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Inference of adult female dispersal from the distribution of gypsy moth egg masses in a Japanese city

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Abstract

1 The native range of the gypsy moth *Lymantria dispar* (L.) spans the temperate forests of Eurasia. Across this region, a clinal female flight polymorphism exists; gypsy moth females in eastern Asia are mostly capable of directed flight, those in western and southern Europe are largely incapable of flight and populations distributed across the centre of the distribution exhibit a range of intermediate flight behaviours.

2 Although information exists about the timing and duration of female flight from laboratory and wind tunnel studies, little or no quantitative data are available on average distances flown by Asian gypsy moth females prior to oviposition in the field. This information is critical for estimating risk of contamination at specific ports and transit terminals, as well as for predicting the spread of populations that might someday invade currently uninfested regions of the world.

3 In the present study, an extensive visual survey of gypsy moth egg masses was conducted during a walk through streets and paths in a 3.92×5.76 km area in Kanazawa, Japan. This area consisted of a matrix of urban, agricultural and forest land uses. The distribution of egg masses relative to distances from host forests was used to infer the magnitude of pre-ovipositional female flight.

4 A total of 3172 egg masses was recorded from surveys conducted during the search of a path totalling 384 km. Within urban areas, egg masses were most abundant in the area <1 km from the edge of forest land.

5 These results suggest that most female gypsy moth flight is limited to the area within 1 km of host forests. They also suggest that shipping containers and other parcels located >1 km from forests are at a much lower risk of contamination with Asian gypsy moth egg masses.

Keywords Asian gypsy moth, flight, Japan, Lepidoptera, *Lymantria dispar*, Lymantriidae.

Introduction

The native range of the gypsy moth, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae) extends over most of the temperate forests of North Africa, Europe and Asia (Giese & Schneider, 1979). Around 1869, the gypsy moth was accidentally introduced to North America where it has been gradually expanding its range (Liebhold *et al.*, 1992). In populations from France, southern Europe and North Africa, female gypsy moths possess fully-formed wings but are incapable of flight (Reineke & Zebitz, 1998; Charlton *et al.*, 1999; Keena *et al.*, 2001, 2007). North American populations are believed to have originated from France and therefore females are also flightless. By contrast, most East Asian gypsy moth females are capable of sustained flight (Koshio, 1996; Reineke & Zebitz, 1998). In central Europe and other portions of Eurasia, there exist populations in which females possess full, partial or nil flight capabilities; these populations appear to represent a zone of genetic introgression between entirely flight capable and flight incapable phenotypes (Baranchikov, 1989; Keena *et al.*, 2007).

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In recent years, there has been some concern that gypsy moths from East Asia might accidentally be introduced to North America or Australasia and that such populations would be difficult to eradicate because of their greater dispersal capabilities compared with West European strains (Matsuki *et al.*, 2001; USDA APHIS Plant Protection and Quarantine, 2003). Over the last 10 years, there have been several incidents in which Asian strains of the gypsy moth have been detected in the U.S.A., Canada and New Zealand, and most of these have triggered massive and expensive eradication campaigns (Gibbons, 1992; Wallner, 1996; Myers *et al.*, 2000; Ross, 2005). The primary pathway for entry of gypsy moth egg masses from Asia is considered to be transit of cargo, including shipping containers and vessels (Wallner *et al.*, 1995; Cannon *et al.*, 2004). Shipping terminals tend to be brightly lit and the phototactic flight of females can lead them to these locations where they sometimes oviposit on outgoing cargo.

Given that Asian gypsy moth egg masses can become associated with cargo at shipping terminals, it is prudent to identify terminals in far East Asia where this hazard might be greatest (Canadian Food Inspection Agency, 2000). Presumably, shipping terminals located near to forests that harbour gypsy moth outbreaks would comprise locations where the hazard is greatest. However, identifying the level of proximity where this risk exists would depend upon the flight capabilities of female gypsy moths. Although there are some published measurements of the duration of female flight in the laboratory (Charlton *et al.*, 1999; Keena *et al.*, 2001) and anecdotal reports of female flight distances (Baranchikov, 1989), quantitative studies of female flight distances in the field are generally lacking.

