Line census and gnawing damage of introduced Formosan squirrels (*Callosciurus erythraeus taiwanensis*) in urban forests of Kamakura, Kanagawa, Japan

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Abstract The Formosan squirrel (*Callosciurus erythraeus taiwanensis*) is a tree squirrel introduced to Japan from Taiwan. Its distribution in Japan is currently expanding and its impacts on Japanese ecosystems are considerable. To obtain basic ecological information on this species, we conducted line censuses and observations of gnawing damage in the urban forests of Kamakura City, Japan. We set a 2.5km transect line in a preserved green area, the Hiromachi Green Reserve, where sighting, hearing and nesting points of squirrels were recorded in the summer and autumn of 2002－2004. Gnawing damage on trees was recorded along nine transect lines in various forests in Kamakura City in the summer of 2004. Formosan squirrels were sighted at almost all surveys in the Hiromachi Green Reserve for two years, but the population trend has not yet been determined. Although squirrels were observed throughout the census lines, regardless of vegetation or topography, they significantly preferred evergreen broad-leaved forest for their nesting sites. Gnawing damage on trees was widely observed. Two modes of gnawing were observed on the tree bark: scratch and spread gnawing. Scratch gnawing was found in evergreen trees of *Ilex integra*, *Camellia japonica*, *Elaeocarpus sylvestris*, and *Quercus myrsinifolia,* while spread gnawing in *Cinnamomum japonicum*, *Neolitsea sericea*, and *Rhus succedanea.* Both types of gnawing were found in *Cornus controversa* and *Machilus thunbergii.*

Keywords: Formosan squirrel; *Callosciurus erythraeus taiwanensis*; line census; gnawing damage; introduced species; Kamakura

INTRODUCTION

The Formosan squirrel (*Callosciurus erythraeus taiwanensis*) is a tree squirrel originated in Taiwan (Fig. 1). It was introduced to Japan around 1930s as a zoo animal, and is now established in several areas of the forests through south and central Japan. In Kanagawa Prefecture, the Formosan squirrel was introduced in the 1950s and since then its distribution has rapidly expanded (Shiozawa *et al.* 1985, Kobayashi 1987, Furuuchi *et al.* 1990, Kamiya and Noguchi 1995) and its population has showed exponential growth (Tamura 2004). Its distribution continues to expand and rapid growth of local populations is also reported (Fujita *et al.* 1990).

Some of the economic impacts of Formosan squirrels are gnawing damage on garden trees, house exteriors and electric cables. They also interact with Japanese ecosystems in various ways, and ecological impacts are also considerable. Their intake of seeds and fruits contributes to the mortality of native plants, and may disrupt the regeneration process. Formosan squirrels are also known to gnaw and damage the tree bark, which may cause physiological disruption to trees although the reason for bark gnawing is not known. Gnawing damage increases during winter when the availability of food decreases (Yamada, personal observation), so they may feed on the inner bark or phloem. The predators of Formosan squirrels, such as snakes and birds of prey may also be affected although their predatory pressure is lower than that in Taiwan (Tamura 1989). Competition may occur with native Japanese squirrels (*Sciurus lis*) in future. Currently the habitat of the Japanese squirrel is

Figure 1: An adult Formosan squirrel in Kamakura, photographed 16 February, 2002.

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restricted in suburban forests (Yatake and Takahashi 1987, Tamura 2000), and the distribution areas of these two species do not overlap. It is important to understand the risk of competition with Japanese squirrels by gathering sufficient ecological information.

The ecological habits of Formosan squirrels in Japan are different from those in their native range, due to cold weather (Tamura 1989). Nesting sites are an important and limiting resource for rodents. Although a large-scale habitat preference model is available (Tamura *et al.* 2004, Okubo *et al.* 2005), detailed information on nesting-site preference has not yet been recorded in Japan. Our research aimed at obtaining basic ecological information on Formosan squirrels in their central distribution area in Japan. To assess tree gnawing impacts and habitat use in Japanese forests, line censuses were carried out.

