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Invasion level of alien plants in semi-natural agricultural habitats in boreal region

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ABSTRACT

We quantified the level of invasion (i.e. number or proportion of aliens of all species) of archaeophytes (introduced before 17th century) and neophytes (introduced after 17th century) in five semi-natural agricultural habitats and identified the factors affecting the occurrence of alien species in boreal region. The differences in native and alien plant species richness were analysed with generalized linear mixed models.

One-third of the recorded plant species were aliens. The highest levels of invasion were detected from frequently disturbed field and road margins, whereas the lowest levels were in grasslands and forest margins. All species groups had temperature-related decreasing trend northward, and increasing trend towards east. Archaeophytes responded like neophytes to geographical location and the amount of bare ground. Factors related to disturbance (the amount of bare ground, mowing) may increase the level of invasion. To prevent the establishment and spread of invasive alien species, management practices, which increase the disturbance, should be limited.

1. Introduction

Alien plant species both contribute to species diversity, and threaten biodiversity by displacing native species. Understanding the factors that affect the level of alien plant invasion is a key to developing management and control strategies for alien plant species. In an agricultural environment the intensity of management differs among habitats, resulting in differences both in the level of invasion and the threat to biodiversity.

The level of invasion is measured as the total numbers of alien plant species or their proportion of the total species richness (Lonsdale, 1999; Hierro et al., 2005; Chytrý et al., 2008a). Agricultural habitats are among the most invaded habitats (Chytrý et al., 2005; Vilà et al., 2007; Pyšek et al., 2009), and in agricultural habitats, the level of invasion varies according to disturbance regime (Hobbs and Huenneke, 1992; Smith and Knapp, 1999), resource availability (Davis et al., 2000; Foster et al., 2002), propagule pressure (Lockwood et al., 2005; Colautti et al., 2006) and management factors (e.g. Lososová et al., 2004). In addition, geographical location and climate (e.g. Lonsdale, 1999; Kivinen et al., 2006) with residence time (Pyšek and Jarošik, 2005) and the structure of the plant community (Dukes, 2002; Stohlgren et al., 2002) contribute to the level of invasion.

Among agricultural habitats, arable land is most invaded by alien plants, whereas natural and semi-natural grasslands undergo lower levels of invasion (Chytrý et al., 2005, 2008b; Pyšek et al., 2009). High levels of alien species richness are often associated with a dry, warm climate and low altitude (Stohlgren et al., 2002; Gassó et al., 2009), whereas among arable weeds native species have been found to favour more wetter and colder climate than alien species (Pyšek et al., 2005). Generally, alien species favour mesic, disturbed habitats with high availability of resources, such as light and nutrients (e.g. Rejmánek, 1989; Milbau and Nijs, 2004).

Agricultural habitats are frequently regarded as supporting high invasion levels of alien plants (Lonsdale, 1999; Chytrý et al., 2005; Vilà et al., 2007; Pyšek et al., 2009). However, within-habitat variation in the level of invasion of alien plants species and the factors affecting are scarcely studied (Dajdok and Wuczyński, 2008). This is especially true for boreal regions, where the invasion history is shorter and the land-use intensity lower than in temperate regions of Europe.

In this study, we aimed at comparing the invasion levels in five different types of semi-natural agricultural habitats in the boreal region in Finland, and detecting the key environmental factors influencing invasion. We expected to record lower invasion levels in our study area than have been recorded in central and southern Europe (e.g. Chytrý et al., 2009; Pyšek et al., 2009), and hypothesized

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that the most frequently disturbed and intensively managed habitats support the highest levels of invasion. In addition, agricultural habitats, especially semi-natural grasslands, maintain plant species diversity in boreal regions (Cousins and Eriksson, 2002; Raatikainen et al., 2007), thus we tried to estimate the degree of threat caused by alien plant species to native plant species diversity.

We expected to find differences in the factors affecting the species richness of native and alien plants (e.g. Pyšek et al., 2005) as well as alien plants with different residence times (Pyšek et al., 2005; Simonová and Lososová, 2008). Archaeophytes were introduced to Finland before the early 17th century and neophytes after that date (Hämet-Ahti et al., 1998). The definition differs from the one used in Central Europe where species are classified as archaeophytes if introduced before 16th century, and neophytes if introduced after that date (e.g. Pyšek et al., 2004). On arable land, archaeophytes respond like neophytes to climate and like natives to increasing agricultural intensification and propagule pressure (Pyšek et al., 2005). We expected to find similar patterns in semi-natural agricultural habitats, and hypothesized that archaeophytes and neophytes respond similarly to climate and geographical region. To our knowledge, this is the first attempt to quantify the invasion level of alien plant species in boreal agricultural landscape based on comprehensive field data.

