

## Assessment of sea buckthorn (*Hippophaë rhamnoides* L.) long distance dispersal on the internal waste heap of the Belchatów lignite mine

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**Abstract.** Long distance dispersal is a key process occurring in plant communities and is particularly important for pioneer species like sea-buckthorn (*Hippophaë rhamnoides* L.) which survival strongly depends on colonizing newly created post-disturbance habitats. Sea-buckthorn, a cluster-forming shrub, is commonly used in Poland in the reclamation of soil-less areas devastated by mining industry and for these areas a generative expansion of planted populations is usually observed. The main objective of this study was to assess the long-distance dispersal of this species in areas previously disturbed by industrial activity. Our observations were made on a 223.75 ha large section of the internal waste heap of the Belchatów lignite mine, Central Poland. The area was colonized by sea-buckthorn specimens originating from a population planted on the nearby external waste heap. During the search for newly established sea-buckthorn clusters, their position and size were recorded and the preferences for specific site conditions were assessed using the Ivlev's electivity index. New specimen were observed at distances between 600 m and 3600 m from their potential seed source. The mean cluster density was 1.37 ha<sup>-1</sup>. The observed pattern of long distance dispersal is linked with to behavior of frugivorous birds. The largest cluster densities were observed along ditches (9.83 ha<sup>-1</sup>) and on open areas with less developed plant cover, while the lowest cluster density occurred in afforested areas (0.51 ha<sup>-1</sup>). Poor sandy substrate reduced the probability of plant establishment compared to richer loamy sands. There appeared to be no influence of slope aspect on the probability of sea-buckthorn establishment.

**Keywords:** long distance dispersal, sea-buckthorn, soil conditions, slope aspect

### 1. Introduction

Common sea buckthorn (*Hippophaë rhamnoides* L.) occurs naturally in Poland only along the shores of the Baltic Sea (Kapuściński 1978; Surminski 2008). It is most often found on the cliffs where sea waves washing the banks quite frequently result in the formation of landslides revealing soilless areas. Sea buckthorn effectively 'finds' and colonizes new areas as a result of generative expansion (mainly zoochoria). It is a typical pioneer species, which by its presence stabilizes the substrate, increases the availability of nitrogen in the emerging soil through its leaf litter and improves the growth conditions of other plants. Beech (*Fagus sylvatica* L.), sycamore (*Acer pseudoplatanus* L.) and other tree species of further succession stages are

often renewed in the thickets of sea buckthorn, overgrowing and eliminating it over time from the claimed habitat (Kornaś 1977). Its weakness in competition with late-successive species makes the survival of common sea buckthorn highly dependent on its ability to disperse to new, often distant areas. Long-distance expansion, an important aspect of the ecology of this species, has only been mentioned in the literature (Zalewska 1955; Pearson, Rogers 1962) and has rarely (Bolibok et al. 2009) been the subject of study.

Researching the long-distance dispersal of sea buckthorn on cliff landslides in natural habitats is difficult for methodological reasons. According to Levey et al. (2008), in the case of long-distance dispersal (over 150 m), the density of seeds reaching a unit of area decreases sharply with distance, with

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at most 1% of the total seed production dispersing over long distances (Cain et al. 2000). The relatively small area of landslides and the large dispersal distance result in the fact that a potentially scant percentage of seeds will reach such a location. This may be sufficient for the population of this species to function, but it is not enough to describe its expansion using quantitative methods.

The fact that sea buckthorn grows well in soilless areas has resulted in its use for many years in the reclamation of degraded areas (Greszta, Morawski 1972; Kluczyński 1979), where it is easily spread generatively (Bolibok et al. 2009). The expansiveness of sea buckthorn can cause serious economic problems. In some regions of Poland, for example, in the Olkusz Forest District, the sea buckthorn introduced for reclamation purposes is spreading in afforested areas, constituting serious competition for the intentionally renewed species. In the Bełchatów Forest District, clusters of sea buckthorn are overgrowing and blocking several forest roads within an external waste heap. Understanding the potential and determinants of sea buckthorn expansion may have practical implications for forest management in regions where the introduction of this species is planned.

