Agent-Based Modeling for Simulating Population Dynamics of Wild Boar (*Sus scrofa*) in Chiba Prefecture of Japan

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ABSTRACT: Local populations of wild boars (*Sus scrofa*) in Chiba prefecture of Japan were considered extinct during 1970s. However, a new local population, which was not native to Chiba prefecture, has been introduced for hunting purposes and increasing rapidly in the past four decades. Rapid rise in the introduced population has brought a serious problem by causing damages to agricultural crops and/or human beings. To cope with the situation, control measures for nuisance animals must employ multiple methods including: the direct removal method by trapping and hunting nuisance animals; and the barrier method by installing a wildlife fence that prevents nuisance animals from feeding on agricultural crops. An advanced method includes designing a land management plan effective for nuisance animal control. However, success of the advanced method relies on the information about spatially explicit population dynamics of wild boars in Chiba prefecture. We developed an ABM using NetLogo environment (Wilensky 1999) to simulate population dynamics of wild boars in Chiba prefecture, Japan. The ecological behaviors of individual wild boars, interactions among individuals and environmental conditions were implemented into the ABM. Spatial and temporal variations of environmental conditions were represented using a set of 300m * 300m grid cells. Preliminary results showed that the model can simulate the realistic dynamics of wild boar populations in the last decade, while there still remains a problem concerning processing time.

1. INTRODUCTION

Local populations of wild boars (*Sus scrofa*) in Chiba prefecture of Japan were considered extinct during 1970s. However, a new local population, which was not native to Chiba prefecture, has been introduced for hunting purposes and increasing rapidly in the past four decades. Rapid rise in the introduced population has brought a serious problem by causing damages to agricultural crops and/or human beings. The cost of wild boar damage to agriculture crops in Chiba prefecture is estimated to over 201 million yen in 2011, while the area of damaged crop field is estimated to be approximately 330 ha (Chiba prefecture government, 2013).

To cope with the situation, control measures for the nuisance animal must employ multiple methods such as: the direct removal method by trapping and hunting a nuisance animal; and the barrier method by installing a wildlife fence that prevents nuisance animals from feeding on agricultural crops. An advanced approach is to design a strategy for deploying the most effective method in the right place and at the right timing. However, insufficient information on spatially explicit population dynamics of wild boars in Chiba prefecture has constituted an obstacle to the strategy planning.

A statistical modeling approach that considers habitat suitability and dispersal probability was applied to predict the spatial distribution pattern of wild boars in Chiba prefecture (Saito et al. 2012). However, the approach cannot take into account the effect of introduction, i.e., population movement by human activities. Agent-Based Model (ABM), which is a sort of computer simulation model, whereby phenomenon is modeled in term of agent and their interaction, is expected to provide us with an alternative means to predict population dynamics of wild boars at given locations under different introduction scenarios.

We developed an ABM using NetLogo environment (Wilensky 1999) to simulate population dynamics of wild boars in Chiba prefecture. The ecological behaviors of individual wild boars, interactions among individuals and environmental conditions were implemented into the ABM. Spatial and temporal variations of environmental conditions were represented using a set of 300m * 300m grid cells. Preliminary results showed that the model can simulate the realistic dynamics of wild boar populations in the last decade, while there still remains a problem concerning processing time.

2. MATERIAL AND METHODS

2.1 Study Area and Data

Chiba prefecture is on the east coast of Honshu, Japan and largely consists of the Boso Peninsula, which encloses the eastern side of Tokyo Bay (Figure 1). Spatial and temporal variations of environmental conditions in Chiba prefecture were represented in the Agent-Based Model using a set of 300m * 300m grid cells. The total area of Chiba prefecture, which is approximately 5,156 Km^2, was covered by 350 pixels and 450 lines of the grid cells. Each grid cell has information on: (1) Land Use and Land Cover (LULC) category; (2) pheromone concentration; and (3) the municipality within which the grid cell falls.

