The Interaction between Urban Residential Market and The Ecosystem under Global Warming

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Some wildlife creatures (e.g., bears, coyotes, boars and mosquitoes) encroach into cities and harm human lives, causing injuries, infectious disease, but they are important because they contribute to biodiversity. We develop a new model that includes two life stages of omnivores (immature and mature omnivores) and a dynamic model by introducing the overlapping generations (OLG) model into the animal model. With this developed model, we conduct two analyses. At first, we reveal the effects of global warming on the population and spatial distribution of omnivores at equilibrium. Second, we identify the impact and mechanisms of extermination policies on omnivores and humans for the purpose of population management, and to conduct welfare analysis. The results of numerical simulations show that (i) when the impact of food consumption on the number of births is large, the time duration of omnivores' staying within the city increases under global warming. (ii) when a steady extermination policy is continued, the effects can be reversed in the short term and the long term.

Key Words*: human-wildlife conflicts, immature and mature omnivores, dynamic model, global warming, location-dependent externality*

1. INTRODUCTION

Some wildlife creatures (e.g., bears, coyotes, boars, and mosquitoes) encroach into cities and harm human lives, causing injuries, serious infectious disease, but they are important because they contribute to biodiversity. In order for humans to coexist with wildlife, we must properly manage their populations and habitat distribution. It is thought to be efficient to use different measures for immature and mature animals to manage populations because immature and mature animals have different behavioral patterns and characteristics. In addition, changes in growth of vegetation due to global warming affects the populations of animals.

However, there are no studies that can reflect the effects of global warming and dynamic changes in population and habitat distribution, considering the interactions between humans and wildlife. Several studies investigate how large the natural habitat must be to sustain the ecosystem service, focusing on land use competition between humans and wildlife, but ignoring the conflict between them (Brueckner,2000; Walker, 2001; Eppink et al., 2004; Eichner and Pethig, 2006, 2009). They focus on land-use competition between wildlife and humans. Yoshida and Kono (2020) develop a new model that add a continuous distance dimension to the urban-habitat allocation model of Eichner and Pethig (2006) and investigate how the spatially dependent human–wildlife interaction in cities gives rise to inefficient outcomes and to propose second-best optimal policies.

Therefore, we construct a theoretical model

including two generations of omnivores (immature and mature omnivores) and a dynamic model by introducing the overlapping generations (OLG) model into the animal model. Using the model, we conduct two analyses. At first, we reveal the effects of global warming on the population and distribution of wildlife at equilibrium, and the value of wildlife humans perceive, the fear humans feel when encountering omnivores, and the risk of being infected with fatal viruses from them. Second, we identify the impact and mechanisms of extermination policies on omnivores and populations for the purpose of population management, and to conduct welfare analysis.

2. THE MODEL

We consider a closed monocentric city adjacent to a natural habitat. The city is linear with the width of one unity, and the size is defined by $x \in [-Z^H, Z^H]$, where x denotes a distance from the city center and Z^H is the urban boundary. The land is divided into the following three zones: (i) a point CBD ($x = 0$), (ii) a housing zone ($x \in [0, Z^H]$), and (iii) the natural habitat ($x \in [Z^H, Z^A]$), where Z^A is the boundary of the habitat. Superscript H indicates the housing zone, and superscript A indicates the natural habitat throughout the paper.

The model includes omnivores and households. Omnivores are composed of two generations: immature and mature omnivores. Some omnivores eat nuts of plants in the natural habitat ($x \in [Z^H, Z^A]$), and others leave the habitat up to location $X \in [0, Z^H]$ in the residential area to seek a human-related source of food such as garbage. We assume that the number of births depends on food intake. The populations of immature and mature omnivores are represented by the overlapping generations (OLG) model. We set the duration of immature and mature omnivores to be two and eight years, respectively. The terms that affect the population change are food intake, which depends on the number of births, and the number of omnivores exterminated by humans. These terms depend on the total length of time. We define time density $\pi_t^j(x)$ ($j = H, A$) as the total length of time that an individual omnivore spends at location x in year t.

An individual omnivore maximizes the net increase in its own immature omnivores due to this season's foraging behavior each year. That is, the difference between the number of births and the number of immature omnivores killed by humans in year t by controlling $\pi_t^H(x)$. The optimal behavior of an omnivore is as follows:

$$\max_{\pi_t^A(x), \pi_t^H(x)} \alpha(Q_{m,t}) \frac{N_{m,t+1}}{N_{m,t}} - M_{i,t}, \tag{1}$$

where α is individual reproduction efficiency per prey eaten, $Q_{m,t}$ is food intake of individual mature omnivore in year t, $N_{m,t}$ is the population of mature omnivores in year t, and $M_{i,t}$ is the number of immature omnivores killed by humans per family in year t. The first term represents the number of births in year t.

