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Spatial expansion pattern of black cherry *Padus serotina* Ehrh. in suburban zone of Białystok (NE Poland)

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Abstract: The object of the study is the distribution and spatial pattern of black cherry *Padus serotina* Ehrh. population and the impact of landscape structure on the expansion of this alien species in the suburban zone of the city, where the land-use has rapidly been transforming recently. The population of black cherry expands centrifugally, spreading from fringes of the city to outer zones of the agglomeration with more agricultural character. Individuals of *P. serotina* are distributed in clusters in this area. The maximum observed population density reaches 371/ha (mean 11.3/ha for colonized plots). The main factor influencing the landscape invasibility is cessation of agriculture. Although the first sources of spread of *P. serotina* are localities in forests, where 46% of the total number of individuals are concentrated, nevertheless, the largest group of juveniles (48%) was found on abandoned farmlands. Over 90% of all youngest individuals were recorded at a distance of up to 100 m from older ones. Chances of isolated occurrence are small and the probability of the colonization is strongly dependent on the occupation of adjacent areas by the species. Black cherry disperses, primarily, according to a spatial pattern of phalanxes, by occupying areas immediately adjacent to places previously colonized and then filling the available habitats. Long-distance dispersal seems to play a minor role for its expansion. Autocorrelation and diffusion models of spread should be taken into account in preventing further expansion of black cherry and planning conservation measures in natural protected areas.

Key words: alien species, expansion, invasion, landscape structure, *Padus serotina*, spatial pattern

1. Introduction

Invasions of alien species of plants and animals are among the most important threats to biodiversity and nature specificity in the ecosystem and landscape both on regional and global scale (Faliński 1968; Thiele & Otte 2008; Thuiller *et al*. 2008). The need to counteract the dispersion of alien species and to monitor progress of their expansion plays a special role in areas of high natural values and habitats slightly transformed by anthropogenic processes (Pyšek *et al*. 2002). It is a constant element in the assessment of natural habitats and species of European importance, protected under the Habitats Directive.

The rate and spatial pattern of alien species expansion are affected mainly by two groups of factors (Higgins & Richardson 1996; Richardson & Pyšek 2006): reproductive and dispersal potential of the species and, on the other hand, habitat susceptibility. An important role is played by various mechanisms and patterns of colonization (such as phalanx and guerilla), in particular, the ability for long-distance transport of seeds and propagules of any other types (Nathan & Muller-Landau 2000; Sebert-Cuvillier *et al.* 2008) as well as different vectors of their dispersion.

The course of expansion also depends on landscape structure, including the spatial arrangement of habitat patches of varying susceptibility to colonization by alien species, their mutual relations, neighborhood and the character of background (landscape matrix). The landscape structure influences expansion of alien species on many different levels. Alien species dispersion is promoted by appearance of disturbed areas which split up homogeneous habitats and enhance their invasibility. Along with changes in the landscape spatial structure and its fragmentation, the edge effect also escalates pressure on increasingly shrinking interior habitats (With 2002). Alien species will spread at different rates in relatively homogeneous landscape, for example, in vast areas of abandoned farmlands or dense forests, and otherwise in the landscape with varying degrees of habitat fragmentation and diverse network of ecological corridors (Chmura 2004; Wołkowycki 2004; Pearson & Dawson 2005). To date, relatively few studies have verified theoretical concepts describing the impact of the spatial structure of the landscape on the course of alien species expansion (Rouget & Richardson 2003; Pearson & Dawson 2005; Sebert-Cuvillier *et al*. 2008).

The subject of the study was the population distribution and spatial pattern of black cherry *Padus serotina* Ehrh., its invasive spreading in NE Poland and the impact of landscape structure on the expansion of this alien species.

Black cherry *P. serotina* is a shrub or tree originating from North America. It was formerly planted in Poland as, a so-called, biocenotic additive on poorly fertile habitats in the understory of Scots pine forests and, at the present time, it is rarely cultivated as an ornamental plant. *P. serotina* was introduced to forests in the northeastern part of the country mainly during 1970s and 1980s. Fruits are willingly eaten and dispersed by birds (Deckers *et al*. 2008). With this vector of spread, the species is able to sustain and effectively increase the population on spontaneous posts (Stypiński 1977; Halarewicz 2011a, 2011b; Tokarska-Guzik *et al*. 2012), and its control is very difficult. Black cherry is a very serious threat, especially for heliophilous species in the herbaceous layer of well-lit pine forests, such as *Arnica montana*, *Diphasiastrum* spp., *Pulsatilla patens* as well as in non-forest habitats, like xerothermic grasslands. *P. serotina* has reached an intermediate stage of expansion in NE Poland (see: Tokarska-Guzik 2005) and, so far, it has not managed to colonize a large portion of suitable habitats.