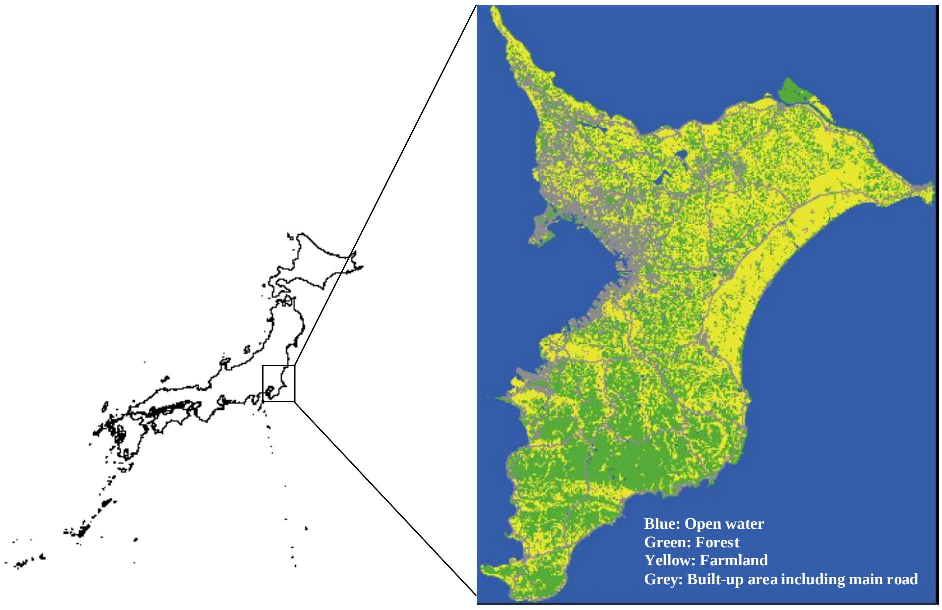

Figure 1. Study area

LULC category is an important factor affecting autonomous behaviors of all the wild boar agents, because it is relevant to food availability and ecological barriers which impede movement of agents. LULC category was defined based on the "National actual Vegetation map" provided from Biodiversity Center of Japan (Biodiversity Center of Japan, 2016). Although the original version of the vegetation map was comprised of polygons with attribute information over 900 landcover types, the polygons were aggregated into 4 broad categories: (1) Open water; (2) Forest; (3) Farmland; and (4) Built-up area including main road. Then the polygons were converted into ASCII Raster format for use in the NetLogo environment.

Pheromone concentration is also an important variable, since the pheromone released by female wild boars is considered to have an effect attracting male wild boars during the mating season. Attribute information on municipality is necessary to facilitate the calibration and validation of the ABM, because the number of trapping and hunting of wild boars is reported by summarizing at each municipality unit.

2.2 Model Description

The model description begins with a general overview of behavioral ecology of wild boar in Chiba prefecture. The male wild boar got weight range between 50kg to 150kg and size from 110cm to 160cm long while females are tend to be smaller than male. They can jump through a 120cm high fence without running from distance. Wild boars have poor eyesight that they hardly identify the difference between red color and yellow color, but they have an incredible sense of smell. During the day time, they are staying close to abandoned farmland in one community and after a week in average they move to other abandoned farmland in other community or turning back. Wild boar lives in groups which are composed of females and their underage up to 1 year old piglets while mature males live in solitary life, except during the mating season. Mating season usually starts from December or January and last 3 months that males come to find group of females by eating little food along the way. Once mated, the female wild boar gives birth to 5 piglets in average and 8 piglets in maximum. The death rate of young piglets is high; around 50% of young wild boar can grow to be mature. Wild boar can survive up to 10 years and over in the natural environment (Chiba prefecture Government, Wild boar counter manual, 2015). Japan wild boar eat some kind of tree underground element (i.e. bamboos, roots, tubers), agricultural fruit and seed (i.e. rice, seeds, fruit) and some small animal matter (i.e. frog) during summer season (Kodera et al, 2013).

Considering the behavioral ecology mentioned above, the following autonomous and interacting behaviors of wild boar agents were implemented in the ABM. All the parameters regarding to the agents of global type, grid cell type and wild boar type are summarized in Table 1.

Table 1. Parameters implemented in the ABM.