The individual mature omnivore ($y=m$) eats food waste in human zone and plants in animal zone to share with its immature ones and sustain offspring. The supply-demand equilibrium equation for feed is as follows:

$$(Q_{m,t} + Q_{i,t}) * \frac{N_{m,t}}{2} = \int_X^{Z^H} \pi_t^H(x) \rho^H(\pi_t^H(x)) n_h(x) dx + \overline{F} K_t * (Z^A - Z^H) \tag{2}$$

The left side represents the demand for feed. $Q_{i,t}$ is food intake of individual immature omnivore in year t. $Q_{m,t} + Q_{i,t}$ means the amount of food consumption per animal household and $N_m / 2$ represents the number of households. While, the right side represents the supply of feed. $\rho^H(\pi_t^H(x))$ expresses the availability of food waste, $n_h(x)$ is human population density, $\rho^A(\pi_t^A(x))$ expresses the availability of plants, $\overline{F}$ is the amount of nuts per unit distance, and K_t is temperature in year t.
Regarding plants, we assume that the total amount of nuts, which is food of omnivores, increases year by year because the nuts production increase due to global warming.

Concerning the sum of intake of prey species per individual immature in year t, we define $Q_{i,t}$ as

$$Q_{i,t} = q \frac{N_{i,t}}{\frac{1}{2} N_{m,t}} \quad , \tag{3}$$

where q is constant and $N_{i,t}$ is the population of immature omnivores. This means that the food of immature one is certainly secured by its parents.

Similarly, $M_{y,t}$ ($y = i$ (immature omnivores), m (mature ones)) is expressed by integrating $\pi_t^H(x)$ multiplied by the density of humans $n_h(x)$ over its search range:

$$M_{i,t} = \int_X^{Z^H} \frac{N_{i,t}}{\frac{1}{2} N_{m,t}} \pi_t^H(x) \beta_i n_h(x) dx, \tag{4}$$

$$M_{m,t} = \int_X^{Z^H} 2\pi_t^H(x) \beta_m n_h(x) dx, \tag{5}$$

where β_y is the probability of extermination per unit of time the individual y spends within the city, and $n_h(x)$ is the number of humans at location x in the human zone and might be killed by them.

Each household resides at location $x \in [0, Z^H]$. They commute to the CBD and earn an exogenous wage w. As omnivores search the residential area for food, households may encounter them. To reduce their time density, government try to increase omnivores' risk directly by using the risk-increase-measure such as guns or alert or monitoring systems. The utility function in year t is

$$v_t(x) = U_h\left(C_t(x), f(x)\right) - g_1\left(M_{h,t}(x)\right) + E(N_{1,t}, N_{2,t}), \quad (6)$$

where $C_t(x)$ is the consumption of numeraire composite goods in year t, $f(x)$ is the housing lot size, $g_1(M_{h,t}(x))$ is the disutility from a fear of encountering omnivores and the risk of contracting infectious diseases in year t, β_y indicates the extermination intensity and E is existence value of omnivores and plants.

Subject to the constant utility level defined in (6), households decide the consumption of numeraire composite goods, the housing lot size and extermination intensity based on bid-rent theory. The maximization problem of households is as follows.

$$\max_{C_t(x),\ f(x),\ \beta_t(x),\ \beta_m(x)} r_t(x) = \frac{w + \Omega_t - \tau(x) - C_t(x)}{f(x)}, \quad (7)$$

where Ω_t is the per-resident revenue from land ownership in year t, $r_t(x)$ is the land rent at location x in year t, and $\tau(x)$ is the commuting cost. We assume that, after the second period, housing lot size $f(x)$ is kept at those at the first period because residents cannot change these sizes at least for a short term.

3. SIMULATIONS AND RESULTS

We conduct two analyses. At first, we reveal the effects of global warming on the population and distribution of wildlife at equilibrium, and the value of wildlife humans perceive, the fear humans feel when encountering omnivores, and the risk of being infected with fatal viruses from them. Second, we identify the impact and mechanisms of extermination policies on omnivores and humans for the purpose of population management, and to conduct welfare analysis.

(1) The effects of global warming

We show the effects of global warming on the population and spatial distribution of omnivores. Figure 1 and Figure 2 show the total time of omnivores' staying within the city and the populations of immature and mature omnivores when $a(Q_{m,t})$ set as 0.17, 0.66 respectively. The total time of omnivores' staying within the city is expressed as the product of the time density of an omnivore within housing zones and the populations of omnivores.

In Figure 1, the total time of omnivores' staying within the city (shown by the green bars) decreases until period 8, but after period 8, it increases year by year. The reason is as follows. In early periods, nuts production increases in the natural habitat due to global warming, and more food is available in the natural habitat. So, omnivores decide to stay in the natural habitat rather than in housing zones. Simultaneously, the number of births increases, and the population of omnivores increases with a delay because the consumption of food increases. As their population grows, they eat up the food in the natural habitat, and it is hard for them to find food. Accordingly, they appear in urban areas.