2. Material and methods

2.1. Area of study

The research was conducted in the southern part of Białystok agglomeration which is the capital of Podlaskie province in NE Poland. After analyzing the cartographic materials and field reconnaissance, a rectangular area of 60 km^2 was selected, located on the land of several villages, namely, Bronczany, Dojlidy Górne, Halickie, Horodniany, Hryniewicze, Ignatki, Koplany, Księżyno, Lewickie, Niewodnica Korycka, Niewodnica Nargilewska, Olmonty, Skrybicze, Solniki, Stanisławowo and Zalesiany, belonging to municipalities of Juchnowiec, Turośń Kościelna and Zabłudów, the county of Białystok in Podlaskie Voivodeship. A small part, administratively, belongs to the city of Białystok. The study area is located on the Białystok Uplands, within the North Podlasie Lowland.

Until the end of the 20th century, the vicinity of the city of Białystok was characterized mostly by an agro-forestry landscape, typical for the region of Podlasie. In recent years, however, this area has rapidly undergone progressive suburbanization, which involves abandoning of agriculture, the secondary succession of varying stages of advancement, as well as modernization of existing settlements and new housing development on former farmlands.

Transformations of land-use affect the landscape mosaic in this area in very different ways. Fragmentation of large tracts of arable land and meadows occurs as a result of secondary succession, whereas forest patches are split by increasing and sprawling suburban settlements. On the other hand, the development of initial woody communities on abandoned farmlands leads to changes in field-forest boundary and merging of forest patches over time.

2.2. Data collection and analysis

Individuals of black cherry *P. serotina* were identified during systematic field penetration carried out by dense but irregular routes and mapped using satellite navigation devices (GPS) in 2011 and 2012. Places of occurrence of species spaced apart by more than 5 m were treated as separate locations. The number of individuals in each location was counted separately for different height classes (or stages of development): seedlings and juveniles (up to 0.5 m, occurring in the herbaceous layer), middle-aged individuals (0.5 to 5 m, in the shrub layer) and the oldest ones (over 5 m in height, forming a part of tree-stand). The data collected in the field were subsequently compiled in the form of numerical maps and cartograms of distribution.

Maps prepared in this way and treated as the input data, were subjected to study in the GIS using a topological analysis and spatial statistics. GeoMedia Professional and ESRI ArcGIS software was used for this purpose.

Data for some spatial analyses were processed through tessellation, assigned to basic plots and elaborated by the

Table 1. Population of black cherry *Padus serotina* in the southern part of the Białystok agglomeration (NE Poland)

Population size [number of individuals]				Percentage of individuals [%]		
in tree-stand (a)	medium-sized (b)	seedlings and juveniles (c)	all	in tree-stand (a)	medium-sized (b)	seedlings and juveniles (c)
27	2042	1370	3439	0.8	59.4	39.8

Table 2. Occurrence frequency of *Padus serotina* in the plots of different size

x	Number of colonized plots				Percentage of colonized plots [%]			
side of the plot	tree-stand (a)	medium-sized (b)	seedlings and juveniles (c)	all	tree-stand (a)	medium-sized (b)	seedlings and juveniles (c)	all
125 m	34	130	67	145	0.9	3.4	1.7	3.8
250 m	14	179	57	195	1.5	18.6	5.9	20.3
1000 m	10	43	28	44	16.7	71.7	46.7	73.3

cartogram method. Study area was divided into square plots of different sizes: 60 plots with a side of 1000 m, 960 plots – of 250 m and 3840 with a side of 125 m.

In order to characterize the spatial distribution of alien species, methods based on measuring the distance between point localities, including the method of the nearest neighborhood and modified Ripley's K function (L), as well as the method based on data processed by cartogram and neighborhood matrix (Moran's I coefficient) were used. This kind of spatial analysis was performed using Passage 2 (Pattern Analysis, Spatial Statistic and Geographic Exegesis) and SAM 4.0 (Spatial Analysis in Macroecology) software.

Correlation analyses, based on the Spearman coefficient, logistic regression and the proportion test, were performed using Statgraphics Centurion program.

On the basis of orthophotomaps and aerial photographs, using current data collected in the field, the numerical map of land-use was developed, distinguishing the following categories: forests, coppices and thickets (on former agricultural land occupied by initial communities with the dominance of trees under the age of 20 years), abandoned former farmland with herbaceous vegetation, agricultural land, orchards, built-up areas (with traditional rural character and, separately, with modern suburban housing), waters and swamps, pits and landfills.

