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Short Communication

Wind dispersal of alien plant species into remnant natural vegetation from adjacent agricultural fields

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ABSTRACT

Knowledge regarding the seed dispersal of alien species is crucial to manage invasion risk in fragmented natural habitats. Focusing on wind dispersal, this study assessed the spatial and quantitative extents to which a remnant natural fen receives the seeds of alien species dispersed from adjacent hay meadows in Hokkaido, northern Japan. I established a total of 80 funnel seed traps in the fen at distances of 1, 2, 5, 10, 20, 30, 50, and 100 m from the meadows. The proportion of alien species in the seed rain at each distance was quantified, and the 99th-percentile dispersal distance from the meadows was estimated for each alien species by constructing dispersal kernels. Despite the presence of a marginal ditch and an elevational difference between the fen and the meadows, five alien species, including four grasses that do not have modified seed structures for wind dispersal, dispersed their seeds into the fen. These alien species accounted for up to 65.9% of the seed rain in terms of quantity. The 99th-percentile dispersal distances of the alien species ranged from 3.8 m to 309.3 m, and these distances were longer than the values predicted on the basis of their functional traits, such as terminal velocity. The results of this study demonstrated that numerous seeds of farmland-derived alien species were transported into the remnant vegetation via wind dispersal, and that simple predictions of dispersal distance based on functional traits could underestimate the potential area that alien species can reach. Continuous management both in farmland (to reduce seed escape) and in remnant vegetation (to prevent the establishment of alien species) is necessary to protect native vegetation from biological invasion in agricultural landscapes.

1. Introduction

The conversion of natural ecosystems into agricultural, industrial, and urban areas has progressed worldwide, resulting in highly divided, fragmented landscapes (Vitousek et al., 1997; Foley et al., 2005). The areas of remnant natural vegetation act as refugia for various plant species, including those that are endangered (Bruun, 2000). Conservation of the remnant vegetation is a pressing matter in maintaining local and regional biodiversity (Hanski and Ovaskainen, 2000; Newbold et al., 2015).

Fragmented natural vegetation, however, often suffers from invasion by undesired alien species from the surroundings, which threaten native flora (Morgan, 1998; Wilkerson, 2013). This is particularly true when the vegetation is surrounded by farmland because farmland generally contains numerous alien weeds (Marshall et al., 2003; Jauni and Hyvönen, 2010). In addition to weeds, cultivated crops themselves can become invasive aliens when they escape from arable fields (Ellstrand

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et al., 2010; Goyal and Sharma, 2016). For instance, imported forage crops, particularly pasture plants, tend to become invasive in natural habitats, and they have a serious impact on the diversity of native species (Lonsdale, 1994; Driscoll et al., 2014). To reduce invasion risk in the remnant vegetation in agricultural landscapes, knowledge of seed dispersal of alien species from farmland into natural habitats is crucial. However, while the occurrence patterns of alien species in remnant fragments have been well documented (e.g., Morgan, 1998; Vilà and Ibáñez, 2011), empirical studies on the processes and extent of their seed dispersal into the fragments are still limited.

Wind is a pivotal dispersal vector for plants (Soons and Bullock, 2008). Because the wind blows continuously across the landscape, wind dispersal would play a key role in the invasion of remnant natural habitats by farmland-derived alien species. Wind dispersal distance is strongly related to plant functional traits, particularly terminal velocity (Tamme et al., 2014). Species possessing modified seed structures for wind dispersal, such as wings, hairs, and pappi, have low terminal velocities and long dispersal distances (Cousens et al., 2008). Species without specific seed structures also disperse their seeds using wind (Quick and Houseman, 2017), but their dispersal distances are relatively short (Jongejans and Telenius, 2001). Predictions of wind dispersal distances using functional traits of alien species are useful for knowing the potential invasion ranges (Thomson et al., 2011; Tamme et al., 2014). However, a recent empirical study using two herbaceous species demonstrated that the distances of wind dispersal for these species measured under natural field conditions exceeded the maximum dispersal distances predicted on the basis of their functional traits (Herrmann et al., 2016). This finding leads to the unfavorable possibility that simple predictions of wind dispersal distances using functional traits can underestimate the area that seeds of farmland-derived alien species can actually reach.