Using the open-pit method to mine lignite in Poland creates very extensive soilless areas, devoid of vegetation. The very large spatial scale of these areas increases the possibility of finding a large enough number of new sea buckthorn individuals so that conclusions can be drawn about the mechanisms of its expansion. Common sea buckthorn was introduced artificially on an external heap to stabilize the accumulated waste material at the Bełchatów Mine (Krzaklewski 1978). The sea buckthorn population established there is a strong, concentrated (at the scale of the landscape) primary source of seeds, from which it began to spontaneously spread over vast areas of the internal waste heap (where

it was not intentionally planted). The aim of this article is to assess the long-distance dispersal of common sea buckthorn on the internal waste heap of the Bełchatów Mine, with particular emphasis on the factors affecting the density of the clusters of this species in the studied area.

## 2. Study area

The research was carried out in 2008 on the eastern part of an internal waste heap of the Bełchatów Mine (51°13'50"N; 19°22'15"E). As of 1989, the overburden seams began to be deposited in the exploited out part of the excavation of Bełchatów lignite field. The final shape of the above-ground part of the internal dump was gradually formed from the eastern side as of 1994 (Krzaklewski 2000). It was then that the areas became available for colonization by common sea buckthorn, as they were no longer to be disturbed by further formation work. The internal heap made of overburden material forms a hill towering 40–50 m above the adjacent area. The heap slopes have an inclination of 1:4 and are interrupted by horizontal shelves and transportation terraces. The surface of the dump is covered with sands with variable admixture clay and silt fractions and by loams with a granulometric composition from loose and weakly loamy sands through loamy sands to sandy loam (Krzaklewski 2000). The features of these materials suggest that poor quality habitats (suitable for less demanding coniferous and mixed coniferous forests) will prevail there in the future.

## 3. Study methods

Field work was conducted in the finished part of the internal waste heap, where access was not prohibited in 2008 (marked in Figure 1 in grey), covering an area of 223.75 ha. The study did not include the lacustrine chalk heap loca-

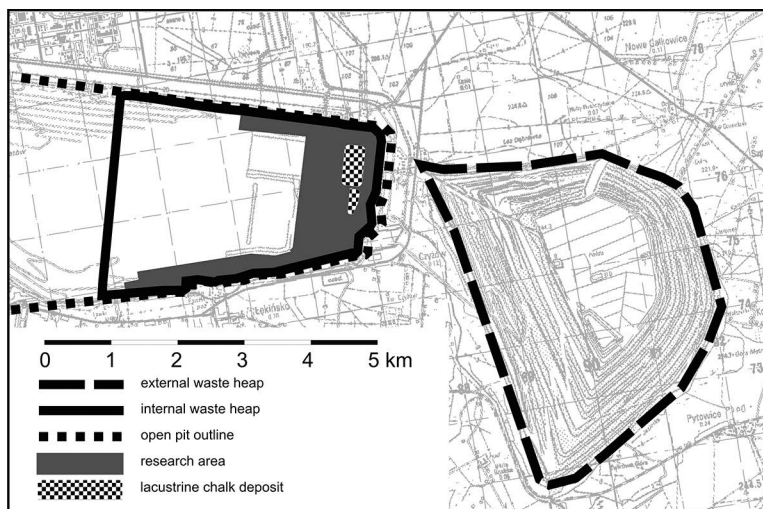


Figure 1. Localization of research area

**Table 1.** Surface share of different fragments of research area

Code	Fragment description	Area [ha]	Share [%]
D	roads with berms	8.96	4
T	open non-afforested areas	22.37	10
O	sediment fields	8.95	4
P	setting ponds	2.24	1
R	ditches	8.94	4
Z	areas afforested until 2008	161.10	72
W	embankments	11.19	5
	total area	223.75	100

ted on the object's uppermost area. During the field work, clusters of common sea buckthorn were searched and their location in the field and their diameter was recorded.

Using the cartographic materials provided by the mine administration, the proportion of characteristic fragments of the waste heap within the study site were determined (Table 1). Based on a map of the location of soil pits and distinguished soil types (Krzaklewski et al. 2000), the frequency of the occurrence of various soil types found in the eastern wooded part of the internal waste heap were estimated. On the basis of this map, each location of sea buckthorn in this area was assigned to the appropriate type of soil, taking into account the description of the nearest soil pit.

