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

Tatsuhito Kono[1], Yuki Shirakawa [2], Jotaro Urabe [3*] and Jun Yoshida [4*]

[1]Member of JSCE, Professor, Graduate School of Information Sciences, Tohoku University
(Aoba 6-3-6, Sendai, Miyagi 980-8579, Japan)
E-mail: kono@plan.civil.tohoku.ac.jp
[2] Master Student, Dept. of Civil Eng., Tohoku University
(Aoba 6-3-6, Sendai, Miyagi 980-8579, Japan)
E-mail: yuki.shirakawa.t7@dc.tohoku.ac.jp
[3]Professor, Aquatic Ecology Lab, Dept. Ecology and Evolutionary Biology
Graduate School of Life Sciences Tohoku University
(6-3 Aoba, Aramaki, Aoba-ku, Sendai, 980-8578, Japan)
E-mail: urabe@tohoku.ac.jp
[4] Assistant Professor, Graduate School of Engineering, Kyushu University
(744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan)
E-mail: j-yoshida@doc.kyushu-u.ac.jp
*Alphabetical listing of authorship.

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 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. The results of numerical simulations show that the time duration of omnivores' staying within the city temporarily decreases, but after a certain period, it begins to increase in the existence of global warming. In addition, changing the level of the extermination intensity, we see that, as the level increases, population change is different between immature and mature omnivores in early periods.

Key Words: *human-wildlife conflicts, immature and mature omnivores, dynamic model, global warming, urban residential market*

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 reveal the effects of global warming on the population and spatial distribution of omnivores 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.

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 the population of immature omnivores in year t, 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:

$$\max_{\pi_t^A(x),\, \pi_t^H(x)} \quad a(Q_{m,t})(1-M_{m,t}) \ -M_{i,t}, \qquad (1)$$

where α is individual reproduction efficiency per prey eaten, $Q_{m,t}$ is food intake of individual mature omnivore in year t and $M_{i,t}, M_{m,t}$ are the number of the number of immature and mature omnivores killed by humans in year t. The first term represents the number of births in year t. In this paper, we set $a(Q_{m,t})$ two ways, $aQ_{m,t}$ and $a\sqrt{Q_{m,t}}$.

The individual mature omnivore (y=m) eats food waste in human zone and plants in animal zone to share with its immature ones. So, $Q_{m,t} \equiv Q_{m,t}^H + Q_{m,t}^A - Q_{i,t}$. Regarding the sum of intake of prey species per individual immature in year t, we define $Q_{i,t} = qN_{i,t}$, 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.

The sum of intake of prey species per individual mature omnivore in zone j in year t is expressed by integrating the expected intake of prey species at location x over the search range:

$$Q_{m,t}^H = \int_{D^H} \pi_t^H(x)\rho^H(\pi_t^H(x))n_h(x)dx, \qquad (2)$$

$$Q_{m,t}^A = \int_{D^A} \pi_t^A(x)\rho^A(\pi_t^A(x))n_1(x)dx, \qquad (3)$$

where $\rho^H(\pi_t^H(x))$ expresses the availability of food waste, $n_h(x)$ is human population density, $\rho^A(\pi_t^A(x))$ expresses the availability of plants, $n_1(x)$ is the density of plants. D_y^j is omnivore's search range in zone j.

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:

$$M_{y,t} = \int_{D^H} \beta_y \pi_t^H(x)k(x)n_h(x)dx, \quad y \in \{i, m\} \qquad (4)$$

where β_y is the probability of extermination per unit of time the individual y spends within the city, $k(x)$ is a parameter that explains humans' chance of encountering omnivores 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

$$v_t(x) = U_h(C_t(x), f(x)) - g_1(M_{h,t}(x)) + g_2(\beta_i(x), \beta_m(x), f(x)) + E(N_{1,t}, N_{2,t}), \qquad (5)$$

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, $g_2(\beta_i, \beta_m, f(x))$ is the utility gained from a sense of security by installing the defensive measures.

Subject to the constant utility level defined in (5), 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.

$$\max_{C_t(x),\ f(x),\ \beta_l(x),\ \beta_m(x)} r_t(x) = \frac{w+\Omega_t-\tau(x)-C_t(x)}{f(x)}, \qquad (6)$$

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.

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.

3. SIMULATIONS AND RESULTS

We conduct numerical simulations to reveal the effects of global warming on the population and spatial distribution of omnivores at equilibrium under the condition that the extermination intensity is fixed. We also clarify the mechanism of the effects of changes in extermination intensity.

(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 $aQ_{m,t}$, $a\sqrt{Q_{m,t}}$ respectively.

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.

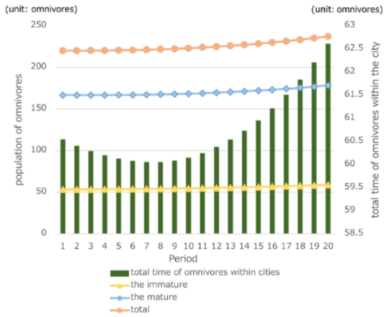


Figure 1. The total time of omnivores' staying within the city and the populations when $a(Q_{m,t})$ is $aQ_{m,t}$

On the other hands, in Figure 2, the total time of omnivores' staying within the city (shown by the green bars) decreases as time goes unlike Figure 1. 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. This suggests that the impact of the decrease in the time density within housing zones is more significant than the impact of increased population growth due to the increase in consumption of food in the natural habitat caused by global warming. This intuitive interpretation is that the effect of the consumption of food on the number of births is smaller than in the linear case ($a(Q_{m,t}) = aQ_{m,t}$), and thus the growth in the population of omnivores is mitigated.