Agents	Variables	Value ranges / Factor types	Types	Calibration
Global	Simulation period	1985 AD to 2005 AD	Constant	
Grid cell	Maximum food availability at Open water and Built-up area	0	Constant	
	Maximum food availability at Forest and Agricultural area	15	Constant	
	Maximum concentration of pheromone	20	Constant	Yes
	Evaporation rate of pheromone	0.4	Constant	Yes
	Diffusion rate of pheromone	0.1	Constant	Yes
	Administrative ID	1 to 60	Constant	
Wild boar	Scaling factor for release population number	2	Constant	Yes
	Sex	Male / Female	Random	
	Lifespan	10 + 1 to 5 years	Random	
	Young piglets age	0 to 1 year	Constant	
	Young mature wild boar age	1 to 2 years	Constant	
	Old mature wild boar age	2 year up	Constant	
	Maximum group member	30	Constant	
	Group range radius distance	1 grid cell	Constant	Yes
	Maximum angle turning into/leaving from group	45 degree	Constant	Yes
	Duration of mating season	150 days from Dec 1st	Constant	
	Probability of getting pregnant	0.32	Constant	Yes
	Duration of pregnancy	120 days after pregnant	Constant	
	The number of piglets	{4,5,6,7,8}	Random	
	Probability of piglets' death	0.5	Constant	
	Maximum energy	50	Constant	Yes
	Energy gained from 1 food grid cell	5	Constant	Yes
	Energy loss per day	0.12	Constant	Yes
	Probability of agent avoiding built-up area	0.75	Constant	Yes
	Probability of agent avoiding farmland	0.60	Constant	Yes
	Short distance movement	0.35 grid cell	Constant	Yes
	Long distance movement	3.0 grid cell	Constant	Yes
	Angle turning of short distance movement	[0, 90]degree (left /right)	Random	Yes
	Angle turning of long distance movement	[0, 15]degree (left /right)	Random	Yes
	Average day of changing from short distance movement to long distance movement	7 days	Constant	Yes

The wild boar agent would look for foods that contain on each grid cell agent. The foods provide wild boar agents the energy for their moving behavior process and they would die or remove from system if this energy value went below zero. Every wild boar agents are programmed to make daily decision considering the food availability at each of grid cells. If there is enough level of food around them, they moved and turned in short distance. The wild boar agents also moved and turned in long distance to new location in average 7 time steps after short distance move. A calculation of probability of moving from one type of grid cell to others was also operated. Otherwise, they would turn back to the same type of gird cell.

In simulation process, for each time step equal to one day, the maximum age to which wild boar agent could stay, was 3650 plus random 2000 time steps which is equal to 10 years over. Wild boar agents would be removed from the system when the age parameter have reached at the maximum. The death rate of young piglet agents which were born from one female agent, was considered to be 50 % which means that only half number of young piglets agents could grow up to be mature wild boar agents.

For the wild boar agents, 2 distinct types of groups were defined. The first group included the agents of young piglets young mature female, and old female. The second group contained the agents of young mature male. Meanwhile, old male agents were programmed to be not belonging to any group. To make the behavior of young piglets more realistic and reduce the processing time, the numbers of young piglets were considered as variable in old female agent. The young piglet were separated from their mother after 365 time steps. After the separation, they were programmed to behave as young mature male or female agents. Unless the number of members in a group was greater than the predefined value, the members of a group were programmed to keep the pre-defined distance between each other by confirming their age and sex.

During mating season which starts from December 1st and lasts after 150 time steps, the mature female agents could release their pheromone to attract the mature male agents. If female and male wild boar agents were on the same grid cell, the female agent would become pregnant at the probability of getting pregnant. The duration of the pregnancy was predefined as 120 time steps. The young piglets' agent number was considered to be 5 in average and maximum 8.

For each time step running, food availability at each grid cell would increase in a constant rate up to the maximum value if the food at the grid cell was consumed by wild boar agents. Meanwhile, the pheromone which was released by female wild boar agents would evaporate and diffuse by a constant rate. The parameters were adjusted in the calibration phase described in the next sub-section.

2.3 Calibration

In 1985, wild boar had been released again in study area. The model runs from 1985 to 2005 in daily time steps. We analyzed the simulation data from 1996 to 2005, 10 years period, in order to do our model calibration. Wild boar agents and grid cell agent were defined in model. In each grid cell agent except water area consists of a certain level of food, administrative location representing each municipality in the study area, and concentration of pheromone leaved by female wild boar agents. Each wild boar agent will lose a certain level of energy for the activity. To charge the energy, the wild boar agents perform looking and eating food behavior process. To maintain population, mature wild boar agents chased each other for grouping or produce young piglets during mating season. Each wild boar agent made daily decision on what process they would perform.