In order to determine the preferences of sea buckthorn in relation to the available habitat conditions, we used Ivlev's electivity index  $E_i$  (1961):

$$E_i = \frac{r_i - p_i}{r_i + p_i},$$

where:

$r_i$  – the use of a given habitat  $i$  (e.g., the share of sea buckthorn clusters observed in ditches in relation to the total number of observed clusters),

$p_i$  – share of habitat  $i$  in the environment (e.g., share of ditch area in the total area of the study site).

The  $E_i$  index has values from -1 (total avoidance of a given habitat), through 0 (a given habitat is used proportionally to its availability), up to 1 (very frequent use of a given habitat).

Parallely to  $E_i$  index calculation, the hypothesis about the randomness of the use of individual habitats by the sea buckthorn was tested with the use of chi-squared test.

When the hypothesis of random habitat use was rejected, we used the Bonferroni correction to calculate the confidence intervals needed to indicate that habitats were selected more often or less often than would be expected in the case of random selection (Neu et al. 1974).

## 4. Results

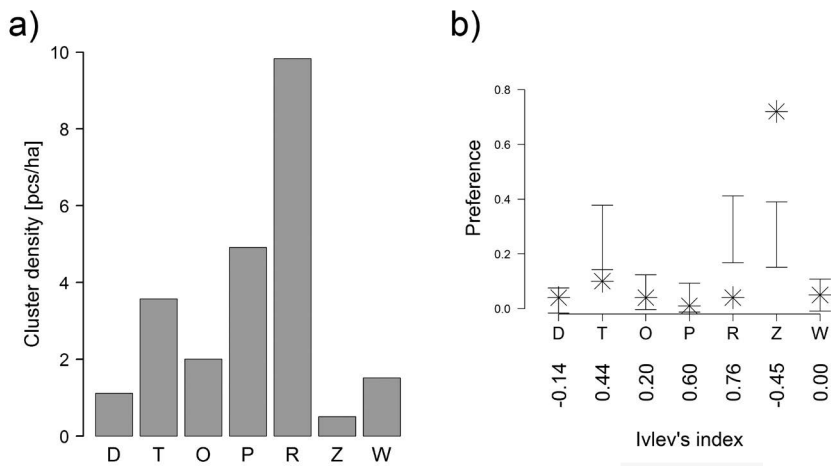
306 common sea buckthorn clusters were found in the study site (average density of 1.37 clusters/ha). The found clusters of sea buckthorn were diversified in size, and the older female plants bore fruit. The farthest cluster from the external waste heap, the size of which suggests that it originated from seeds coming from the population established on external heap, was located 3.6 km from the base and 6 km from the centre of this heap. The density of clusters observed on characteristic fragments of the waste heap is shown in Figure 2a. The highest density of common sea buckthorn clusters was observed in the parts of the heap relating to the drainage system (ditches and setting ponds as well as in open areas, while the smallest densities were found in the forested areas. The occurrence of common sea buckthorn in particular categories of areas was not random (Figure 2b). Clusters appeared more often than randomly in the vicinity of ditches and open areas, but their avoidance of forested areas was statistically significant. The values of the Ivlev index correspond with the results of the statistical analysis. According to this criterion, ditches ( $E = 0.76$ ) and open areas ( $E = 0.44$ ) are the most preferred habitats, while wooded areas are most avoided ( $E = -0.45$ ). The Ivlev index gave a high positive value for setting ponds ( $E = 0.60$ ), but this preference was not confirmed statistically. Analysis of the occurrence of common sea buckthorn in the forested areas of the internal waste heap (Figure 3a) showed that the areas with the potentially poorest soil deposits (PL – loose sands and PLP – sand with silt admixture) had the smallest density of clusters (about 0.2 specimens/ha), two times smaller than the density on more fertile soils (PSG – loamy sand with lesser clay content, PGL – loamy sand). The chi-squared test confirmed a negligible probability of the random occurrence of such differences in the density of clusters in the potentially poorest habitats (Figure 3b). Also, the negative valu-

es of the Ivlev index indicate the common sea buckthorn's avoidance of the areas with the poorest soils. No significant differences were found when comparing the density of clusters on the various exposures of the waste heap slopes (excluding the wooded areas, because afforestation can modify the impact of the exposure). The Ivlev index showed values close to 0 (exposures of  $E = -0.02$ ,  $N = -0.12$ ,  $S = 0.06$ ) for the compared areas, which indicates the common sea buckthorn's lack of a clear preference to exposure. Also, testing the randomness of the shrub's presence in areas with different exposures did not confirm the statistical significance of the differences between them. Different density of common sea buckthorn clusters in the afforestation established in dif-

