Ecological Indicators 85 (2018) 468–478

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Research paper

Synoptic scale mammal density index map based on roadkill records

Takafumi Tatewaki*, Fumito Koike

Graduate School of Environment and Information Sciences, Yokohama National University, 79-7 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan

ARTICLE INFO

Keywords:
Density index map
Government data
Nationwide monitoring
Wildlife management
Wildlife-vehicle collision

ABSTRACT

Globally there are few synoptic-scale (over 1000 km) animal density index maps available, except for special cases such as important game species or alien species subject to control programs. Here, we propose a method of estimating synoptic-scale density index distribution of mammals, including non-game and non-pest species, by using roadkill records collected by municipalities.

In order to correct biases caused by location, environment and traffic density to roadkill data, we constructed an animal density index model by using environmental factors as land use and climates, and fitted to roadkill records taking into account road types as delegate of traffic density. Since alien species are expanding geographic ranges and some native species were historically extinct regionally, we considered a regional factor not predictable by environment. We then estimated density indices over the research area for nine animals.

Geographical distribution of density indices in nine mammal species were obtained. Density index maps of three of four animals agreed (AUC $>$ 0.7) with the data on previous presence/absence maps. The exception was that the red fox was distributed over almost of all the research area on previously published maps, but we found that its density was low in southern Pacific areas. The species was considered as endangered in some prefectures there, and it clearly showed the importance of our density index estimation. Significant differences in the regional factor explained ongoing range expansion of alien species (masked palm civet and raccoon) and the historical regional extinction of sika deer.

Roadkill data were useful data source for deriving huge-scale density index maps of wildlife. Animal density index monitoring should now become feasible even at a synoptic spatial scale.

1. Introduction

Estimating nationwide spatial distributions of wildlife density is vital for conserving endangered species and controlling overabundant or alien species. Densities of animals often linked to risk of extinction, severity of wildlife-human conflicts, or impact on other wildlife, thus animal density maps are useful to identify primary areas where management resources should focus on. Presence/absence information of animals are insufficient for such purposes.

However, few synoptic-scale (over 1000 km) animal-density maps are available globally, except in the case of important game species in countries where wildlife is well managed (e.g., Adams et al., 2009) and alien species under nationwide control programs (e.g., National Land and Water Resources Research Audit and Invasive Animals Cooperative Centre, 2008).

To our knowledge, there is no known method of obtaining synoptic-scale density maps of a variety of mammals at feasible cost. Game-bag records are often used as density indices (Acevedo et al., 2014), but hunting and trapping effort data are usually difficult to obtain, and many species other than major game animals are beyond the focus of such records. Distance sampling (Thomas et al., 2010) and camera trapping (Rowcliffe et al., 2008) can be used to calculate densities or density indices for various species at the same time, but these methods are difficult to apply on a synoptic scale because of their high cost and labour-intensive nature.

Roadkill numbers are correlated with live animal density (Visintin et al., 2016) in terms of unit length of road (Baker et al., 2004; Seiler 2004) or traffic volume (McCaffery 1973). Roadkill occurs in a variety of species and is detected more easily than living animals, especially in the case of species with nocturnal or cryptic behaviour. Roadkill is already collected, and roadkill records are made, by police, road managers, wildlife managers, volunteers, or local governments for the purpose of human safety (Visintin et al., 2016), sanitation, and wildlife conservation (e.g., Huijser et al., 2007; Vanlaar et al., 2012; Tatewaki and Koike 2016).

Roadkill information is accumulated in many individual municipal governments of Japan for road management and sanitary purposes. We used questionnaire data obtained in the main islands of Japan

* Corresponding author. Present address: Faculty of Human Environments, University of Human Environments, 6-2 Kami-sanbon-matsu, Motojyuku-cho, Okazaki 444-3505, Japan.
E-mail address: t-tatewaki@uhe.ac.jp (T. Tatewaki).

http://dx.doi.org/10.1016/j.ecolind.2017.10.056
Received 29 November 2016; Received in revised form 10 July 2017; Accepted 25 October 2017