The largest acreage was covered by arable fields, sharing approximately 35%, forests (30%) and abandoned farmland (21%). In order to determine the diversity and habitat mosaic, Simpson's coefficient was applied, using the formula:

$$D = 1 - \sum p_i^2$$

where p_i is the proportion of the type of land-use (in the case of habitat diversity) or habitat patch (in habitat mosaic coefficient) in basic plot.

3. Results

In the vicinity of the city of Białystok, 3 439 individuals of black cherry *P. serotina* were noted in the area of 60 km^2 covered by the study. The observed maximum population density reached 371/ha (mean 0.06/ha, including unoccupied plots or 11.3/ha for set of colonized ones). The largest part of the population consisted of a group of medium-sized individuals (middle-aged), of 0.5 to 5 m in height. This cohort formed slightly over 59% of the population. Seedlings and juveniles, not exceeding 0.5 m in height, accounted for approx. 40% of population, while the group of the oldest individuals (reaching more than 5 m in height) shared less than 1% (Table 1).

Frequency of the species varied with the spatial scale (Table 2; Fig. 1). Localities of black cherry existed in 4% of the smallest area plots (side of 125 m), in 20% of medium-sized (side of 250 m) and 73% of the biggest

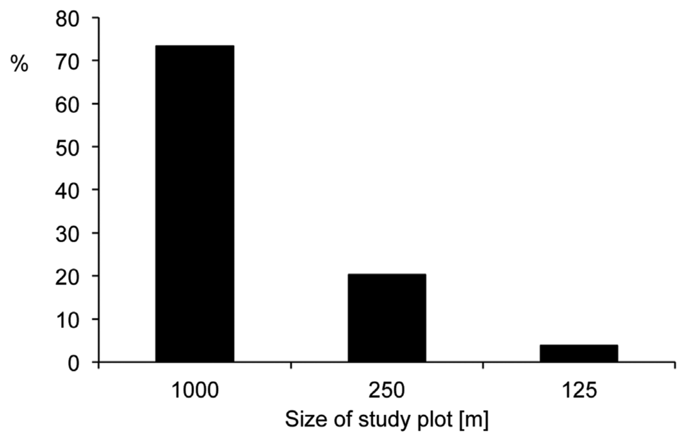

Fig. 1. Frequency occurrence of *Padus serotina* in the plots of different size

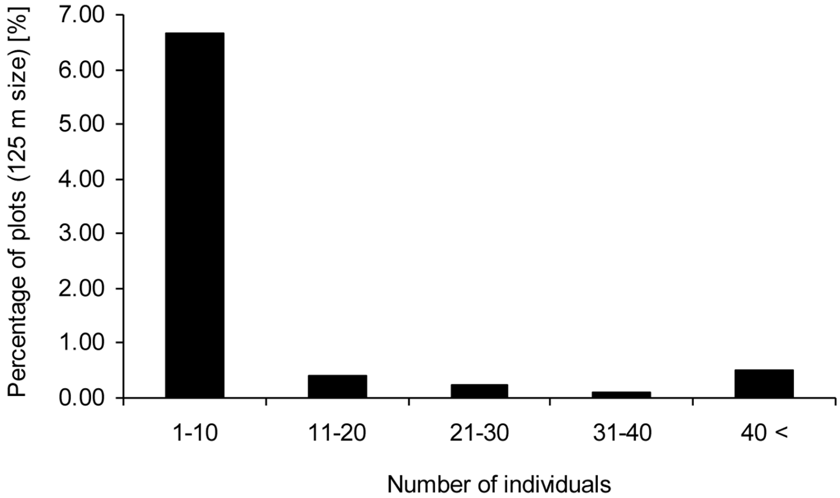

Fig. 2. Proportion of basic plots (125 × 125 m) with the different population sizes of *Padus serotina*

ones (side of 1000 m). Local populations were usually small, not exceeding 10 individuals per basic plot (125 × 125 m; Fig. 2).

The species was most common in north and north-west parts of the area of study, adjacent to the city fringes. The plots occupied by black cherry became less frequent in the typical rural landscape in the south and south-east.