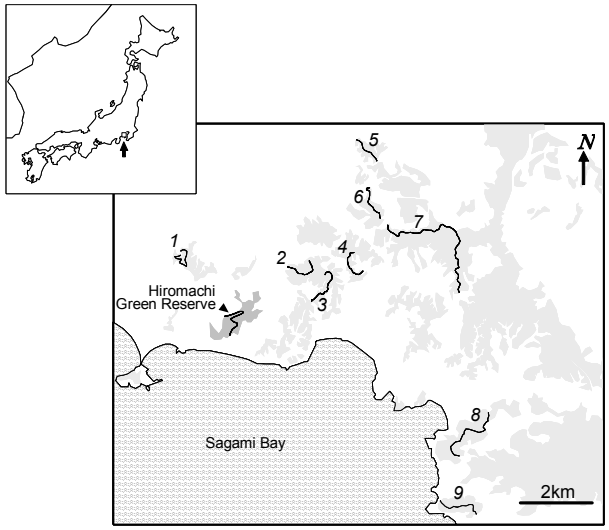

Figure 2 Location of the study area. Kamakura city is indicated by a black arrow on the upper map. On the large scale map, shaded areas are forests, and white areas include commercial, residential or agricultural areas. The solid lines with numbers in forests are the transect lines for gnawing research.

METHODS

Study area

The study area is located in and around Kamakura City, which is an ancient capital of Japan. Its historic landscape, including suburban forest areas, has been well preserved (Fig. 2). These green areas offer favourable habitats for Formosan squirrels. The mean annual temperature is 15.9 °C and the mean annual precipitation is 1448mm (during 1992 - 2000, at the closest meteorological station in Tsujido, Japan Meteorological Agency).

Line censuses were conducted in the Hiromachi Green Reserve (139°30'E, 35°18'N), which is one of the reserved forests in Kamakura. This reserved area is located in an isolated urban forest surrounded by residential areas, and consists of about 100ha of abandoned rice fields and forests. The altitude ranges from 15-75m above sea level. The management of both rice fields and forests was abandoned about 10 years ago. The current forest vegetation is roughly classified as natural forest of evergreen broad-leaved trees, secondary forest of deciduous broad-leaved trees, and artificial plantation of conifer trees.

Bark gnawing was investigated in nine isolated transect lines in various forests in and around Kamakura City. These transect lines passed through evergreen broad-leaved forest, deciduous secondary forest, and artificially planted evergreen coniferous forest.

Squirrel census

A 2.5km transect line was established through the abandoned rice fields and forests in the Hiromachi Green Reserve. The squirrel survey started in March 2002, and has been conducted every month or twice a month with an interval of more than two weeks, from the beginning of summer to the end of autumn each year. Observers walked at a rate of 1km/hour from 6:30am. During the survey, the points of sighting, hearing and locations of nests of Formosan squirrels were recorded. Their alarm call is characteristic, and clearly distinguished from sounds of other animals. Their spherical nests built with twigs and leaves on tree branches are easily detected. No distinction was made between nests that were currently utilised and those that were not.

Nest site preference was analysed with a GIS (Koike 2005). Geographical coordinates of the observed nest points were read from the map. Additional points were taken at 50m intervals on the transect line (transect line points), and these points were used to represent vegetation along the line. The percentage cover of vegetation (such as evergreen broad-leaved forest, deciduous broad-leaved forest, evergreen conifer plantation, other forests such as bamboo, abandoned paddy field, and residential area - from Biodiversity Centre of Japan 2004, Fig. 5a) was obtained within a 25m radius around the nest points and the transect line points. Existence or absence of a nest at the points was used as the dependent variable, assuming that nest was absent at the transect line points. Percentage cover of each vegetation type and four topographic variables (altitude, slope steepness, laplacian representing convexity, and catchment area representing wetness of the site) were used as independent variables. A stepwise variable selection

Figure 3 Gnawing damage by Formosan squirrels in Kamakura. Scratch gnawing on *Ilex integra* (left) and spread gnawing on *Cornus controversa* (right). Photographed on July 24, 2004.

procedure of logistic regression (SPSS 13.0J) was used to evaluate nest site preference.