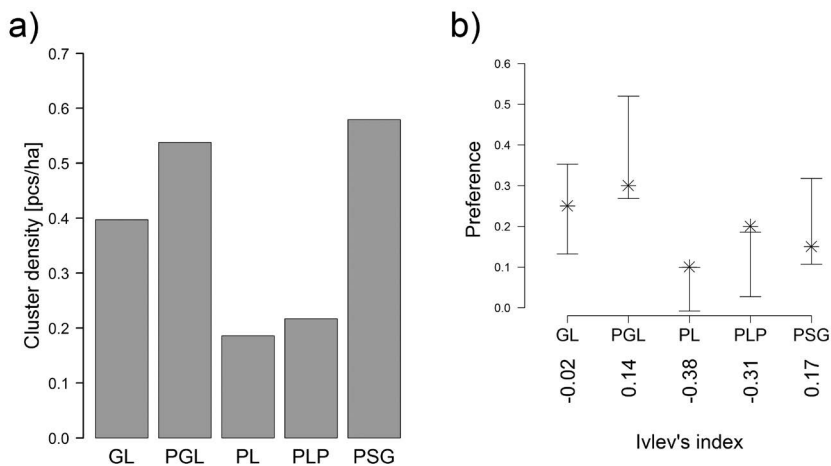
ferent years were observed in the studied area (Figure 4), but there was no increase in the density of the clusters associated with the growing age of the afforestation. However, we observed a trend of an increased number of clusters along with a decreased size of the cluster (Figure 5).

### 5. Discussion

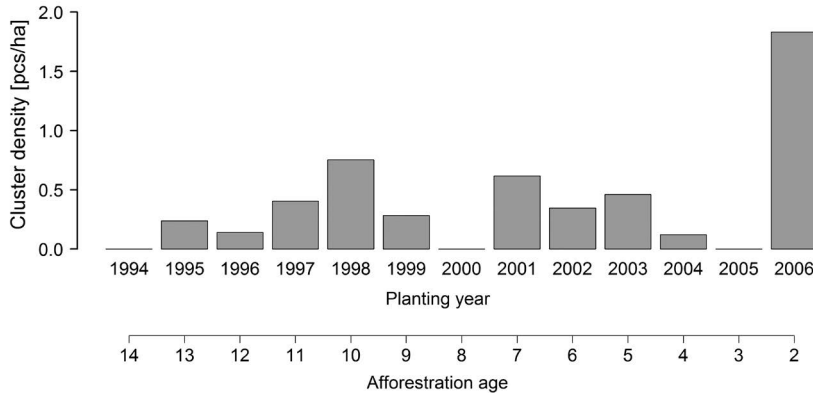
Extensive areas of reclaimed land provide a unique opportunity to study the processes relating to landscape heterogeneity occurring at large spatial scales (Bell et al. 1997). The distance of the internal waste heap from the original source of seeds (Figure 1), as well as the large diversity of habitats



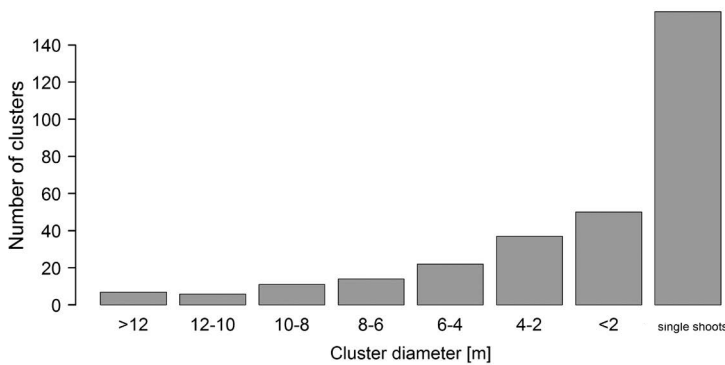
**Figure 2.** Density of sea-buckthorn clusters detected on different parts of internal dumping ground (descriptions as in tab. 1) and assessment of sea-buckthorn preferences to particular areas (test for non-random use of habitats and Ivlev's index)