Individuals of *P. serotina* were distributed is clusters. Such type of spatial pattern was suggested just by the overview of the map and cartogram of species distribution (Figs. 3-4), and certified by the results of the comparison of theoretical random distribution and observed in the real, carried out by the analysis of the modified Ripley's function (L). The degree of density of localities varied depending on the spatial scale. There were very strongly marked clusters of individuals in the nearest vicinity of their locations. The increase of density was observed with lengthening the radius of the zone surrounding the locations of species to approx. 2 km. After exceeding this value, the opposite trend was observed, leading to disappearance of highly concentrated clusters

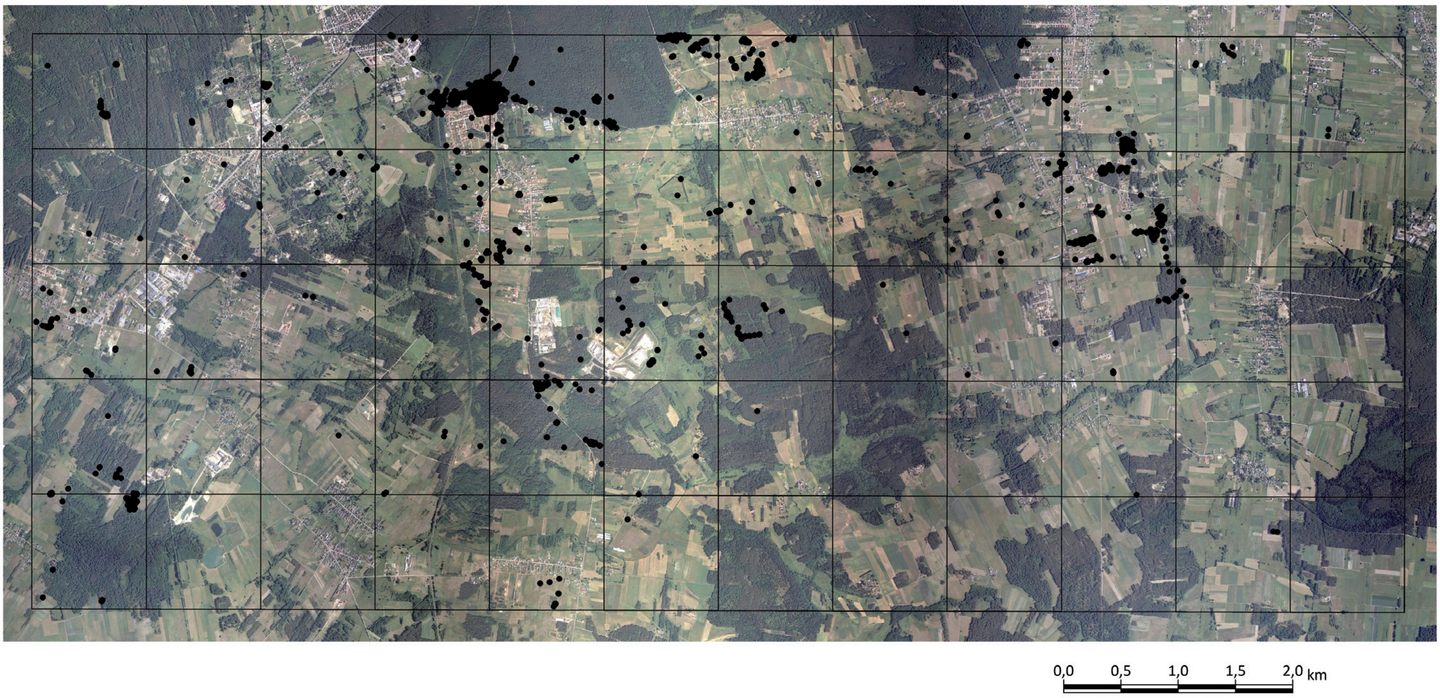

Fig. 3. Distribution of *Padus serotina* in the southern part of surroundings of Białystok (NE Poland). The plots of 1000 x 1000 m in area are marked; the orthophotomap is in the background

