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Responses of four hornet species to levels of urban greenness in Nagoya city, Japan: Implications for ecosystem disservices of urban green spaces

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ABSTRACT

Although there is a common trend towards increasing green space in modern cities, urban green spaces provide not only ecosystem services but also disservices for urban dwellers. However, the relationship between urban greenness and ecosystem disservices has been poorly examined. We aimed to understand the effect of greenness level on the abundance and species composition of hornets – critical pests in Japan and to identify the best spatial scale for estimating their abundance with reference to greenness levels. We used a dataset that contained eight years of abundance data for four hornet species at 11 sites in Nagoya city. The levels of greenness around the hornet sampling points were measured using averages from the Normalized Difference Vegetation Index (NDVI) with radiuses of 0.1–10.0 km. We analysed the relationship between abundance and species composition of hornets and NDVI at different spatial scales using generalized linear mixed models. Higher NDVI values positively affected the abundance of all the hornet species except *Vespa analis*. The abundances were estimated most effectively using the NDVI average with a 1–2 km radius for all species. The species composition of hornets drastically changed along the gradient of NDVI values; *V. mandarinia* was dominant in greener areas (over 0.2–0.3 NDVI average with a 2 km radius) and *V. analis* in less green areas (below 0.2–0.3 NDVI average). Our study showed that the abundance and species composition of hornets were both strongly associated with the level of urban greenness. This suggests that increases in the greenness of urban areas can increase hornet abundance and alter the species composition of hornets; a more aggressive species, *V. mandarinia*, may also increase in urban areas, although *V. analis* is currently the most critical species according to regional consultants. Balancing ecosystem services and disservices has become crucial for the planning and management of green spaces, particularly when urban green space increases. We also demonstrate how human tolerance towards wildlife may have to be improved in order to live in greener environment where wildlife can be expected.

1. Introduction

Green spaces are crucial elements in cities, providing several ecosystem services such as the mitigation of heat island effects, the reduction of pollutants in the air, and the improvement of health conditions for urban residents (Lee and Maheswaran, 2011; Gómez-baggethun et al., 2013; Tsilini et al., 2015). At the same time, the spaces can provide valuable habitats for diverse plants and animals, organisms which otherwise would be unable to survive in cities (Jones and Leather, 2012; McKinney, 2008; Melles et al., 2003). These benefits are well known as ecosystem services, and this issue has brought global awareness to the importance of urban biodiversity conservation. As a result, the amount of urban green space in various cities around the world is increasing or will increase in the near future (Secretariat of the Convention on Biological Diversity, 2012).

This increase in urban green space, however, does not always provide benefits for urban dwellers. Many of the characteristics of urban green spaces are also perceived as negative, particularly for human wellbeing, such as allergen emission, damage to infrastructure and people by plants and animals, fear and stress in dark green areas, and an increase in unwanted species, such as pests and nuisance animals. These negative effects have recently

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Table 1
Differences in body size of workers, preference for nesting sites and prey, aggressiveness towards humans, and the amount of poison released per individual worker among four hornet species based on Matsuura (1984, 1990). The level of aggressiveness and the amount of poison of the four species are ranked, with 1 being the highest level and 4 the lowest.

Features	Species			
	V. analis	*V. crabro*	*V. mandarinia*	*V. ducalis*
Body size (mm)	22–28	21–28	27–38	24–37
Nesting site	tree branch building eaves, rock wall	attic, underground, tree hollow	underground, tree hollow	attic, underground, tree hollow
Prey	various insects and spiders	mainly cicadas	various insects including other hornets	paper wasp
Aggressiveness	3	2	1	4
Poison	3	2	1	4

been termed ecosystem disservices (Lyytimäki and Sipilä, 2009). In contrast to ecosystem services, ecosystem disservices are rarely discussed in green space management and biodiversity conservation (Lyytimäki and Sipilä, 2009; Lyytimäki, 2015), with limited quantitative evaluation of these disservices (von Döhren and Haase, 2015). Particularly, the possible increase of unwanted wild species due to increase in green spaces have not been demonstrated.