**Figure 3.** Density of sea-buckthorn clusters detected on afforested eastern part heap hilltop on different soils (GL – sandy loams, PGL – loamy sand, PL – loose sand, PLP – sand with silt admixture, PSG – loamy sand with lesser clay content) and assessment of sea-buckthorn preferences to detected soils (test for non-random use of habitats and Ivlev's index)



**Figure 4.** Density of sea-buckthorn clusters observed in afforestation of different age



**Figure 5.** Numbers of sea-buckthorn clusters in different size classes

associated with the reclamation process (Table 1) allowed us to study the selected factors determining the success of long-distance dispersal of common sea buckthorn seeds. It is worth emphasizing that seed dispersal over relatively large distances was analysed. The study area extends from 600 m to 4700 m from the base of the external waste heap. Directly documenting long-distance seed dispersal is usually very difficult (Cain et al. 2000). The long distance from the original seed source and the size of the study site makes it very difficult to practically use methods based on the direct observation of seed-dispersing animals (Malmborg, Willson 1988; Alcántara et al. 2000); the low density of actual seed fall makes it impossible to draw conclusions based on the data collected from seed traps (Alcántara et al. 2000; Levey et al. 2008). In the study of the internal waste heap, the ‘a posteriori’ method was selected based on the analysis of the occurrence of common sea buckthorn clusters that colonized the area (Hewitt, Kellman 2002). Assessment of long-distance dispersal on the basis of the reported cases of colonists is one of the main methods of studying this phenomenon (Nathan et al. 2003) and often used in this type of

work (Dzwonko, Loster 1992; Matlack 1994; Brunet, Von Oheimb 1998). Assessing dispersal based on the occurrence of newly settled specimens may be burdened with a certain error due to various environmental filters affecting the survival of seeds and seedlings (Kollmann 2000). However, reaching a new location is a basic condition for colonization and this is why some researchers attribute it with decisive importance (Robinson, Handel 1993). In long-distance seed dispersal studies (Cain et al. 2000; Nathan et al. 2003), great importance is attached to determining the empirical distribution of the observed dispersal distances. Due to the spread of the common sea buckthorn population over a large area of the external waste heap (source), it was impossible to indicate objectively the point from which the distance should be calculated. For this reason, the analysis focused more on the preference of sea buckthorn in relation to the habitats it settled in than on directly determining the dispersal distance.

Female specimens of common sea buckthorns begin to bear fruit in their 2–3 year of life (Pearson, Rogers 1962) and potentially can become a secondary source of seeds relatively quickly in the colonized area. Spreading over the

land by dispersing seeds from the farthest-out individuals is a faster way to colonize an area than by seed dispersal from the main line of the colonization front (Matlack 1994). Probably, however, the initial low concentration of sea buckthorn clusters on the internal waste heap made it difficult to use this strategy because the female specimens must be relatively close to the males to bear fruit. This is such an important factor limiting the production of seeds that in sea buckthorn orchards from 6 to 12% of planted specimens are males (Li, Schroeder 1996). Two premisses may provide evidence for such a limitation of expansion. During the field studies, very few cases of younger satellite clusters were found around the older female clusters that could have originated from seeds already produced on the internal waste heap. Meanwhile, such situations occurred relatively more frequently on the external waste heap, where we found a greater density of clusters (Bolibok et al. 2009). The second promise is related to the observed frequency of clusters of various size classes (Figure 5). There is a strong relationship between the diameter of the sea buckthorn cluster and its age (Bolibok et al. 2009). The number of clusters in the four largest size classes (the oldest) is very similar, then the numbers gradually begin to increase and only rapidly increase in the smallest size class (the youngest). This may suggest that the research on the internal waste heap was conducted at the beginning of the period when the importance of secondary seed sources in the colonization of this area was starting to increase.