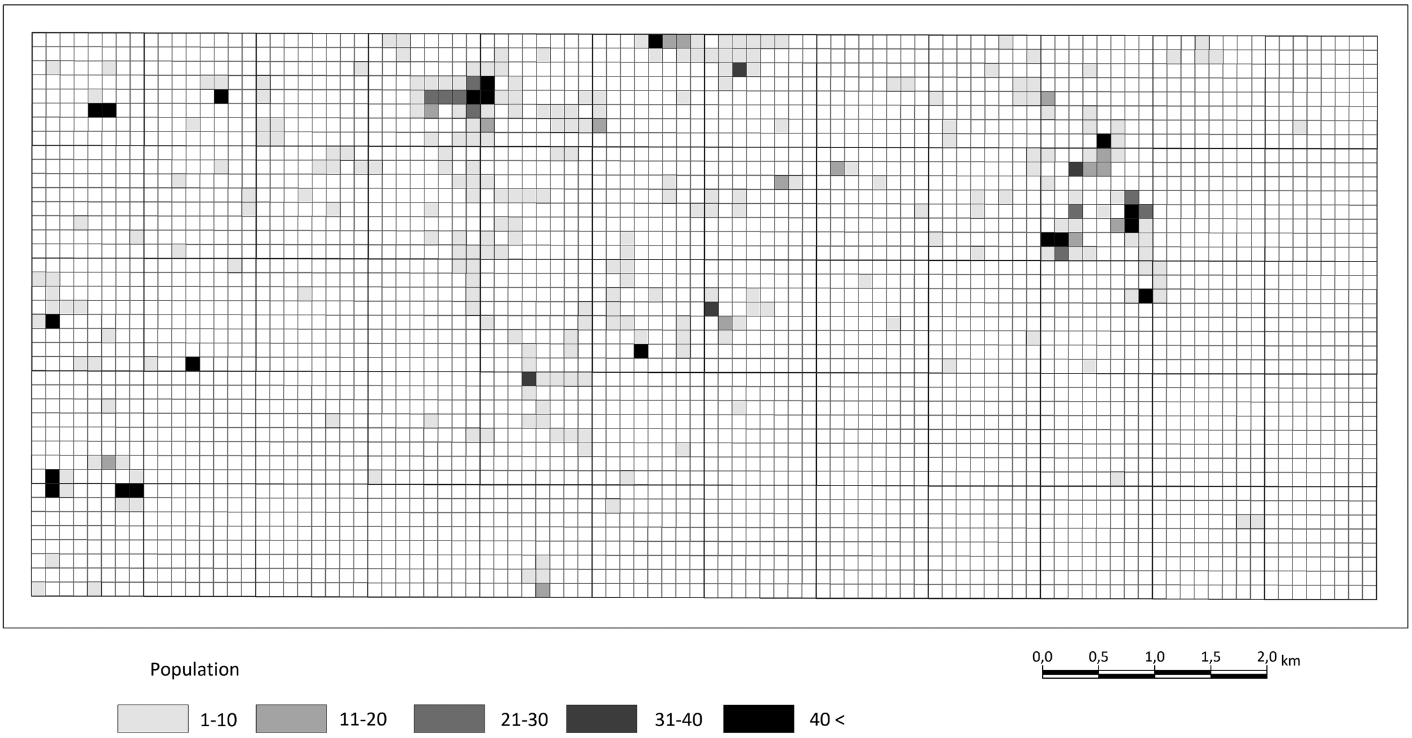

Fig. 4. Cartogram of distribution of *Padus serotina* in the plots of 125 x 125 m in area

and gradual transition to a random distribution, within a radius from 4.5 to approx. 7 km. Then, at distances of approx. 7.5 to 9.5 km, spatial distribution became regular, and above this values, it returned to random type (Fig. 5).

Most individuals of black cherry were recorded in the woods. Forest habitats comprised 46% of their total number and 62-67% of individuals from shrub and tree layers. On the other hand, the largest group of the youngest individuals of the species (48%) was found on abandoned farmlands and approx. 20% – in forests and thickets (Fig. 6). In forests, the black cherry occurred mostly under Scots pine and mixed tree-stands on fresh habitats. The species did not colonize bog forests with alder at all.

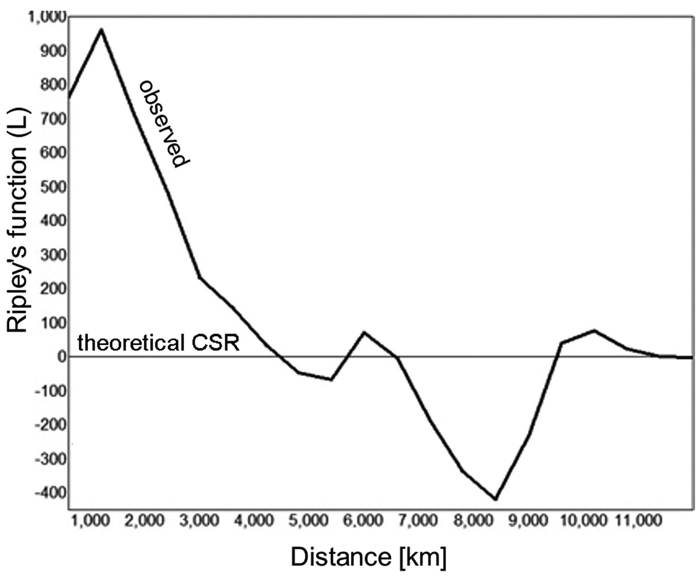

Fig. 5. Theoretical random distribution (CSR) of the number of individuals of *Padus serotina* versus distribution observed in nature, based on the analysis of the modified Ripley's function (L)