2. Materials and methods

The data originated from a long-term national monitoring study on the effects of the Finnish agri-environment support scheme (MYTVAS) (see Kuussaari et al., 2008). In 2001 and 2005, a total of 52 one km^2 quadrates situated in four geographical regions (western, eastern, south-western, and southern Finland) were sampled using stratified random sampling (see Kuussaari et al. (2004, 2008) for details of the sampling design). In each region, the first sampling quadrate was randomly selected, and the second quadrate was randomly selected within at least 1 km distance from the first square. In most cases, the distance between quadrates was at least 10 km. Only squares with < 20% cover of cultivated fields were included (Kuussaari et al., 2004). The study region was situated mostly within southern boreal vegetation zone, except the most south-western parts which were situated in the hemi-boreal zone (Ahti et al., 1968). The study area covered the major agricultural areas of Finland, varying in terms of cultivation intensity and plant species richness (Luoto, 2000; Kivinen et al., 2006).

Each 1 km^2 quadrate was divided to quarters, and the plants were sampled in two quarters of 1 km^2 quadrate (Kuussaari et al., 2004). From the quadrate, native and alien vascular plants were recorded in 12 separate 50 m long and 1 m wide transect lines (with total monitored area of 50 m^2) in both study years. The transect lines were located in the centre of the habitat patch, at least 50 m distance from each other. Land-use changes caused differences in the transects between the study years. Monitoring results concerning the species diversity have been reported nationally by Jauni and Helenius (2008).

The transects (hereafter referred as plots) were placed according to maps, aerial photographs and field work in open and semi-open uncultivated habitats, which could be classified into five habitat types, most of which were linear strip elements in the landscape: (1) field margin (margin between two agricultural field parcels), (2) forest margin (margin of an agricultural field next to a forest), (3) road margin (including margins of an agricultural field next to a road and road verges within the open agricultural landscape), (4) grassland (including patches of uncultivated meadows, abandoned fields and cultivated or natural pastures), and (5) other habitats (including margins of an agricultural field next to a waterway, cart-tracks and other habitats few in number) (Table 1). The habitats differed in their level of disturbance: field margins and road margins representing heavy disturbance, and grasslands less disturbed by agricultural management, transport and other types of disturbance. In some plots, the habitat type changed because of the land-use changes between the two study years (Table 1). However, the 580 plots were exactly the same in both years. Thus, only the data of the same 580 plots studied in both years were included in this study.

Table 1
Characteristics of the studied habitats, variables and numbers of plots.

Variable	2001	2005
Number of plots used in the study	580	580
Habitats[a]		
Field margin	205	205
Forest margin	127	126
Road margin	116	117
Grassland	88	86
Other habitats	44	46
Variables of habitat quality		
Mowing		
Not mowed	452	481
Mowed	105	91
Shadiness		
Sun-baked	19	112
Sunny	417	385
Partly shady	130	74
Shady	11	9
Moisture		
Dry	22	59
Mesic	510	482
Moist	42	39
Bare ground (%)		
Mean ± SD	4.1 ± 9.0	7.2 ± 15.1
Height of the vegetation (m)		
Mean ± SD	60.4 ± 25.7	69.7 ± 28.8
Spatial variables		
Latitude		
Min.	66.70	66.70
Max.	70.72	70.72
Longitude		
Min.	32.06	32.06
Max.	36.92	36.92

[a] The number of the habitat types is not exactly the same in both study years, due to land-use changes. However, the same plots have been studied in both years.

Environmental variables were measured or estimated at the local and landscape level. Climatological variables included: (1) total temperature sum >5 °C (April–July), (2) total precipitation (mm) (April–July), (3) total number of frost days (April–July) and (4) the starting date of the growing season. The data were derived from the Finnish Meteorological Institute, and were estimated for each 1 km^2 quadrate. Variables describing the quality of the habitats included: (1) shadiness (four classes based on exposure to sunshine: sun-baked, sunny, partly shady, shady), (2) moisture (three classes: dry, mesic, moist), (3) amount of bare ground (estimated in 9-step %-classes), and (4) the average height of the vegetation (cm). In addition, mowing (in two classes: not mowed, mowed) was detected from each plot. Longitude and latitude were defined from the centre of each plot. To study the effect of geographical location on species richness, we built a trend surface of the form: $f(x,y) = b_0 + b_1x + b_2y + b_3x^2 + b_4xy + b_5y^2 + b_6x^2y + b_7xy^2$ where x and y represent the longitude and latitude of the centre point of plot. By adding also quadratic terms of the coordinates and their interactions into the analysis, more complex spatial features can be detected (Legendre and Legendre, 1998).

The plant species nomenclature follows that of Hämet-Ahti et al. (1998). The species were categorized by residence status (native, archaeophyte and neophyte) according to Hämet-Ahti et al. (1998) and Suominen and Hämet-Ahti (1993). Most of the detected