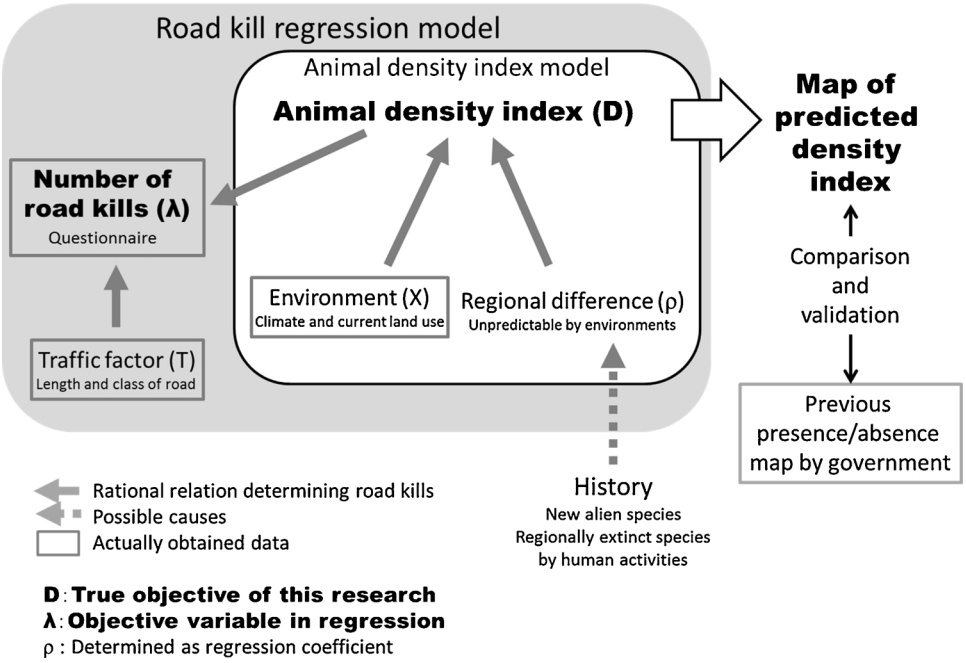

Fig. 1. Structure of the model used to predict animal density index on the basis of environmental variables and a regional factor, fitted to roadkill records.

(Tatewaki and Koike 2016). In this research, in order to obtain density index maps of wildlife, we built a regression model for annual roadkill number based on traffic factors, climate, land use, and mesoscale historical properties (Fig. 1) for various species. We then depicted estimated animal densities index over a synoptic-scale research area.

2. Methods

2.1. Study site

The study was conducted on the main islands of Japan (Fig. 2; 361,000 km^2 area, 1872 km maximum width, latitude 31.0° to 45.5°, longitude 129.6° to 145.8°).

The density of roads in Japan is 335 km/100 km^2 area; this is higher than the Organisation for Economic Co-operation and Development average (44 km/100 km^2) (OECD 2013). Roads in Japan were categorised into four classes: national expressways, national highways, prefectural roads, and municipal roads; the length of roads were 8, 55, 129, and 1022 thousand kilometres, respectively (Ministry of Land, Infrastructure, Transport and Tourism of Japan, 2014). Average traffic volume varied among road classes (national expressways 27,884, national highways 11,551, prefectural roads 3679 vehicles per day), but municipal roads were rarely surveyed (Ministry of Land, Infrastructure, Transport and Tourism of Japan, 2010).

The study area lies mainly in the temperate climate zone, although the southern part lies in the subtropical zone (average temperature of coldest month 8.5 °C and of warmest month 28.5 °C as Kagoshima) and the northern part is in the boreal zone (average temperature of coldest month −4.7 °C and of warmest month 19.6 °C as Wakkanai); the seasonal patterns of temperature change are very similar among the zones (Ministry of Internal Affairs and Communications of Japan, 2016). Urban-rural-forest landscape gradient is one of key environments in this area for mammal distribution (Saito and Koike 2013), and forest, agricultural, and urban areas covers 69.8%, 16.5%, and 7.3% of the study area (calculated from a land cover map: Ministry of Land, Infrastructure, Transport and Tourism of Japan, 2009).

The geographic ranges of some alien mammals are expanding (e.g., Koike 2006), and even though an environment is suitable, these animals may not yet have arrived there. Moreover, some native mammals suitable as human food (e.g. sika deer *Cervus nippon* Temminck, 1838 and wild boar *Sus scrofa* Linnaeus, 1758) became regionally extinct in the early 1900s (Tsujino et al., 2010), when hunting became popular after the end of the Edo period (1603–1868), in which hunting was banned. We considered such differences by taking into account a specific factor for regions (Fig. 2). The study area on Japan's four main islands was divided into eight economic regions in the early 1900s (Higuchi 1982; average area of regions 45,222.3 ± SD 20,350.1 km^2, average width of minimum bounding rectangle 233.0 ± SD 79.4 km) and we followed this division. Sika deer were driven to extinction in the Tohoku region about 100 years ago, where hunting was a common job, but their distribution in this region is now recovering (Tsujino et al., 2010). The distribution of two alien species, namely the masked palm civet *Paguma larvata* Smith, 1827 (introduced about 100 years ago) and common raccoon *Procyon lotor* Linnaeus, 1758 (naturalised in the late 1960s), are expanding throughout Japan (Agetsuma-Yanagihara 2004; Inoue et al., 2012).

2.2. Roadkill data

Roadkill data were collected by a questionnaire send to selected municipalities between May and December 2014 (Tatewaki and Koike, 2016). The questionnaire requested data on annual (from April 2013 to March 2014) numbers of roadkill collected for 11 taxa: bears (brown bear *Ursus arctos* Linnaeus, 1758 in Hokkaido and Asiatic black bear *Ursus thibetanus* G. Cuvier, 1823 in other regions); sika deer; wild boars; Japanese macaques *Macaca fuscata* Blyth, 1875; red foxes *Vulpes vulpes* Linnaeus, 1758; raccoon dogs *Nyctereutes procyonoides* Gray, 1834; hares (mountain hares *Lepus timidus* Linnaeus, 1758 in Hokkaido and Japanese hares *Lepus brachyurus* Temminck, 1845 in other regions); two naturalised alien species, namely masked palm civets and raccoons; and two feral domestic species namely feral dogs *Canis lupus familiaris* Linnaeus, 1758, and feral cats *Felis catus* Linnaeus, 1758. Hokkaido has slightly different fauna from other islands, and congeners occur in both islands as hares and bears. We considered a pair of congeners as a taxon.

We chose municipalities by using two steps. In the first step, the questionnaire was send to 567 randomly selected municipalities (34.5% of 1643 on the main islands of Japan). We received 254 answers by 23 October 2014. The answers received came mostly from urban regions, because the areas covered by municipalities in urban regions are small,