Unfortunately, direct measurement of female flight distances would prove to be complex given the practical difficulty of tracking the paths of individual female moths over long distances. The present study reports on the distribution of egg masses in a forest/urban matrix in Japan as a method of inferring female flight distances. By assuming that egg masses in urban areas were laid by females emanating from nearby forest areas, information could be obtained about the range of distances flown. Presumably, females are attracted to lights in urban areas, much as they are attracted to shipping terminals, and the distribution of egg masses in relation to the distance from nearby forests can be used to predict egg mass distributions in shipping terminals.

Materials and methods

Egg mass surveys were conducted in late winter and spring of 2004 (prior to egg hatch) in the northeastern portion of Kanazawa City, Japan (Fig. 1). During this time period, all gypsy moths were in the egg stage and therefore were part of the same generation. This location was selected because it consisted of mainly urban land use adjacent to forests dominated by *Quercus* spp. in foothills adjoining to the east. These forests were known to support relatively high-density gypsy moth populations and egg masses were observed both within these forests and in adjoining urban areas. The urban areas had a dense network of roads that allowed easy access by foot to most of the area.

The sampling area consisted of a 3.92×5.76 km (easting $\times$ northing) rectangular region. The region was divided into a 20×40 grid of adjacent 196×144 m quadrats. The size of these quadrats was chosen such that exactly four quadrats fit on a single page in a book of 1: 1500 maps (Zenrin Corp., 2004). These maps revealed considerable detail (e.g. the outline of every house), which allowed the observers to easily determine their location.

Surveys were conducted by walking along streets and paths and scanning all walls, posts, tree trunks, fences, etc., for egg masses. Within the sampling area, surveys were conducted along most (>95%) streets. The location of all egg masses was recorded directly onto the maps. At periodical intervals along the walk, observers recorded their route along the street or path as a coloured line on the map.

Surveys were conducted in forest areas by similarly scanning trees, rocks and other objects for egg masses when walking along forest trails and roads. However, the system of these paths was sparse in many areas and thus additional surveys were conducted when walking through roadless portions of forests, following arbitrarily selected courses that tracked routes of approximately constant elevation and were relatively free of dense vegetation.

After the field season, all data were recorded in a geographical information system (GIS). All data in the GIS were associated with individual raster cells, which represented the 196×144 m quadrats. The total number of egg masses in each cell were totaled and recorded. An electronic measuring wheel was used to estimate the length (m) of survey walks conducted in each quadrat by tracing routes recorded on paper maps. Egg mass density was estimated in each quadrat as the ratio of the total number of egg masses versus the total length of the survey route in each quadrat.

During surveys, the habitat in each quadrat was classified as either forest, urban or agricultural based upon the dominant land use. Forest areas were mostly dominated by oaks (primarily *Quercus serrata* and *Quercus variabilis*), which are preferred gypsy moth hosts. Egg masses were also commonly found on boles of *Prunus* spp. as well as several shrub species in the forest interior. Other non-host species, such as bamboo (*Phyllostachys heterocycla*), were also present but rarely served as oviposition sites. Areas classified as urban consisted primarily of individual homes, multi-unit dwellings, or commercial structures. Some of the homes had gardens and a few of these had plantings of gypsy moth host plants, although they were relatively rare. Agricultural areas consisted of fields of rice *Oryza sativa* or abandoned fields covered with grassy vegetation, none of which are suitable gypsy moth host material.

Results and Discussion

A total of 3172 egg masses were recorded from surveys conducted during the searching of a path totalling 384 km in

