Road Network Impacts On Wildlife Animals: A Simulation Study

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***Abstract*—Habitat fragmentation is a harmful impact on wild animals. In this paper, we propose an agent-based simulation model to estimate the fragmentation impacts (FIs) on wild animals caused by road network. We employ predator-prey system as a simplified ecological system, and investigate FIs on wildlife by adding roads gradually into the habitat of wildlife. Simulation results are well consistent with the ecological observation from previous researches. We find that (1) when road density increasing, but still below the critical threshold, wolves' population decrease monotonically; (2) when road density steps over the critical threshold, wolves are extinct; surprisingly, (3) after the extinction of wolves, sheep cannot recover to the carrying capacity of the initial state without wolves. Our simulation model provides not only a way to estimate the ecological impacts caused by the existed road network, but also a tool for considering alternative regional policies of road network planning.**

Keywords—Multi-agent simulation; ecological fragmentation; road network

I. INTRODUCTION

Traditionally, road network planning focuses on providing safe and efficient human traffic [1]. Meanwhile, when roads slice through a region, some harmful ecological impacts appear. For example, roads create barriers and additional disturbance that in turn cause fragmentation of the landscape and its wildlife populations. Ecologists have found that some species of small animals simply refuse to cross roads or even venture onto road surfaces [2, 3, 4]. For these kinds of species, road network effectively breaks their population into pieces. Once a population is separated into smaller subpopulations, the chances of extinction of these subpopulations dramatically increase [1] due to the higher vulnerability of smaller populations to `regular' fluctuations [5]. When road density exceeds a threshold, large carnivores or hunted game species cannot persist. This kind of ecological condition is called as fragmentation.

Fragmentation is a frequently studied problem from an ecological point of view. However, in road (network) planning, this problem has not obtained adequate attention so far. The aim of this work is to provide a tool to estimate the fragmentation impacts (FIs) of road network on wildlife species by using an agent-based simulation model, which combines population dynamics and road planning together. This model also enables ecologists to get an insight view of habitat fragmentation caused by road network.

The organization of this paper is as follows. In the next section, we define the most important quantities (e.g. fragmentation) we aim to study, whereas the construction of an agent-based model and its simulation results are detailed in Section 3. Finally, in Section 4, we discuss how this model can be used in planning the future road networks and how to improve the model to more suitable for estimating the FIs on wild animals caused by road network.

978-1-4799-3197-2/14/$31.00 ©2014 IEEE

II. MEASUREMENTS

Several spatial concepts have been devised to quantify fragmentation of landscape, focusing on roads or traffic. In this paper, we address this issue focusing on roads.

Road density ρ is a common measurement of fragmentation. It's defined as

$$\rho = \frac{l}{a} \tag{1}$$

where, l is the length of the roads (km) and a is the land area (km^2). It measures how many roads per unit area [1]. In this paper, an ecological region is represented by a given square space, i.e. $N \times N$ area, which is surrounded by roads on the edges. Then FIs on wildlife species are assumed to spread evenly over both sides of a road. Because there is one half FIs acting on the outside of the study area, only half length of roads on the borders of the study region is taken into account.

Mesh-width of road network is directly related to road density. It's defined as

$$w = \frac{2}{\rho} \tag{2}$$

where, w is the mesh-width (km). Then one can easily calculate the mesh-size of road network as

$$s = w \times w \tag{3}$$

where s is the mesh-size (km^2). The above calculations are used to theoretically measure the spatial continuity of landscape units. In the formulae (1) and (3), every unit is implicitly assumed to be equal with the same size. However, in reality the continuous landscape units are heterogeneous, each with their own specific size [6].

TABLE I. PARAMETERS

Parameter	Value
Region	
Size	80×80**
Wolves	
Energy from sheep	20
Birth rate	5%
Birth energy	50%
Sheep	
Energy from grass	4
Birth rate	4%
Birth energy	50%
Grass	
Regrowth time	30

III. SIMULATION MODEL

We construct a stochastic, spatially explicit, agent-based simulation model, which is extended from the NetLogo model called "Wolf Sheep Predation" [7, 8, 9]. Such an ecosystem is called unstable if it tends to result in extinction for one or more involved species. In contrast, an ecosystem is stable if it tends to maintain itself over time, despite fluctuations in population sizes [7]. Hereby, we will use the relative variety of population sizes to measure the influences on ecosystem caused by road network.

The study region is represented by a two dimensional grid of "patches", and is separated from the outside by roads initially existed on the borders. Wolves and sheep randomly wander around the landscape, while the wolves prey on sheep and the sheep feed on grass. Each step of wandering costs their energy. They must eat in order to refill their energy, otherwise they will die when they run out of energy. At each time step, each wolf or sheep has a fixed probability of reproduction, and this rule makes the population evolving continuously. Once grass is eaten, it will only regrow after a fixed amount of time. Parameters used in simulations are given in Table 1.

