure to a negligible level.

1. Introduction

In Hokkaido, Japan, potentially alarming trends in the interaction between brown bear (*Ursus arctos*) and local residents call for innovative and more effective population management strategies. While the brown bear population in question has historically been known to cause agricultural damage and injuries, in the period from 1988 through 2005, a 6.7% annual increase rate in the number of culls was accompanied by more than a 5% annual increase rate in the amount of agricultural damage (Mano, 2009). These trends may result in social pressure for more aggressive bear kills, which in turn may harm the viability of the brown bear population, especially because the causes behind the rising tendency toward crop field intrusions are poorly understood. In this context, the introduction of new and non-lethal techniques, such as aversive conditioning with relocation, may provide a new layer of flexibility for management of the brown bear population, improving the chances of its survival and suppressing the number of crop field intrusions below the socially acceptable level.

A quick and cost-effective manner to test the consequences of introducing new management methods is the modeling approach. In Hokkaido, for example, modeling was used to examine a management policy for sika deer (Matsuda et al., 1999). In the case of the brown bear, modeling was applied to produce concrete conservation management recommendations in Slovenia (Jerina et al., 2003). In the central Apennines, Italy, habitat modeling proved to be useful in identifying critical areas for a brown bear conservation strategy (Posillico et al., 2004). In the present study, we focus on examining the effectiveness of combining existing lethal (i.e. culling) and new non-lethal (i.e. aversive conditioning with relocation) population management methods in an adaptive manner. For that purpose, a population dynamics model is formulated together with several realistic management scenarios. The model is run to make future projections of the population size and estimate risks of management failure under each scenario. We assume that the failure occurs if either of the two management goals is not satisfied; (i) the number of intrusions into crop fields is not suppressed below the acceptable level, or (ii) a viable population is not maintained at all times. Because the lethal method is in direct conflict with the goal of maintaining a viable population, while aversive conditioning may be unsuccessful in suppressing bear intrusions (Mazur, 2010; Nakanishi et al., 2007), a tradeoff between the two management goals is a fundamental property of all scenarios considered. The risk of failure is a quantitative measure of our ability to balance this tradeoff, and therefore provides an objective criterion for assessing the relative performance of the scenarios to

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be evaluated. Moreover, the modeling approach enables us to perform such an evaluation long before the time consuming and costly implementation of any management policy takes place.

2. Study area

To simplify the analysis performed henceforth, we restrict its scope to a geographically narrow area. In Hokkaido, the existence of the three distinct brown bear subpopulations allows for such a restriction (Matsuhashi et al., 1999). Particularly interesting in this context is the southwestern subpopulation residing on the Oshima Peninsula, partly because it is isolated from the other two subpopulations, and partly because it is receiving considerable scientific attention with respect to the increasing occurrence of bear intrusions (Mano, 2009; Tsuruga and Mano, 2008). The Oshima Peninsula – an area of 7300 km^2 and a home to around 500,000 inhabitants – hosts a brown bear population of 800 ± 400 individuals (Hokkaido Prefectural Government, 2010), characterized by (i) no significant changes in the bear density index for almost two decades, (ii) a 5.8% annual increase rate in the number of bear kills, and (iii) the highest incidence of bear-inflicted agricultural damage during the late summer. These findings suggest that although the population size appears stable, the number of bears killed for intruding into crop fields continues to increase. The late summer is an especially problematic season. During this period, the diet of the bears shifts from early summer foods to autumn foods, i.e. from herbaceous plants and ants to berries, acorns, and nuts (Sato et al., 2005). On the Oshima Peninsula, which is approximately 80% covered by woodland, acorns and nuts originate from the predominant species like the Mongolian oak (*Quercus crispula*) and Japanese beech (*Fagus crenata*). At times, the shift from early summer foods to autumn foods does not proceed smoothly because acorns and nuts are still unripe when the herbaceous plants die above ground and are no longer suitable as foodstuffs. Consequently, during this period the bears may rely heavily on crops to survive. Once a bear learns a particular foraging behavior and becomes food conditioned (Gunther and Wyman, 2008), it is probable that the acquired knowledge will be quite persistent (Mazur, 2010) and subject to vertical transfer from sows to cubs (Mazur and Seher, 2008), potentially aggravating the problem of bear intrusions.