The opinion on the dominant role of birds in common sea buckthorn dispersal is mentioned in many descriptions of the ecology of this species (Pearson, Rogers 1962; Ranwell 1972; Lu et al. 2006). For this reason, the interpretation of the observed spatial variation in the density of sea buckthorn clusters should be made primarily in reference to the behaviour of birds feeding on its fruits, as described in the literature. The average density of clusters on the internal waste heap (1.37 specimens/ha) colonized from seed sources located at least 600 meters from the study site was more than two times smaller than the density found by Bolibok et al. (2009) during research on the external waste heap (3.2 specimens/ha), which was probably colonized mainly by seeds originating from clusters located at a distance of not less than 250 meters. The negatively exponential decline in the density of renewals with increasing distance from a potential source of seeds is well documented in publications analysing ornithochromia (Willson 1993; Alcántara et al. 2000). However, this is only a general trend, and in practice, the density of dispersed seeds may be quite variable at the same distances away from the seed source and strongly related to the spatial differentiation of the landscape (Haas 1995; Kollmann, Schneider 1999) and vegetation (McDonnell, Stiles 1983; McDonnell 1986; Malmberg, Willson 1988). Diversity in the density of common sea buckthorn in various parts of the

internal waste heap (Figure 2) is consistent with such observations. The particularly high density of sea buckthorns in the ditches on the heap corresponds with the data describing the impact of ditches on the movement of birds in the landscape (Arnold 1983; MacDonald, Johnson 1995; Parish et al. 1995; Hinsley, Bellamy 2000). A large number of these publications indicate the positive impact of ditches on its 'attracting' role to other structures (e.g., hedges), but some publications directly indicate that ditches (Arnold 1983) or streams (Bartuszevige, Gorchov 2006) may be a more attractive place for birds than open (field) spaces.

Afforested areas, which were at the early stages of development (seedlings and young trees) during the study period, were found to be extremely unfavourable habitats for the colonization of common sea buckthorn. The presence of trees or other raised objects attracts birds and increases the seed fall around them (McClanahan, Wolfe 1993; Robinson, Handel 1993, 2000), because birds prefer higher 'perches' (McDonnell 1986; Robinson, Handel 1993; Kollmann 2000) and usually avoid a few years old afforested areas. Also, afforestation in the thicket phase, although higher, is not very attractive for fruit-eating birds, which usually avoid dense forest fragments and concentrate on its edges or in the vicinity of gaps within the tree stands (Thompson, Willson 1978, Malmberg, Willson 1988).

The variability of the density of common sea buckthorn clusters in afforestation established in various years (Figure 4) does not indicate that with time, new clusters of sea buckthorn would begin growing in them. This may suggest that a forested area may be available for generative sea buckthorn growth only for a short period of time at the beginning of afforestation. This probably relates to the high demand of this species for light and its intolerance of shade (Pearson, Rogers 1962). The factor of light availability may be responsible for the higher than average, statistically confirmed density of common sea buckthorn clusters in open areas (Figure 2). In the study period, herbaceous vegetation of various densities occurred there, but it was definitely less abundant than in the sediment fields, where smaller densities of clusters were observed. An additional factor limiting the colonization in the afforestation by seed dispersal may be their large proportion of pine. The acid litter produced by this species modifies the pH of the topsoil in an unfavourable direction for the common sea buckthorn (Bolibok et al. 2008).

The comparison of the density of common sea buckthorn clusters in the afforested waste heap areas differing in the granulometric distribution of the substrate (Figure 3) indicates that other factors not related to seed dispersal influence the success of common sea buckthorn colonization. Although the average density of the clusters is small in the forested areas, it was particularly low in areas of loose and loose silty sands, soils with potentially the lowest fertility and water

retention capacity among those found in the wooded area. Probably this type of substrate had the least favourable conditions for the growth of common sea buckthorn seedlings.

The topography of the area can potentially influence the course of succession in degraded areas (McChesney et al 1995; Bell et al. 1997; Wali 1999; Martínez-Ruiz, Marrs 2007). The slope exposure can potentially modify the conditions for germination and plant growth due to differences in insolation (Bolibok et al. 2015), which is particularly important in the case of very light-demanding common sea buckthorn (Li, Schroeder 1996). Although other studies (Bolibok et al. 2009) found that growing clusters of common sea buckthorn modify their structure depending on geographical direction, the current study did not find that waste heap slope exposure had a significant impact on their density.

### Conflict of interest

The authors declare no potential conflicts of interest.

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The authors' own research.

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### Authors' contributions

L.B., M.K. – study concept and development of study methods, field work, compilation and analysis of data; L.B., M.K., S.M. – literature review, manuscript preparation; L.B., S.M. – editing, corrections and coordination.