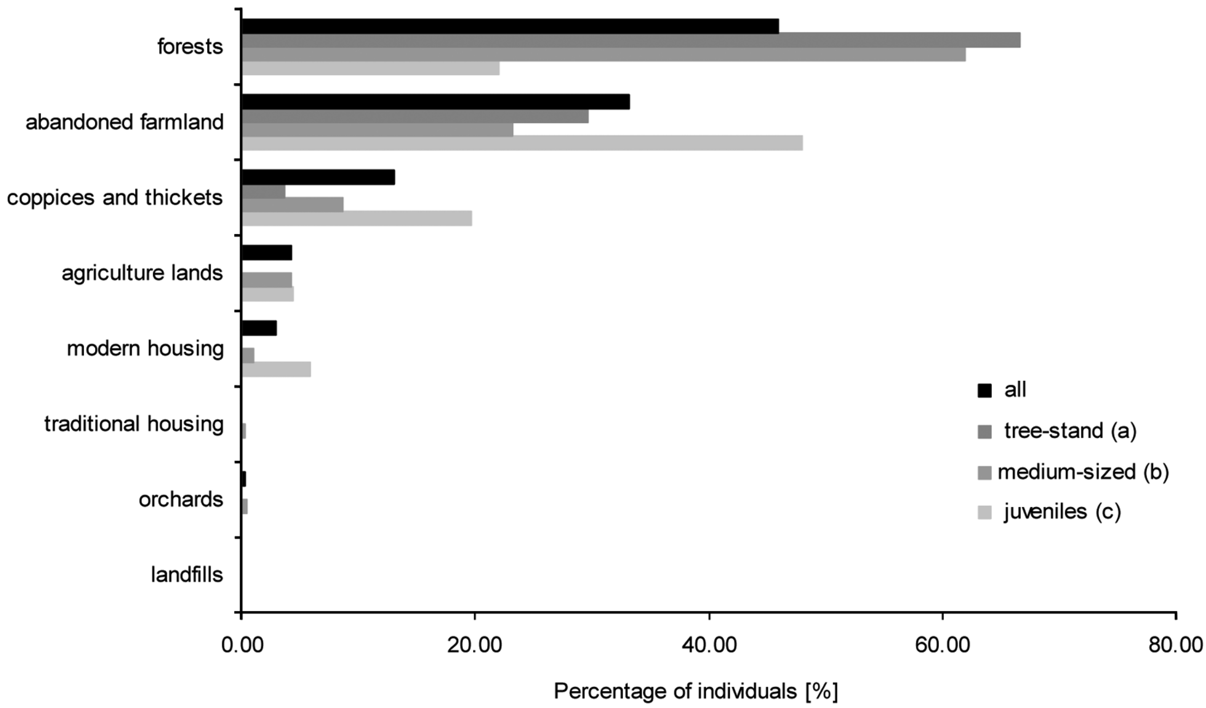

Fig. 6. Occurrence of *Padus serotina* in the habitats of different type

Data on the effectiveness of dispersion were provided by the analysis of the distance of juvenile plants, not exceeding the height of 0.5 m, from higher individuals of the species (Fig. 7). Over 70% of all youngest individuals were recorded at a distance of up to 10 m from older ones, and 91% – up to 100 m from them. This type of autocorrelation relationship can also be analyzed as the chance of appearing of individuals in isolation, at a greater distance from neighboring locations of the species. The chances of such events are small and the probability of the occurrence of black cherry in a given area is strongly dependent on the occupation of adjacent areas by the species. Within the radius of 10 m around each location, we can find another specimen of the spe-