Census of gnawing damage on forest trees

Gnawing damage on tree stems and branches was surveyed in nine forests in and around Kamakura City (Fig. 2). The length of the transect lines varied depending on the area of forest. The survey was conducted in the summer of 2004. For a damaged tree, species name, height, diameter at breast height, gnawing mode and the proportion of the damaged area to the total surface of the tree trunk were recorded.

Two kinds of gnawing modes were designated; scratch and spread (Fig. 3). Scratch gnawing leaves trace of horizontal lines about 1cm width on the bark of the tree, as if carved by a wood chisel. Usually many are found on a tree and the length is variable. Spread gnawing shows as a patch with the bark removed. There are no agents which can cause such damage on the trees, other than Formosan squirrels.

We recorded the dominant tree species along the transect lines to avoid the bias of observation to specific vegetation, but we did not count the total frequency of each tree species to analyse the exact preference (the proportion of damaged trees of the total frequency).

RESULTS

Census of Formosan squirrel

Formosan squirrels were sighted during almost all surveys in the Hiromachi Green Reserve, though the observed number of squirrels varied among the surveys (Fig. 4). The average numbers of observed squirrels along the census line was 4.1 individuals in 2003, and decreased to 1.6 individuals in 2004, while the frequency of squirrels heard did not differ between these two years (3.2 times in 2003 and 3.3 times in 2004 on average). The frequent canopy trees along the census line were evergreen *Castanopsis sieboldii* and deciduous *Quercus serrata*, *Cornus controversa*, *Prunus jamasakura,* and *Celtis sinensis* var. *japonica*. The observation points of Formosan squirrels were scattered through the transect line (Fig. 5b). The distribution of the points did not show a clear relationship with vegetation or topography. Contrary to this, the nesting points were significantly concentrated on evergreen broad-leaved forest ($P<0.001$) (Fig. 5c). *Castanopsis sieboldii*, a broad-leaved evergreen tree was dominant there and often utilised for nesting. Other vegetation and topographic variables were not significantly different for points with and without squirrels ($P>0.05$).

The gnawing damage on forest trees

Gnawing damage was found along all nine transect lines (Table 1). Formosan squirrels were also sighted on every survey. Dominant canopy species of evergreen trees were *Ilex integra*, *Machilus thunbergii* and *Castanopsis sieboldii*, and those of deciduous trees were *Quercus serrata*, *Cornus controversa*, *Prunus jamasakura,* and *Celtis sinensis* var. *japonica*. *Chamaecyparis obtusa* and *Cryptomeria japonica* were used in plantations. Although both evergreen and deciduous trees were observed along all transect lines, *C. controversa* was scarce along

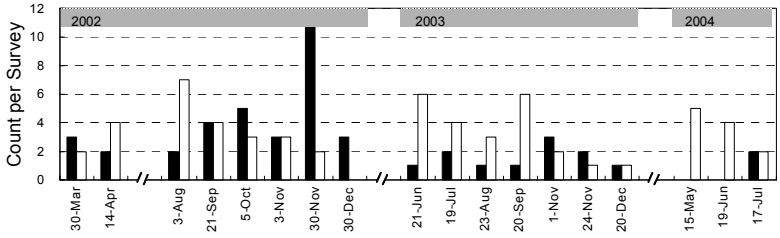

Figure 4 Observed number of sightings and hearings of Formosan squirrels during the monitoring in Hiromachi Green Reserve. Black bars are the sightings while open bars are the hearings. The horizontal axis is broken if the interval between the surveys was more than two months.