In Europe, East Asia, and Southeast Asia, hornets (Hymenoptera: Vespidae: *Vespa* spp.) create conflicts with urban residents (Choi et al., 2012). Although they play an important role in ecosystem services, such as pollination and the regulation of pest abundance, they are well known for their poisonous sting, which can sometimes be fatal to humans (Xuan et al., 2010; Kularatne et al., 2014). In Japan from 1983 to 1999, the number of hornet consultations increased in many major cities, including Tokyo, Yokohama, Hiroshima, Sendai, Sapporo and Nagoya (Nakamura, 2007). The number of hornet consultations was greatest among pest consultations for local governments over the past 10 years and has increased 2–3-fold over 20 years in Tokyo (T. Hosaka, unpublished). However, due to a lack of long-term data on hornet abundance, it is not known whether the recent increase in the number of consultations is due to an increase in hornet abundance or due to a decrease in public tolerance for hornets in urban areas.

All of the 24 species of *Vespa* hornets are exclusively distributed throughout Asia, except for one found also in Europe (Ono, 1997). The ecological characteristics (e.g., preferences for food and nesting sites) and harmfulness to humans of *Vespa* hornets can differ among species (Matsuura, 1984, 1990; Table 1). Therefore, it is extremely important to understand the factors that affect the abundance of each hornet species in urban environments. The amount of green space, particularly forest space, is one such important factor. Hornets feed on many forest insects, such as caterpillars and cicadas, and build nests in tree hollows (Matsuura, 1984; Ono, 2003). Some hornet species have also become well-adapted to urban areas, as they use garden trees and buildings for nesting places and use human waste as their food source (Choi et al., 2012; Ono, 2003). Understanding the landscape requirements for each hornet species is necessary to predict changes in hornet abundance in changing urban environments, particularly when there is an increase in green space.

Therefore, the aim of our study is to investigate the effect of urban greenness on the abundance of each hornet species. We used 8 years of hornet abundance data from 11 sites in Nagoya city and Normalized Difference Vegetation Indices (NDVI) for measuring the level of greenness around the sites. Specifically, we addressed five research questions: 1) does the abundance of hornets increase during these years? 2) does species composition of hornets differ among sites? 3) do NDVI values correlate with the abundance and species composition of hornets? 4) are responses to NDVI values different among hornet species? 5) which spatial scale is the most effective at predicting hornet abundance and species composition? By answering these questions, our study aims to demonstrate the relationships between the level of greenness (NDVI) and abundance of hornets as one of the examples of ecosystem disservices.

2. Materials and methods

2.1. Study site

Nagoya city is the third largest metropolitan area in Japan, after Tokyo and Osaka. It has a population of over eight million people with a density of ~6000 people per km^2 (Jenks et al., 2008). The average temperature is 16.1 °C and generally ranges from −2.8 to 38.2 °C. At the time of the 10th meeting of the Conference of the Parties for the Convention on Biodiversity (CBD COP10) held in Nagoya, Nagoya city established “The 2050 Nagoya Strategy for Biodiversity”. The strategy for Nagoya acts as a guideline for the development of a sustainable city that supports biodiversity to conserve and revitalize the environment within the city. It includes support for an increase in green spaces (from 25 to 40% by 2050), improvement in the quality of each green space as a habitat for native species, and the creation of green networks. Based on green spaces distribution in Nagoya city, forest constitute the largest part of the green land cover with 10.7%, followed by grassland(5.1%) and agricultural land(3.3%), with water surface(2.9%) (Nagoya, 2015).

2.2. Hornet sampling

Experienced government staff in sampling and identifying hornets in the area sampled hornets at 11 sites throughout Nagoya city (Fig. 1) from 2007 to 2014, but only from 2013 to 2014 for one location. All of the sampling sites were located in parks except for one located in a cemetery. These sampling sites were chosen considering public safety since the traps attract a number of hornets. The staff set two funnel traps containing an attractant liquid (made up of 60% water and 40% fermented milk drink) at a height of 3 m in each park. They collected the hornets from the traps and renewed the attractants every week from April to November, covering the entire active period of hornets in the region (Matsuura, 1984). All of the hornets sampled were identified, classified by species, and counted by the staff.

2.3. Hornet species characteristics

Seven *Vespa* species are known to live in Japan (Matsuura and Yamane, 1990a,b). In our study, we focused on four species that were abundant in the samples: *Vespa crabro, V. mandarinia, V. ducalis,* and *V. analis.* These four species differ in size, preference for nesting sites and prey, aggressiveness towards human, and quantity of poison in their stings (Table 1). *V. mandarinia* is the largest in body size, is the most aggressive, and releases the greatest amount of poison. This species is also a predator of other hornet species. *V. analis* frequently builds nests on tree branches of home gardens and buildings and thus is the primary species of conflict with residents in Nagoya city; 92% of the 12,898 nest removals in 1983–2007 in