Since there was no record of wild boar in the study area during 1970s, it was believed that the wild boars were extinct. However, according to survey arranged around 1985, they found that the wild boar had been released again at the some hill locations of Chiba prefecture. By testing the genetics of wild boar in this study area, they found that the wild boar were imported from other area and released. Hence, a number of file were imported with input data. The input data provided information which grid cell and when the wild boar agents would be released (Table.2).

Table 2. Wild boar released Data (Chiba prefecture Government, Wild boar counter manual, 2015)

Released location	Released Year	Released number
Eastern of Kamogawa City to southern of Kimitsu City	1985-1988	4
Kamogawa	1995-1996	2
Amatsukominato Town		2
Katsuura City	1985	1
Katsuura City	1993	1
Ichihara City		1
Kyonan Town		4
Kimitsu City	1995	1
Shimousa Town	1995-1996	1

In order to find a good fit of the simulated distribution pattern to the captured place pattern (Figure.2), a number of parameters were adjusted to calibrate the model outcome. Trial and error efforts were repeated to find the optimal values for the two parameters relating to short-distance movement and long-distance movement. The degree of conformity of the population estimated with the ABM to the captured data was analyzed using the data summarized in 3 typical areas (Figure 3).

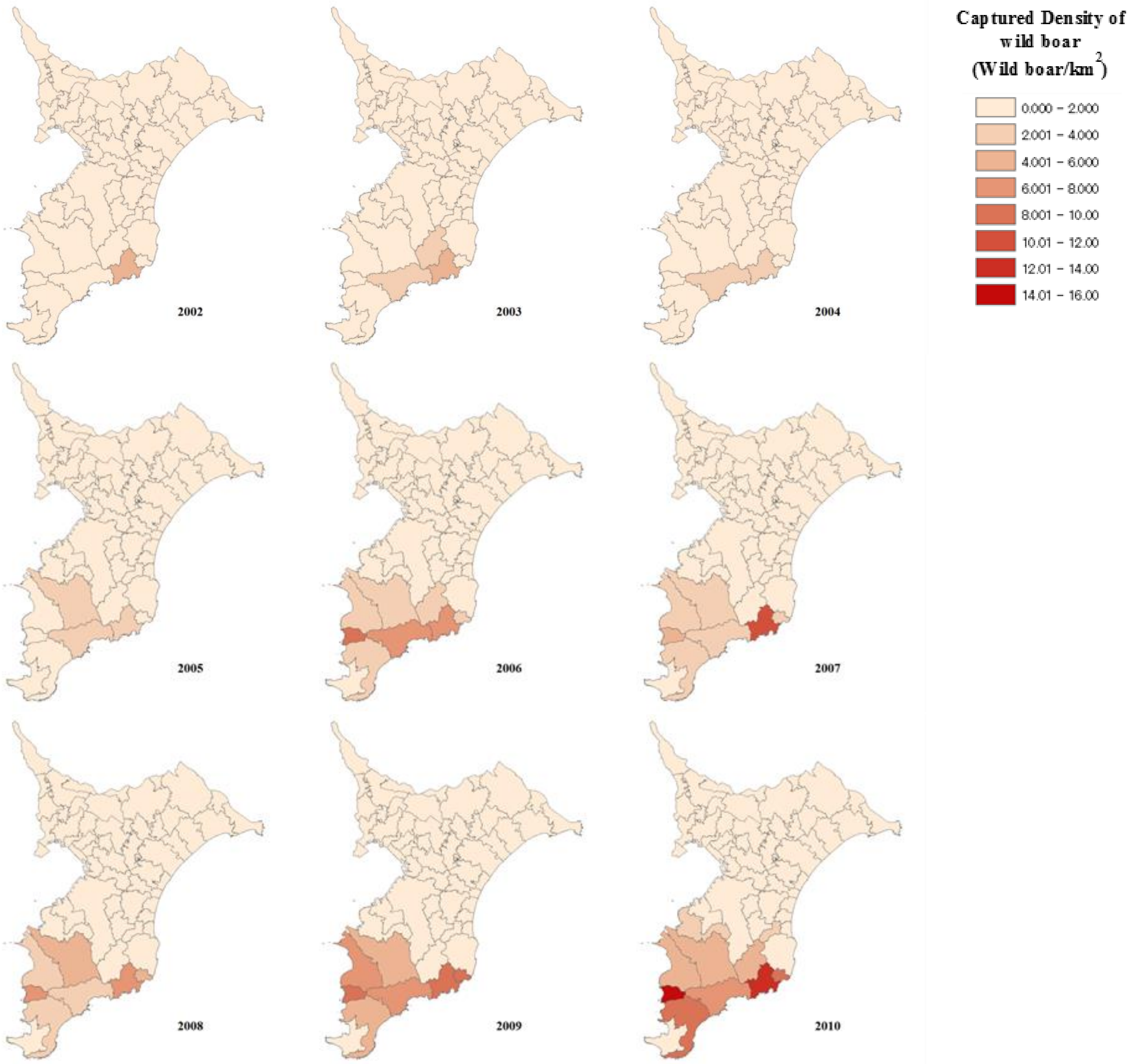

Figure 2. Choropleth map of the number of wild boar captured in the years 2002 through 2010.

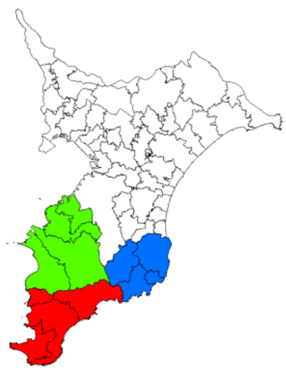

Figure 3. The areas where the population and capture data was summarized (Red: 1, Green: 2, Blue: 3).