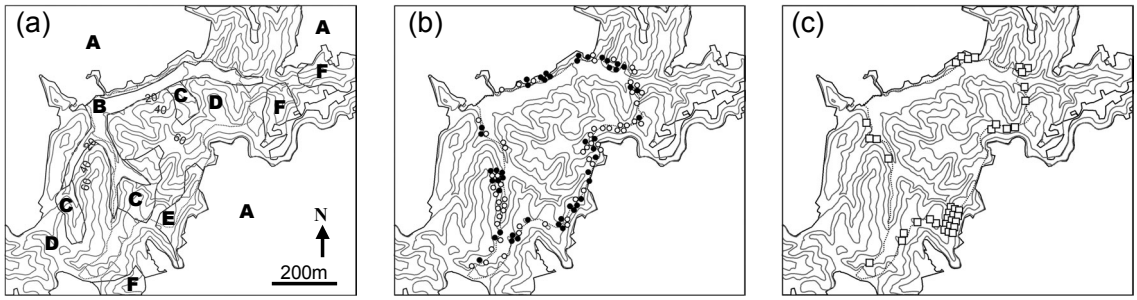

Figure 5 (a) Vegetation map of Hiromachi Green Reserve (Biodiversity Centre of Japan 2004). A: residential area, B: abandoned paddy field, C: evergreen coniferous forest, D: deciduous broad-leaved forest, E: evergreen broad-leaved forest, F: other forests; (b) points of sightings (black circles) and hearings (open circles) of Formosan squirrels on the line census; (c) nesting points of Formosan squirrels. All points throughout the surveys are indicated in (b) and (c). The transect line is indicated as a broken line. The contour interval within the Hiromachi Green Reserve is 10m.

transect 3, 4 and 5. The gnawing damage was found most frequently on *I. integra* (Table 1, Fig. 6). Squirrels also gnawed *C. controversa* and *M. thunbergii*. Among the dominant trees, *Q. serrata*, *P. jamasakura*, *C. sinensis* and coniferous trees were not damaged.

Usually only one type of gnawing, either scratch or spread, was found if a tree was damaged and the frequency of gnawing modes differed between species (Fig. 6). For example, damage of *I. integra* were mostly by scratch gnawing, while for *Cinnamomum japonicum* and *Neolitsea sericea* there was more spread gnawing. On *C. controversa* and *M. thunbergii*, both scratch and spread gnawing were found. The degree of damage varied from a few centimetres in diameter of spread gnawing to the removal of more than half of the trunk surface. However, there were no cases of dead trees with presumed cause of death through gnawing damage.

DISCUSSION

Nest site and habitat preference

The habitat preference of Formosan squirrels was not clear in Hiromachi. In Taiwan, Formosan squirrels inhabit the subtropical evergreen forests (Tamura *et al.* 1989), but in Kamakura, they have adapted to other types of vegetation such as grassland or deciduous woods (Sonoda and Tamura 2003).

Okubo *et al.* (2005) reported that, although

Table 1. Frequencies of trees damaged by Formosan squirrel gnawing along each transect line. Locations of transect lines are indicated in Fig. 2, with corresponding numbers. Tree species are ordered by the total count of damaged trees.

Tree Species	Transect line ID (length, km)									Total
	1 (1.0)	2 (0.9)	3 (1.2)	4 (0.9)	5 (1.0)	6 (1.2)	7 (4.2)	8 (2.1)	9 (1.2)	
Ilex integra	7	1	1				38	10	5	62
Cornus controversa	12	6	1			11	1	6	5	42
Machilus thunbergii	1	1		1	1	7	9	1	5	26
Cinnamomum japonicum	4							7	1	12
Neolitsea sericea							1		6	7
Rhus succedanea			6					1		7
Camellia japonica							6			6
Elaeocarpus sylvestris	5									5
Quercus myrsinaefolia								3		3
Quercus glauca								2		2
Acer palmatum				1				1		2
Aphananthe aspera								2		2
Morus australis		1						1		2
Mallotus japonicus	1									1
Ficus erecta		1								1
Zanthoxylum ailanthoides	1									1
Stachyurus praecox						1				1
Castanopsis sieboldii							1			1
Total	31	10	8	2	1	19	56	34	22	183
Density (count/km)	30.2	11.2	6.6	2.1	1.0	16.5	13.2	16.1	18.0	