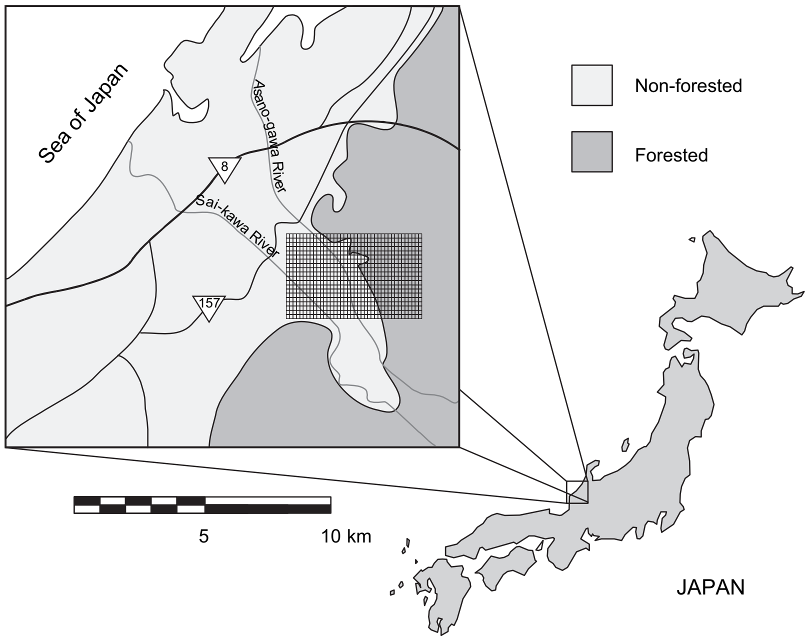

Figure 1 Map depicting the location of the 20 × 40 matrix of 196 × 144 m sampling quadrats in relation to the outline of Japan.

length. Within urban areas, most egg masses were found on vertical surfaces of human-made objects (e.g. buildings, walls, poles, etc); they rarely occurred at heights >20 m. A large proportion of these oviposition locations were in sites that were illuminated by lights, reflecting the previously reported positive phototactic pre-ovipositional behaviour of Asian gypsy moth females (Wallner *et al.*, 1995).

Surprisingly, egg mass density estimates were, on average, almost ten-fold greater in urban areas than in forest areas (Table 1, Fig. 2). Presumably, host resources for larval development were much greater in forest areas and such a difference suggests a type of source–sink relationship in which most adult females disperse away from areas with the most favourable sites for larval development. Although natural selection would not favour such behaviour, it is possible that the advent of lighted cities is a relatively new phenomenon and selection against this behaviour is not complete. However, this hypothesis cannot be definitively substantiated from these data because egg mass-counting efficiency might have been affected by habitat characteristics. Studies in North America indicated that the efficiency of counting gypsy moth egg masses during timed searches is heavily influenced by variation in the habitat (Fleischer *et al.*, 1991; Liebhold *et al.*, 1991). Although female selection of oviposition sites in North America probably differs from that in Japan, it is possible that, in the present study, egg masses in urban areas were more easily found than were egg masses located in forests (egg masses might be hidden behind bark flaps, etc.). Thus, some caution should be exercised when attempting to draw firm conclusions about whether true egg mass populations were more dense in urban than in forest locations. Egg mass densities were low in agricultural areas but this was probably due to the general lack of host material, oviposition sites and illumination.

Table 1 Gypsy moth egg mass density (±SEM) by habitat type in 800 196 × 144 m quadrats located in Kanazawa City

Habitat type	Number of cells	Mean egg mass density (egg masses/m)
Forest	234	0.0015 ± 0.0002
Urban	447	0.0110 ± 0.0017
Agricultural	50	0.0020 ± 0.0012

Charlton *et al.* (1999) documented that, at dusk, mated and unmated female Asian gypsy moths almost simultaneously began fanning their wings and, minutes later, embarked on synchronous, mass flight, although this behaviour varies considerably among various Asian strains of the gypsy moth (Keena *et al.*, 2001). Charlton *et al.* (1999) also observed that most Asian gypsy moths have high wing loads (body mass per unit wing area) and noted that this may limit their ability to fly long distances. Wallner *et al.* (1995) noted that female Asian gypsy moths are phototactic and therefore it is common for them to oviposit on light posts, buildings and other illuminated structures.

In urban habitats, egg mass densities were generally higher in the area in proximity (<1 km) to forest areas (Fig. 3). It is presumed that this pattern resulted from females dispersing out of forest areas. It is quite likely that the phototactic behaviour of females contributed to the dispersal of females from forest to urban locations. The abrupt decrease in egg mass abundance in locations >1 km from forest areas suggests that the limited flight capabilities of females may reduce their ability to disperse longer distances. Attraction to light sources in urban areas may also have arrested female flight and prevented movement over longer distances.

