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Effects of roads on collembolan community structure in subtropical evergreen forests on Okinawa Island, southwestern Japan

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ABSTRACT

Because roads through forested sites may affect the soil invertebrate community within the forest, we investigated collembolan community structure at various distances from roads running through subtropical evergreen forests on Okinawa, Japan. We hypothesized that collembolan communities near roads would be deleteriously affected due to the reduction of litter and changes in water conditions, and tree community composition as compared to those in the inner forest. Collembolan densities tended to be lower near roads (up to 1 m inside the forest) than in inner-forest regions (≥20 m from roads). Collembolan species richness in the soil was also affected by distance from the roadside. A decrease in collembolan density was associated with lower soil water content and changes in tree community composition (principally a decrease in *Castanopsis sieboldii* cover), but the accumulated litter weight had no significant effect, probably because accumulated litter levels were low. The extent of Bray–Curtis dissimilarity between collembolan communities located along roads decreased with distance from the roadside as compared to that of reference sites (>80 m from the roads). Separation of Bray–Curtis dissimilarities into two components revealed that differences between roadside communities and those of reference sites were largely explained by taxonomic turnover (i.e., individuals of certain species at one site were substituted with the same numbers of individuals of different species at another site). The dissimilarities between collembolan community compositions at 1 or 5 m from roadsides as compared to those of reference sites 20 m from roadsides appeared to be attributable to higher density losses of all species found at 1 or 5 m. Distance-based linear modeling showed that the collembolan community composition was associated both with distance from the forest edge and with the index values of tree community structure. *Folsomia octoculata* served as an inner-forest (≥20 m from the roadside) indicator species. The prevalences of certain dominant species were correlated with the first tree nonmetric multidimensional scaling (NMDS) axis. Overall, changes in collembolan communities at forest edges seemed to be caused by diminished soil water content and the presence of tree communities that differed from those in deeper forest.

Introduction

Forest edges are foci of both conservation and ecological research. Exponentially increasing habitat destruction and fragmentation due to recent plantations or the abandonment of adjacent farmland indicate that forest edges are proportionately more important than forest interiors (Magura et al. 2001; Saunders et al. 1991). Road construction in forests creates edge environments and affects wind direction and speed, temperature, relative humidity, and insolation (Coffin 2007). Forest edges usually experience increased solar radiation and higher air and soil temperatures, and are thus more susceptible to drought than forest interiors (Chen et al. 1999; Enoki et al. 2013). Such variation affects crowning trees (Enoki et al. 2013), understory vegetation (Hamberg et al. 2009), vertebrates (Fahrig and Rytwinski 2009; Forman and Deblinger 2000), and invertebrates (Haskell, 2000).

As soil fauna are known to respond to various forms of disturbance (Huhta 1976; Lindberg and Bengtsson 2005; Siira-Pietikäinen et al. 2003), soil fauna censuses may reveal habitat disturbance and biodiversity loss (Ponge et al. 2003; van Straalen 1998). Haskell (2000) found that soil fauna abundance decreased at forest edges, while Aoki and Kuriki (1978) showed that densities

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of Collembola and Acari decreased toward a path within 1.5 m of the forest edge. In contrast, certain edge-associated species were absent in an adjacent habitat (Magura 2002). Didham (1997) reported that invertebrate abundance increased toward forest edges due to the replacement of the natural forest community by invasive (generalist) edge species, while Cameron and Bayne (2009) demonstrated that road age in particular can be an important factor affecting the spread of invasive species. Previous studies have suggested that roads affect soil fauna at forest edges, but the relevant factors have not been fully investigated. Identification of such factors could reveal road construction methods that would minimize the loss of biodiversity.

Okinawa is the principal island of the Ryukyu Islands, located in the subtropical region of southwestern Japan. The northern part of the island, called Yambaru, supports relatively well-conserved primary and semi-primary forests that contain many unique, endemic, and rare species, and as such is considered to be a world biodiversity hot spot (IUCN 2000; Olson and Dinerstein 1998). The effects of road construction and silviculture in Okinawa have been studied (Enoki et al. 2013; Ito and Aoki 1999). Enoki et al. (2013) described changes in tree communities at forest edges, and Kawakami et al. (2011) showed the importance of soil invertebrates as food for specific vertebrates. Collembolan communities are known to vary with litter levels (Hasegawa, 2001; Takeda 1987)—particularly when water conditions change (Lindberg et al. 2002; Verhoef and van Selm 1983) and when the vegetation, including tree communities, is affected (Hasegawa et al. 2009; Sabais et al. 2011; Salamon and Alphei 2009). Therefore, we investigated the effects of roads on collembolan communities in the forest edge habitat of Okinawa and explored potential explanatory variables for shifts in community structures, such as the litter amount, water conditions, and tree community composition. We hypothesized that Collembola densities and diversity would be reduced close to roads due to a decreased litter layer and alterations in tree community composition.