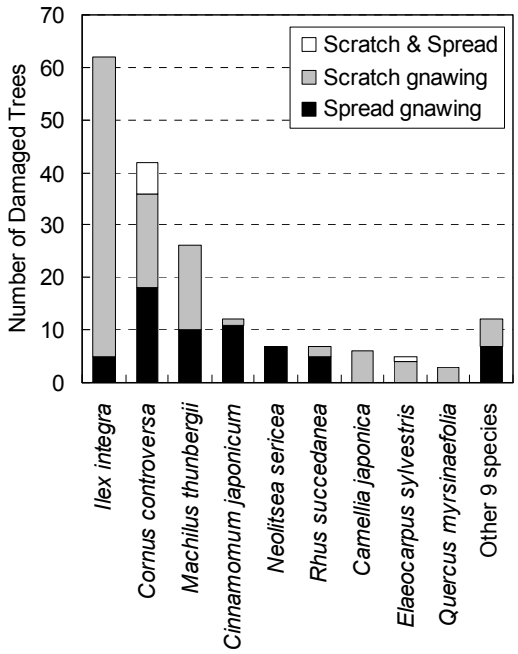

Figure 6 Number and gnawing modes of damaged trees by Formosan squirrels, along the transect lines around Kamakura City. Nine additional species, of which only one or two individual trees were damaged, are pooled into "Other 9 species". All species names are given in Tab 1.

Formosan squirrels use various types of forests, they prefer evergreen broad-leaved forest if it is available in their home range. In the present study, they preferred evergreen trees for nesting. Evergreen broad-leaved forest may be important core habitat for reproduction. Preference for evergreen trees for nesting behaviour was also found for other tree squirrels, for example, Japanese squirrels (*Sciurus lis*) preferred evergreen trees (Tamura 1998), while Abert squirrels (*S. aberti*) preferred closed stand of conifer trees (Halloran and Bekoff 1994). This nesting behaviour may occur because tree crowns can hide the nest from birds of prey. Formosan squirrels mate throughout the year in Japan (Tamura *et al.* 1988), and so evergreen trees may offer more secure nesting places than deciduous trees.

Gnawing damage

The Formosan squirrel seems not to gnaw *Quercus serrata, Prunus jamasakura, Celtis sinensis* var. *japonica*, *Chamaecyparis obtusa* and *Cryptomeria japonica*, although these species are common in secondary and plantation forests in and around the study area. The factors influencing gnawing preference and gnawing mode require further research. Nutrient content or the presence of defensive chemicals, such as polyphenols and flavanols may need to be considered. (Tamura and Ohara 2002).

In total, eighteen tree species were damaged by gnawing. Although there was no evidence of "whole tree mortality", it is likely that tree growth suffered to some degree from die back of branches or damage to the trunk's cambium. Furthermore, species specific gnawing might alter the tree species composition of forests. To estimate the impact, it is necessary to investigate the growth and survival of the damaged trees for a longer period.

A comparative study of native and introduced populations of the Formosan squirrel revealed that it feeds mainly on fruits and seeds both in Japan and in Taiwan; though food availability is lower in Japan because of lower temperature (Tamura *et al.* 1989). Furthermore, under the temperate climate in Japan, food availability decreases during winter, which may cause shift in food preference to nutrient poor sources like tree bark. The relationship between squirrels and their food source and factors influencing feeding behaviour should be studied further.