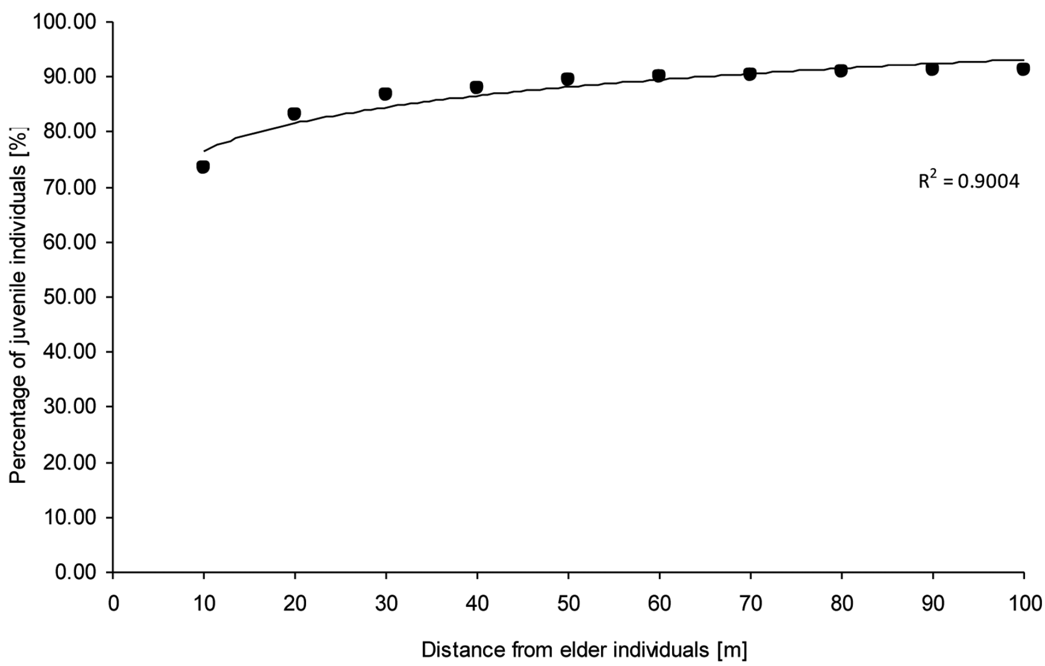

Fig. 7. Proportion of *Padus serotina* juveniles dependent on the distance from elder individuals

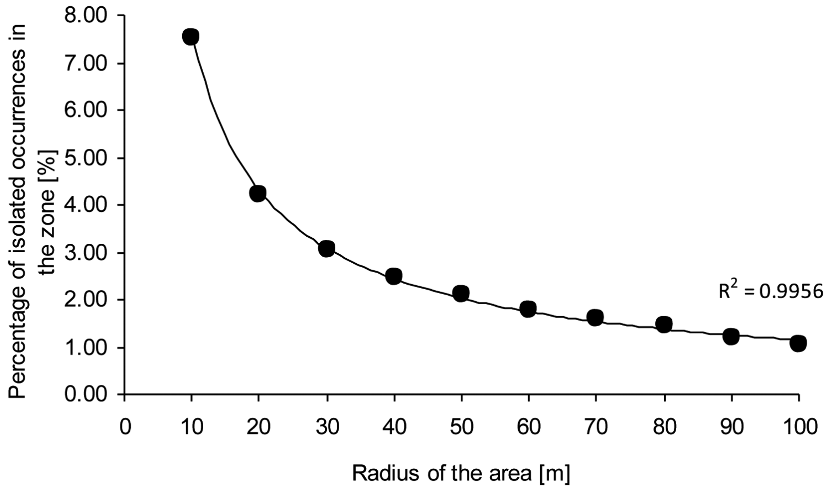

Fig. 8. Proportion of isolated occurrences of *Padus serotina* individuals in the areas of different size

cies in 92.5% of cases. Within a radius of 100 m, this happened in 99% of cases (Fig. 8).

The habitat diversity of the southern part of Białystok agglomeration, as measured by Simpson's coefficient, reached the maximum value of 0.81 (0.34 in average, median 0.38). The maximum value of the landscape mosaic coefficient was 0.87 (0.4 in average, median 0.46). The lowest habitat mosaic as well as diversity was characteristic for the vast areas of agricultural land and large, dense forest patches. The average habitat diversity in the plots (of 1 km^2 area) colonized by *P. serotina* was 0.35, whereas in those which were not colonized – 0.31. Simpson's coefficient values for habitat mosaic were, respectively, 0.41 and 0.37. In both cases, the differences were statistically significant. The plots occupied by the alien species were also characterized by significantly higher average proportion of abandoned farmlands and build-up areas, but only of modern type, developed recently (Fig. 9). The percentage of forest, coppices and thickets as well as traditional housing was almost equal both in case of colonized and not colonized by *P. serotina* parts of the surroundings of Białystok.

4. Discussion

The frequency of occurrence of black cherry in habitats of different type significantly changed in the course of expansion. Undoubtedly, first sources of spread were localities in forests, where offspring populations,