Materials and methods

Study site

We studied a subtropical evergreen broad-leaved forest located in the northern part of Okinawa, southwestern Japan. The region has a maritime subtropical climate, with a mean annual temperature of 21.1 °C and a total annual precipitation of 3167 mm in 2007 (Oku Observation Station, Japan Meteorological Agency, 26°50.1′ N, 128°16.3′ E). Site elevations ranged from 242 to 375 m a.s.l., and the bedrock (primarily phyllite and slate) is covered by yellow and red soil. The evergreen broad-leaved forest is dominated by *Castanopsis sieboldii*, *Schima wallichii*, and *Distylium racemosum* (Enoki 2003; Kubota et al. 2004).

We studied three logging roads (Ie, Uka, and Ginama roads) in the Yambaru area of Okinawa Island. Ie road was constructed more than 30 years prior to sampling, while Uka and Ginama roads were constructed 1–5 years before sampling. We chose a total of 10 study sites (5 on Ie road, 3 on Ginama, and 2 on Uka; Fig. 1). The study site was located in an area delimited by the coordinates 26°47′55.2″–26°49′11.5″ N and 128°15′35.4″–128°17′08.3″ E. The average distance (±standard deviation) between sites was 1615 m (±987 m), and all roads were ∼6 m wide and paved with asphalt.

Tree community structure

To investigate roadside changes in tree communities, we defined three quadrats (1, 5, and 20 m from the road: henceforth "first," "second," and "third," respectively) at each sampling location to relate tree and collembolan community structure (Fig. 2). The size of each quadrat was 5 × 2 m, and each first quadrat was located 1 m into, and parallel to, the forest edge. Each second quadrat was set 5–10 m into the forest, and each third quadrat was set 20–25 m from the forest edge, with the longer side perpendicular to the road. Species and numbers of all living trees in each quadrat over 5 cm in trunk diameter at breast height (DBH; 1.3 m) were noted.

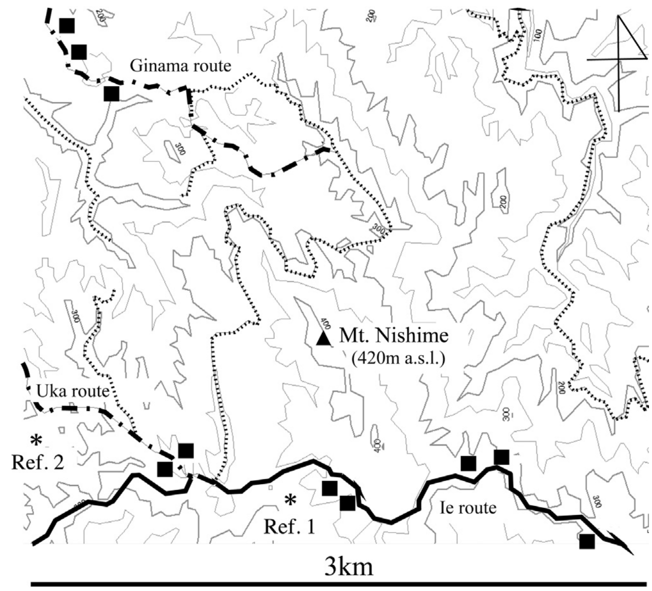

Fig. 1. A contour map of the study sites. Squares indicate plots near the road. Asterisks show the reference sites. A triangle is the summit of Mt. Nishime. Roads are shown by various lines: Ie = solid line; Uka and Ginama = dashed line; other roads = dotted line. In this area, forests cover most regions, apart from the roads.

Collembola sampling

We took samples along a transect from the forest edge to 20 m inside the forest. We established 20-m transects perpendicular to the road at each site, collected samples at the 1, 5, and 20-m points along these transects, and replicated our sampling 10-fold at 5-m intervals along the road (Fig. 2). The effect of the forest edge has been related to tree height at our study site (Enoki et al. 2013). We selected a 20-m transect length for evaluating road edge effects because most trees were under 10 m in height. Longer transects would have been affected by other edge effects and local topography: the roads in our study region are winding, with a complex topography. As roadsides are commonly mowed in Okinawa, we

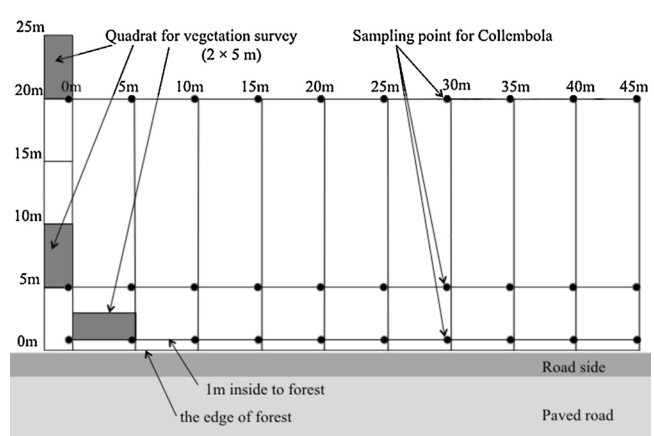

Fig. 2. Sampling design within a plot.