3. Materials and methods

3.1. Model development

We constructed a population dynamics model for adult female brown bears on Oshima Peninsula by considering their essential ecological and physiological characteristics (e.g. feeding habits, reproductive output, and density effects). The reason for turning our attention to adult female bears originated from a principle that adult female survival is crucial to the well-being of populations of the long lived vertebrates and possibly many other sexually reproducing species (Eberhardt, 2002). As an illustration of this principle, it was found that the population growth rate of black bear (*Ursus americanus*) in the Bow Valley of Banff National Park, Alberta, was most sensitive to changes in adult female survival (Hebblewhite et al., 2003).

One might express a concern that the number of male bears should be tracked at least in the context of crop field intrusions – Tsuruga and Mano (2008) indeed found a bias toward males (64.5% of the total) in catch data from Oshima Peninsula. Whereas a larger home range of male brown bears (Dahle and Swenson, 2003) may have been a contributing factor to the observed bias, males appear to be far more reckless when entering a new area, and therefore tend to get caught more easily than females. Another reason not to attach too much of an importance to the observed bias is the previously mentioned vertical transfer of food conditioning from sows to cubs meaning that, unless feeding habits change significantly in the adult stage, the nuisance behavior should be rather equally distributed between sexes.

Table 1
Criteria for categorizing brown bears. Phases 0 and 1 characterize non-nuisance bears, while phases 2 and 3 characterize nuisance bears.

Behavior toward crop fields	Behavior toward humans		
	Evasive	Indifferent	Aggressive
Non-intrusive	Phase 0	Phase 1	Phase 3
Intrusive	Phase 2	Phase 2	Phase 3

In addition to considering adult female bears, our objective of identifying effective management strategies that can ensure the long-term coexistence of human residents and brown bears in the same geographical area, focused us on bear behavior (levels of aggressiveness and intrusiveness) and human–bear interactions (culling, food conditioning, and aversive conditioning). During the model construction, the following assumptions were made:

Assumption 1. We consider the non-nuisance and nuisance female bears to be distinguishable based on their behavior. How clearly this distinction can be drawn is reflected in the language of the indigenous Ainu people, who call non-nuisance bears "kim-un-kamuy" or "god in the mountain" and nuisance bears "wen-kamuy" or "bad god". Rigorous criteria for discriminating between these two bear types (Table 1) are described in literatures (Mano, 2009; Tsuruga and Mano, 2008). For modeling purposes, we assume that non-nuisance bears either evade or ignore human presence and do not cause any agricultural damage (phases 0 and 1 in Table 1). In contrast, nuisance bears are aggressive toward humans or tend to invade crop fields (phases 2 and 3 in Table 1). We also assume that during a single year, a fraction m of non-nuisance bears adopt new foraging behavior, become food conditioned, and effectively turn into nuisance bears. Henceforward, $N_0(t)$ denotes the number of female nuisance bears in year t, whereas $N_1(t)$ denotes the number of non-nuisance females in the same year. The female population size in year t is $N(t) = N_0(t) + N_1(t)$. The year counter t runs from 1 to 123, corresponding to the time period between 1987 and 2109. The past 23 years, from1987 to 2009, serve as a run-up period to reduce the influence of the initial values, and to provide output for a convenient comparison with existing data. The future predictions span a 100 years period from 2010 to 2109.

Assumption 2. The level of catch effort is controllable by the bear managers and varies over time to counteract unwanted bear behavior. For nuisance bears, the manager can vary the level of effort by adjusting the catch rate $\gamma(t)$. We can interpret the value of the catch rate as the probability of catching a single nuisance bear during a period of one year. Because the distinction between nuisance and non-nuisance bears is not absolute, the manager may catch a non-nuisance bear by mistake. The catch rate in this case is $F\gamma(t)$, where F is the false-catch coefficient.

Assumption 3. The degree of reliance on aversive conditioning is also controllable by the manager and varies over time to counteract unwanted bear behavior. The release rate, $\alpha(t)$, indicates the fraction of bears caught in one year that are subjected to aversive conditioning and released again into nature by the manager. As the effectiveness of aversive conditioning cannot be guaranteed (Mazur, 2010), only a fraction β of the nuisance bears subjected to aversive conditioning will abandon their unwanted behavior and become successfully reformed. A fraction $1-\alpha(t)$ of caught bears is eventually culled.