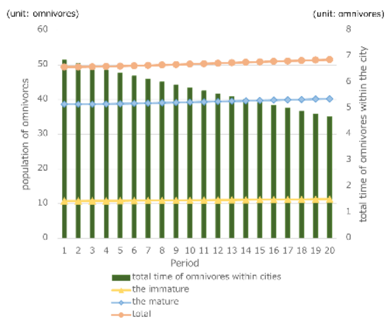
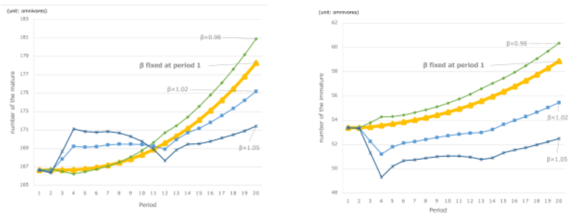


Figure 2. The total time of omnivores' staying within the city and the populations when $a(Q_{m,t})$ is $a\sqrt{Q_{m,t}}$

(2) Changes in the extermination intensity in urban areas

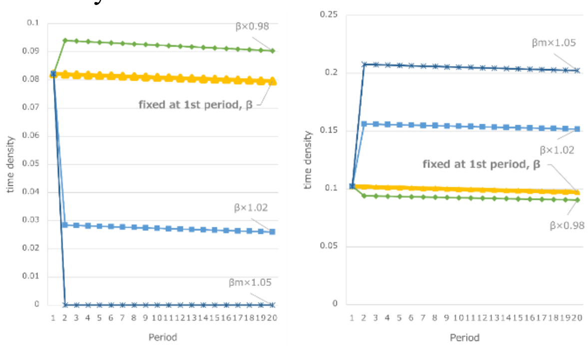
Figure 2 shows the populations of mature and immature omnivores. In Figure 2, population change is different between immature and mature omnivores in early periods. The intuitive interpretation is as follows. When the extermination intensity is enhanced, omnivores move into the natural habitat, and avoid the risk of being killed by humans. So, the population of mature omnivores temporarily increases, compared to the case with a fixed extermination intensity. While the population of immature omnivores decreases in early periods because the consumption of food decreases when the omnivores move to the natural habitat because the natural habitat becomes more crowded and the efficiency of feeding declines. This difference in population fluctuations between immature and mature omnivores implies that it is effective to implement different policies for immature and mature animals in order to effectively control the population of the target animal.



mature omnivores immature omnivores

Figure. 2. The populations of omnivores

Figures 3 shows the transition of time density of an omnivore in each point in the urban area. These figures indicate that there is a difference in the change in the time spent within the same urban area, as we reinforce the extermination intensity. Specifically, omnivores rarely appear at the 4 km point close to the CBD, while they stay longer at the 6 km point farther from the city. The reason is as follows. As the extermination intensity increases, omnivores will move away from the urban centers where the risk of being killed is higher. They will have to go somewhere else to ensure that they have enough food to eat. They move to the the natural habitat and try to eat there, but the the natural habitat becomes crowded. This means that it becomes difficult to eat, so they are forced to go to the urban areas. For these reasons, they will stay longer at the 6 km point (urban boundary) where the risk of being killed is the lowest in the city.



(1) 4km (2) 6km

(boundary of omnivores' search range) (urban boundary)

Figure 3. Time density in the urban area

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 the total time of omnivores staying within the city temporarily decrease, but after a certain period, it begins to increase due to global warming. we also clarify the mechanism of the change in the population and spatial distribution of habitat of omnivores with changes in 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. Specifically, using this model, we can explore i) which we should exterminate, immature omnivores or mature ones and ii) which is the best timing (e.g., early extermination or extermination after population fluctuations) and how much intensity we should target.

ACKNOWLEDGEMENTS

This research was supported by grants from the Ministry of Education, Culture, Sports, Science and Technology (Grant-in-Aid for Challenging research (Pioneering) 21K18128.

REFERENCES

1) Brueckner, J. K. (2000). Urban sprawl: diagnosis and remedies. International Regional Science Review, 23(2), 160-171.Kono, T. and Nakajima, K., and Shoda, K., External Benefits of Geographical Concentration of Firms with Trade Networks, 2019.
2) Eppink, F. V., J. van den Bergh, Rietveld, P., 2004. Modelling biodiversity and land use: urban growth, agriculture and nature in a wetland area. Ecological Economics, 51(3), 201–216.
3) Eichner, T., and Pethig, R., 2006. Economic land use, ecosystem services and microfounded species dynamics. Journal of Environmental Economics and Management, 52(3), 707–720.
4) Eichner, T., and Pethig, R., 2009. Pricing the ecosystem and taxing ecosystem services: a general equilibrium approach. Journal of Economic Theory, 144(4), 1589–1616.
5) Walker, R., 2001. Urban sprawl and natural areas encroachment: linking land cover change and economic development in the Florida Everglades. Ecological Economics, 37(3), 357–369.
6) Yoshida, J., and Kono, T., 2020. Land Use Policies Considering a Natural Ecosystem. Regional Science and Urban Economics 83, 103552.