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REFERENCES

Biodiversity Centre of Japan. 2004. The 6th National Survey on the Natural Environment: 1:25000 actual vegetation maps. *http://www.vegetation.jp/*

Fujita, K., Azuma, Y., Nakazato, N., Kominami, Y. and Ohya, C. 1999. Density changes in Formosan squirrels *Callosciurus erythraeus taiwanensis* in Yokohama Nature Sanctuary over 13 years. *BINOS* 6: 15-20 (in Japanese with English summary).

Furuuchi, S., Arai, K. and Suzuki, K. 1990. Distribution of three species of squirrel in Kanagawa prefecture (2). *Bulletin of Kanagawa Prefectural Nature Conservation Centre* 7: 127-134 (in Japanese).

Halloran, M.E. and Bekoff, M. 1994. Nesting behaviour of Abert squirrels (*Sciurus aberti*). *Ethology* 97: 236-248.

Kamiya, Y. and Noguchi, M. 1995. Distribution of three species of squirrel in Kanagawa prefecture (3). *Bulletin of Kanagawa Prefectural Nature Conservation Centre* 12: 45-54 (in Japanese).

Kobayashi, M. 1987. Recent status of the Formosan squirrel (*Callosciurus erythraeus taiwanensis*) in Kamakura city and its adjacent area. *Natural History Report of Kanagawa* 8: 67-70 (in Japanese).

Koike, F. 2005. Minna de GIS: Spatial information processing

system for education, research and environmental assessment by citizens. *http://www13.ocn.ne.jp/~minnagis/*

Okubo, M., Hobo, T. and Tamura, N. 2005. Vegetation types selected by alien Formosan squirrel in Kanagawa Prefecture. *Natural History Report of Kanagawa* 26: 53-56.

Shiozawa, T., Noguchi, M. and Okada, H. 1985. Distribution of three species of squirrel in Kanagawa prefecture. *Bulletin of Kanagawa Prefectural Nature Conservation Centre* 2: 15-27 (in Japanese).

Sonoda, Y. and Tamura, N. 2003. Habitat type selection by the three species of squirrel and land use patterns in Kanagawa. *Bulletin of Kanagawa Prefectural Nature Conservation Centre* 2 (new series): 13-17 (in Japanese).

Tamura, N. 1989. Snake-directed mobbing by the Formosan squirrel *Callosciurus erythraeus taiwanensis*. *Behavioural Ecology and Sociobiology* 24: 175-180.

Tamura, N. 1998. Forest type selection by the Japanese squirrel, *Sciurus lis*. *Japanese Journal of Ecology* 48: 123-127 (in Japanese with English summary).

Tamura, N. 2000. Distribution of Japanese squirrel and forest fragmentation in suburban area. *Forest Pests* 49: 24-28 (in Japanese).

Tamura, N. 2004. Population dynamics and expansion of introduced Formosan squirrels in Kanagawa prefecture, Japan. *Japanese Journal of Conservation Ecology* 9: 37-44 (in Japanese).

Tamura, N., Hayashi, F. and Miyashita, K. 1988. Dominance hierarchy and mating-behaviour of the Formosan squirrel, *Callosciurus erythraeus taiwanensis*. *Journal of Mammalogy* 69: 320-331.

Tamura, N., Hayashi, F. and Miyashita, K. 1989. Spacing and kinship in the Formosan squirrel living in different habitats. *Oecologia* 79: 344-352.

Tamura, N., Miyamoto, A., Minotani, N. and Takashima, N. 2004. Environmental factors affecting distribution of the alien Formosan squirrel in fragmented landscape. *Ecology and Civil Engineering* 6: 211-218 (in Japanese, with English summary).

Tamura, N. and Ohara, S. 2002. Selective bark-gnawing of Formosan squirrels in relation to the herbivore-repellent components of broad-leaved trees. *Journal of Tree Health* 6: 85-91 (in Japanese with English summary).

Yatake, H. and Takahashi, K. 1987. Habitat of the Japanese squirrel in suburban area. *Transactions of the Japanese Forestry Society* 98: 529-530 (in Japanese)