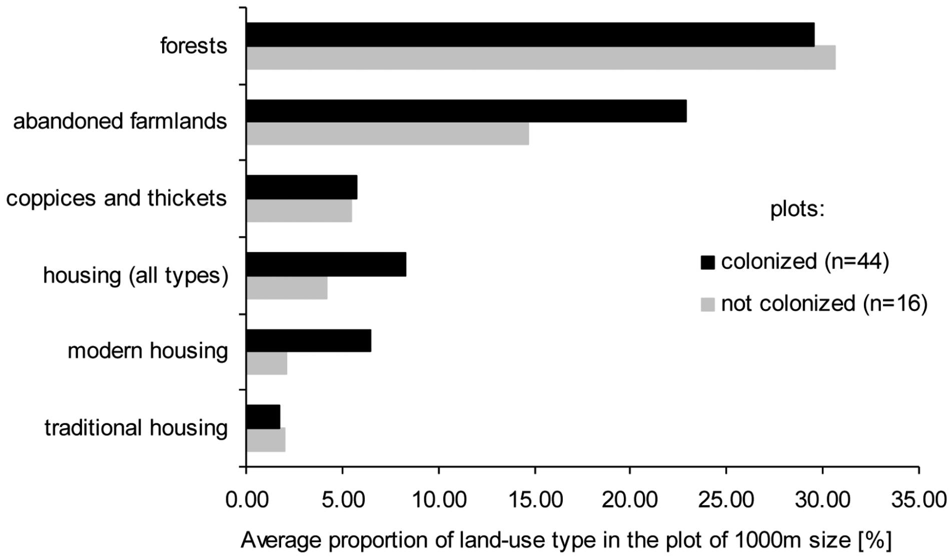

Fig. 9. Comparison of proportion of different land-use types in the areas colonized and not colonized by *Padus serotina*

originating from the individuals intentionally planted under the canopy of tree-stands, were present (Halarewicz 2011a, 2011b). With the increase in the density of understory, shadowing of the forest floor and the competition, further growth of forest populations of black cherry may be inhibited. The next stage of expansion followed with changes in land-use on areas adjacent to forest patches and on glades in their interiors. Over time, seedling recruitment became more effective on abandoned farmlands in such localities.

The main factors influencing landscape susceptibility to expansion of *P. serotina* were processes of suburbanization and, first of all, cessation of agriculture. Changes in land-use resulted in the appearance of unexploited areas of weakened competition which could be easily colonized by alien species. The consequence of such processes was also an increase in landscape fragmentation, as well as diversity and mosaic of habitats (With 2002). Vast forest areas, as well as agricultural landscape were least susceptible to expansion of *P. serotina*.

Landscape structure also affected the distribution and behavior of frugivorous birds, non-randomly dispersing seeds of *P. serotina* (Deckers *et al*. 2008). Birds collected fruits of black cherry more likely on forest edges. The effective recruitment of seedlings from dropped seeds was probably more frequent in open spaces directly adjacent to forests.

The effect of suburbanization on invasibility of the landscape seems to be indirect and of secondary importance. Gardens and public green areas in new-built housings were not the places of black cherry cultivation at all, so they could not be primary foci of its spread. Suburban settlements developed mainly on land where agriculture was previously ceased. There were usually large areas of abandoned farmlands in their vicinity. In addition, the development of new housings was connected with different disturbances and damages of vegetation cover, as a consequence of earthworks, debris and waste disposal. Such changes extremely weakened the competition abilities of the communities of native species.

The population spatial distribution also changed during the expansion. The results of analyses of the neighborhood (with modified Ripley's function) provided clear evidence of it. This phenomenon is well known and frequently described in literature (Tilman & Kareiva 1997). Alien species disperse, primarily, according to spatial patterns of phalanx, by occupying areas immediately adjacent to places previously colonized and then filling the available habitats. Populations grow around initial posts and, locally, a rapid increase in the density of individuals takes place there. At the same time, secondary randomly distributed foci of expansion sporadically appear which initiate development of further clusters of species in the next phase. Nevertheless, long-distance dispersal of propagules seems to play a minor role in the expansion of *P. serotina*. Establishment and development of new outbreaks of invasion, substantially separated from the main areas inhabited by the species, are incidental (Deckers *et al*. 2008). Autocorrelation and diffusion models seem to be appropriate to predict further range of expansion of *P. serotina* on a regional scale (Hastings *et al*. 2005; Dorman 2007; Sebert-Cuvillier *et al*. 2008).

The population of black cherry expanded centrifugally in the surroundings of Białystok, spreading from the fringes of the city to outer zones of agglomeration with more agricultural character. Such an advance in expansion of alien species reflected changes in land-use ongoing in the same pattern. Cessation of agriculture occurred much more frequently in areas located closer to the city outskirts. The observed pattern of expansion of *P. serotina* confirms concepts concerning the role of urban centers in zonation and acceleration of changes in mutual relationships of native and alien species, forming anthropogenic flora (Jackowiak 1998).

Diffuse spread of the species should be taken into account in preventing its further expansion and planning conservation measures. Elimination of black cherry should be carried out in concentric zones projecting around the localities of endangered plant species and their habitats. This rule as well as a relatively low density of the population in the suburban area suggests that active removal treatment of *P. serotina* can succeed in natural protected areas, at least on a local scale.

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