3. RESULTS AND DISCUSSION

After a series of model calibration, we obtained the optimized parameters (Table 1). Assuming that the number of wild boars captured was a function of population density, the degree of adequacy was evaluated based on the correlation coefficient between the population estimated and the capture data for the areas of 1, 2 and 3 (Figure 4). As a result, the positive correlation was confirmed for all the areas of 1, 2 and 3. This suggests that the model can simulate the realistic dynamics of wild boar populations in the last decade, while there still remains a problem concerning processing time.

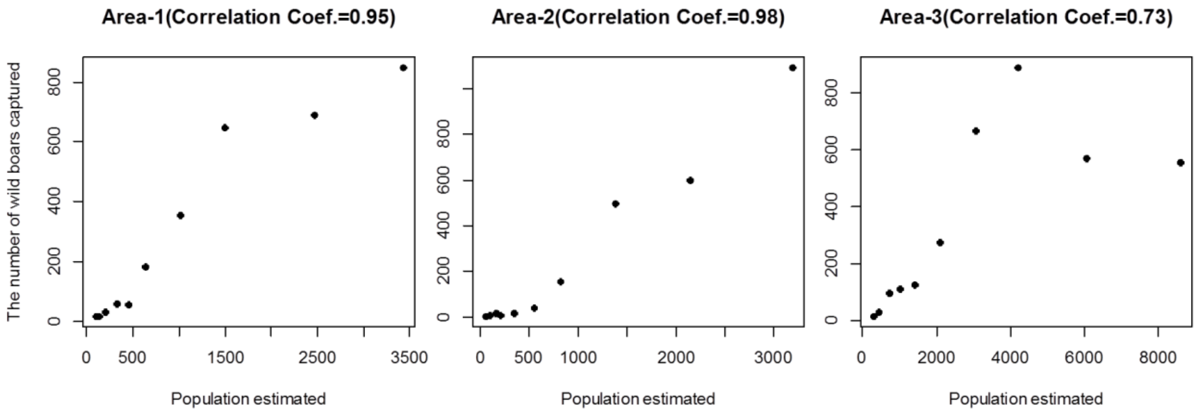

Figure 4. The population of wild boars estimated (horizontal axis) and captured (vertical axis) in the Areas of 1, 2 and 3. The locations of the areas are indicated in Figure 3.

4. CONCLUSION

We developed an Agent-Base Model using NetLogo environment (Wilensky 1999) to simulate population dynamics of wild boars in Chiba prefecture, Japan. The ecological behaviors of individual wild boars, interactions among individuals and environmental conditions were implemented into the ABM. Preliminary simulation results showed that the model can simulate the realistic dynamics of wild boar populations in the last decade, while there still remains several considerations to improve the model performance. Future work will be focused on: (1) considering the effects of hunting or trapping the wild boars; (2) redefining the grid cells agents to distinguish roads from built-up areas; (3) reducing the processing time; and (4) estimating the future wild boar population.

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