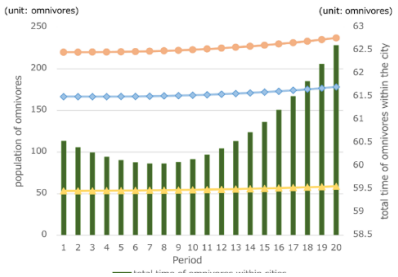


Figure 1. The total time of omnivores' staying within the city and the populations when $a(Q_{m,t})$ is 0.17.

On the other hands, in Figure 2, the total time of omnivores' staying within the city (shown by the green bars) increases as time goes unlike Figure 1. This suggests that the impact of increased population growth due to the increase in consumption of food in the natural habitat caused by global warming is more significant than the impact of the decrease in the time density within housing zones.

This implies that the time duration of omnivores' staying within the city increases under global warming when the impact of food consumption on the number of births is large.

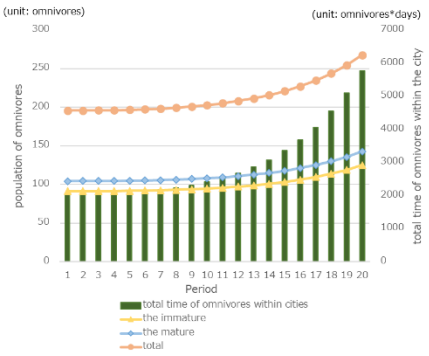


Figure 2. The total time of omnivores' staying within the city and the populations when $a(Q_{m,t})$ is 0.66.

(2) The effect of changes in the distribution of extermination intensity in urban areas

Next, we clarify which is more efficient to exterminate immature or mature omnivores by changing the distribution of extermination intensity. The sum of the extermination intensity of immature and mature omnivores is constant, only the distribution of extermination intensity is changed. We focus on two aspects of social welfare that are related to omnivores: damage caused by omnivores and biodiversity, respectively.

Figure 3 shows damage caused by omnivores which depends on the total time of omnivores' staying within the city. The bold yellow line represents the market equilibrium with the same extermination intensity for immature and mature omnivores, and the brown and blue lines represent the case where the distribution of that of immature and mature omnivores is increased, respectively. This figure indicates that when immature omnivores are exterminated rather than mature omnivores, the total time of omnivores' staying within the city is reduced in the early period, which keeps the distance between omnivores and humans and reduces the damage caused by omnivores. However, from the 11th period onward, the damage from them begins to increase because they return to the city for lack of food due to the increase in the number of the animals.

This suggests when a steady extermination policy is continued, the effects can be reversed in the short term and the long term.

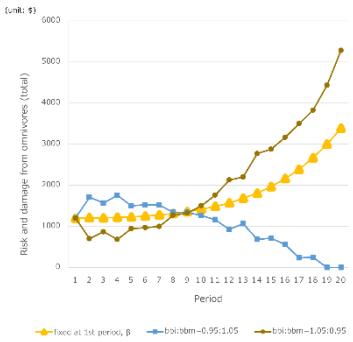


Figure 4. Damage caused by omnivores

Figure 4 shows the populations of omnivores which depends on biodiversity. In Figure 4, the stronger the immature extermination intensity over mature ones, the more they can survive, and therefore the populations of omnivores to be exterminated will be reduced. Therefore, the total number of omnivores is maintained, and the biodiversity is benefited more.

The balance between damage caused by omnivores and biodiversity affects the social welfare.

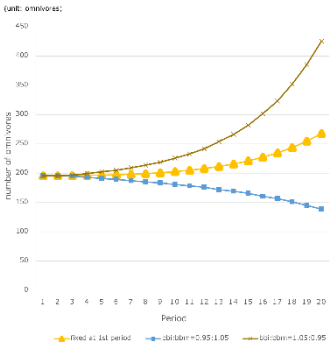


Figure 3. Populations of omnivores

4. CONCLUSION

This paper develops a new model that includes two life stages of omnivores (immature and mature omnivores) and a dynamic model considering the interaction between humans and the ecosystem. Using our model, we reveal that when the impact of food consumption on the number of births is large, the time duration of omnivores' staying within the city increases under global warming. We also clarify which is more efficient to exterminate immature or mature omnivores by changing the distribution of extermination intensity.

Our model provides an optimal solution for the coexistence of humans and the ecosystem. The coexistence of humans and the ecosystem is an important issue that is required in a society where the ecosystem is changing due to global warming. Using our model, we can design policies in terms of i) categories (immature and mature omnivores), ii) timing, and iii) land use policies from the perspective of population management and social welfare.

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