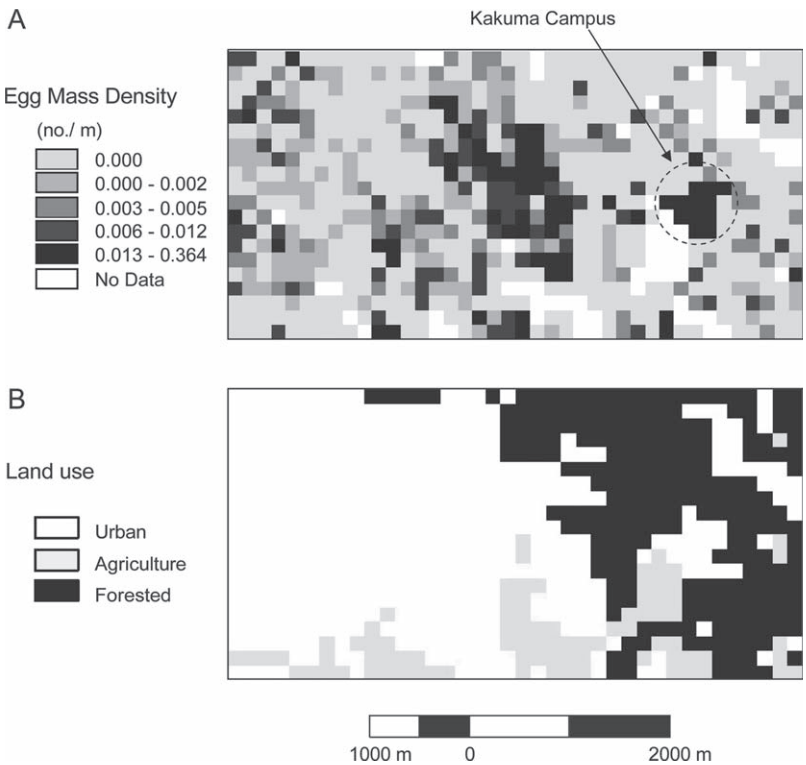

Figure 2 Maps of the study matrix. (A) Egg mass density in each grid cell. (B) Predominant land use in each sample quadrat.

It is likely that some of the egg masses recorded in urban areas were not laid by females originating from nearby forest areas. Instead, it is possible that some females originated locally after larval development on gypsy moth hosts in urban areas. However, as noted earlier, there were only a limited number of gypsy moth hosts in urban areas. Thus, it is likely that the bulk of egg masses exhibiting the pattern seen in Fig. 3 were laid by females dispersing from forest areas. One exception to this may be seen in the small peak at 2750 m in Fig. 3; this probably reflects the slightly higher egg mass densities in and around Kenrokuen Park, which was located within the urban matrix but did contain several large gypsy moth hosts.

The movement of Asian strains of the gypsy moth on ships, shipping containers and other objects is a recognized pathway for the entry of Asian gypsy moth populations to alien habitats (Wallner *et al.*, 1995; Cannon *et al.*, 2004). The proximity of gypsy moth infested forests to terminals in Asia where cargo is loaded for shipment to other continents thus represents a regulatory hazard. The results presented in the present study suggest that, when shipping terminals are located >1 km from forest areas, the risk of contamination with gypsy moth egg masses may be greatly reduced. However, there are several caveats that should be considered when interpreting these results. First, there is tremendous geographic variation among Asian gypsy moth strains in female flight behaviour (Charlton *et al.*, 1999; Keena *et al.*, 2001) and this may affect the relationship. Furthermore, it is possible that female dispersal over the urban area investigated in the present study is not the same with respect to the dispersal

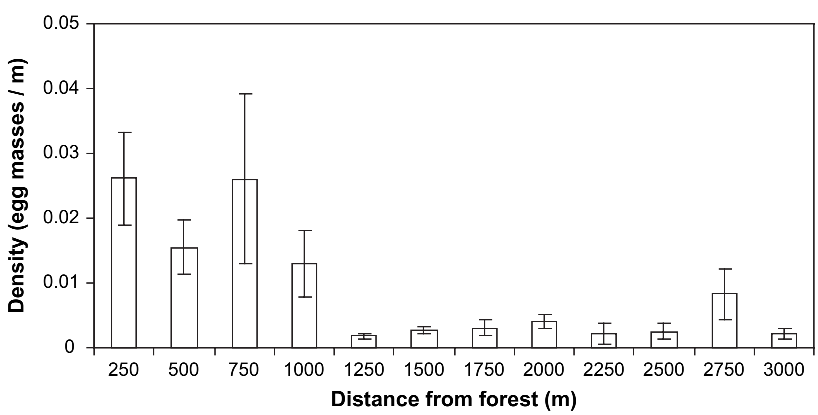

Figure 3 Mean egg mass density (in urban areas) as a function of distance from nearest forest area. Error bars indicate SD.

of females at shipping terminals and this could also affect the probability that egg masses become deposited on ships and other objects. In particular, the presence of extensive areas of illumination in urban areas investigated in the present study might arrest the flight of some females that otherwise would travel longer distances.

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