Computer simulations begin by investigating the carrying capacity of the region for sheep and wolves, and the simulated ecosystem is in the initial state (see Fig. 1a). If wolves are absent, the average population size of sheep is 635. When wolves exist, the population size of sheep and wolves are 400 and 181, respectively. In initial state, road density ρ is 0.025.

Next, we choose some regular road network patterns (Fig. 1(b-f)) based on two principles. (1) The region is separated into smaller areas with same mesh-size. (2) The number of vertical and horizontal roads are very similar.

IV. RESULTS

Simulation results are shown in Table 2. All the data are averaged over 5,000 time steps, after the state of the system has evolved into the steady state. Fig. 2a shows that the mesh size of the study area decreases with the increase of road density (Fig. 2a). Smaller the mesh size, more fragmented the habitat of wildlife animals, and more vulnerable the wildlife animals [10]. With road density ρ increasing, the population size of wolves

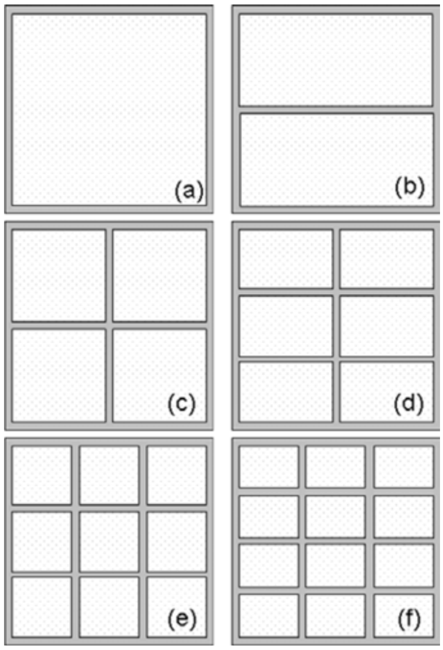

Fig. 1 Road network patterns simulated. (a) initial state, there is no road slice through the study region; patterns (b)-(f) are chosen based on two principles.

monotonically decreases (Fig. 2b). When ρ goes over a threshold ρ_c (≈0.75), wolves are extinction. This is consistent with the observation of ecological study [10]. While, road density ρ increasing do not cause obvious fluctuation of sheep (Fig. 2b). After wolves' extinction, the population size of sheep increases a little, but cannot reach the carrying capacity (according to the data from [10]), due to new roads go through the region cause fragmentation of landscape and wild animals.

While this theoretical model is still not much close to the real world road planning. But we will improve it from the following aspects: (1) make the region has the real shape; (2) collect the ecological data from the road planning project in place. We believe these improvement will make this method give more valuable quantitative reference for transportation engineers.

V. CONCLUSION

This work aims to provide a spatially explicit tools for estimating the fragmentation impacts (FIs) on wild animals caused by road network in a region. According to our simulation results, we argue that this agent-based simulation method will provide the transportation engineers a tool when considering FIs of alternative regional policies of road network planning.

TABLE II. SIMULATION RESULTS

Road network pattern (see Fig.1)	sheep	wolves	ρ	w
(a)	400	181	0.025	80
(b)	390	170	0.0375	53.3
(c)	384	159	0.05	40
(d)	377	148	0.0625	32
(e)	399	92	0.075	26.7
(f)	537	43	0.0875	22.8

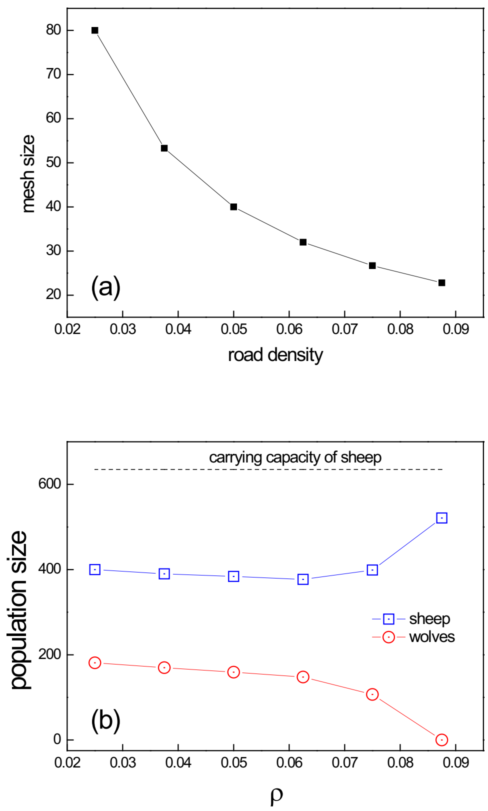

Fig. 2 (a) mesh size changes with road density increasing. (b) population size of sheep and wolves.

ACKNOWLEDGMENT

This work is partially supported by National Basic Research Program of China (no.2012CB725401), National Natural Science Foundation of China (nos.71131001 and 71101009) and Fundamental Research Funds for the Central Universities (no.2012JBM067).

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