To reveal the extent of the wind dispersal of alien species from farmland into natural habitats, this study quantified the seeds dispersed by wind from hay meadows into an adjacent remnant fen in Hokkaido, northern Japan. I first hypothesized that the remnant fen receives seeds of various meadow-derived alien species via wind dispersal, including those of species lacking morphological adaptations for wind dispersal, and second that the wind dispersal distances of alien species from the meadows are longer than the distances predicted on the basis of their functional traits.

2. Materials and methods

2.1. Study site

The study was conducted in a natural fen in a remnant wetland complex, the Sarobetsu Mire, which is adjacent to recently developed hay meadows in Hokkaido, northern Japan (45°04′N, 141°42′E). The Sarobetsu Mire contains dozens of wetland fragments ranging from 0.5 to 5269 ha in area (Fig. 1; the area calculation was conducted by the author using GIS data from a vegetation map derived from the Biodiversity Center of Japan website: http://www.biodic.go.jp/sarobetsu/download.html, accessed on 30 March 2017). The study fen, ca. 16.6 ha in area, is located in the central part of the largest fragment, which includes mined areas and two lakes, and is designated as a nature reserve in the Rishiri-Rebun-Sarobetsu National Park. The mean annual temperature and annual precipitation in the study year, 2016, measured at the weather station located 6.6 km from the study fen were 5.9 °C and 1004 mm, respectively (Japan Meteorological Agency, 2017). The fen is located in a relatively windy area; the daily mean and maximum wind speed during the study period from June to October 2016 measured at the weather station described above averaged 3.1 ± 1.3 m s^{-1} and 6.2 ± 2.1 m s^{-1} (mean ± SD), respectively, with a peak gust of 23.3 m s^{-1} (Japan Meteorological Agency, 2017). The most frequent wind directions were easterly, south-southwesterly, easterly, and west-southwesterly in June, July, August, and September, respectively.

Grassland-based dairy farming is very common in Hokkaido. The island had 512,100 ha of pastures and hay meadows as of 2013, and these covered 83.5% of the total agricultural grassland area in Japan (Ministry of Land, Infrastructure and Transport, Hokkaido Regional Development Bureau, 2017). The grasses and legumes currently used for pastoral purposes in Hokkaido are all introduced species and were mainly imported from North America and Europe during the Meiji era (1868–1911) to increase forage productivity (Japan Livestock Industry Association, 1976); thus, these pasture plants are all alien species.

In the Sarobetsu Mire, intensive conversion of the wetlands into agricultural lands, mostly pastures and hay meadows, has been conducted since the 1960s (Fujita, 2014). The proportion of wetland areas in the region decreased from 26% to 11%, while that of agricultural lands increased from 10% to 35% during the period from 1947 to 1999 (Ministry of the Environment, Hokkaido Regional Bureau, 2009). The hay meadows adjacent to the study fen were established during the 1980s (Fujita, 1997, 2014). The meadows in this area are fertilized regularly, and the seeds of perennial grasses, mostly those of *Phleum pratense* L. (also known as timothy grass), have been sown as mixtures with the seeds of clovers (Egawa, personal communication). In addition to the intentionally sown species, the meadows contain volunteer grasses and various weeds. During the study period, the meadows were mown twice for hay production, in mid-June (first cut) and late September (second cut). There was a 0.5-m-wide unlined ditch between the fen and the meadows, and the elevation of the fen was 1.0 m higher than that of the meadows (Fig. A.1).

Establishment of various alien species, including pasture plants and agricultural weeds, has been observed in many locations in the Sarobetsu Mire (Fujita, 2014). However, the study fen is likely to be free of these species despite being adjacent to the meadows, because the fen has been dominated by *Sasa* spp. (Tachibana et al., 2013), whose dense cover would inhibit the establishment of shade-intolerant pasture plants and agricultural weeds even if their seeds enter the fen. Therefore, the fen was expected to have no sources of seeds of alien pasture plants and weeds and to be suitable for quantifying the seeds of these species dispersed from the meadows. An experimental plot of 170 m × 100 m was established in the fen (Fig. 1). Prior to the sampling of seed rain, I conducted a floristic survey throughout the whole experimental plot and listed all species found