Development and approbation of methodology for monitoring invasive plant species: the Case of Latvia

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Abstract: Categorisation of invasive alien species based on their impact is an important way to improve the management of biological invasions. The impact of 35 alien plant species in Latvia was evaluated based on information in the literature and certain studies of their environmental and socio-economic impacts. As a result, 15 priority monitorable species, or the Black List, have been evaluated, for which seven of the nine criteria set were met. The other 20 invasive plant species make up the list of monitorable invasive plants, or the Grey List. The list and methodology developed during the study were approbated in the vegetation season of 2016 in 16 randomly selected monitoring quadrates, which were further stratified according to geobotanical regions of Latvia, which is proportionally 1,57% from all 1017 quadrates of Latvia. In total, 34 alien species were identified during approbation of methodology as showing signs of invasiveness: 10 from Black List, 10 from Gray List and 14 other invasive species, not included in the monitorable species list of developed monitoring methodology. In general, half of the species found during approbation of the methodology are trees and shrubs that were deliberately imported into Latvia in the past to be used in landscape gardening. A large proportion (41%) of the invasive species encountered come from North America. The most commonly encountered invasive species are *Elodea canadensis* Michx., *Impatiens parviflora* DC. and *Solidago canadensis* L. The data obtained through the field approbation show that the areas rich in invasive species are covered by forests and transit corridors, but the areas where no invasive species have been detected are transition mires and raised bogs as well as intensively managed farmland. Following the developed methodology, it was concluded that 50% of the quadrates to be monitored should be randomly selected while maintaining the principle of geobotanical regions, while the other 50% should be selected in previously known invasive plant populations.

Keywords: alien plant, invasion, habitats, regional distribution, monitoring, Latvia.

Introduction

Invasive species are a growing problem, both economically and ecologically (Nielsen & Fei 2015). Invasive species are currently considered to be an important element of global change and their impact on local species and ecosystems, as well as on human society, is an important topic of numerous studies (Lodge 1993a, b; Simberloff 1996; Vitousek et al. 1996; Rabitsch & Essl 2006; Rutkovska et al. 2009). As these species continue to spread and invade new regions, managing to reduce their impacts becomes crucial (Byers et al. 2002; Ricciardi et al. 2013; Nielsen & Fei 2015). Some of these alien species become invasive and pose threats to the environment and human economy and health (Elton 1958; Kornas 1990; Vilá et al. 2000; Pimental 2002; European Commission 2004; Hulme et al. 2009; Tokarska-Guzik et al. 2010). These trends have dramatically increased in recent centuries and adversely affect native biodiversity on regional, national and global scale (Tokarska-Guzik et al. 2010, 2012; Seebens et al. 2017). Managers often face a suite of invasive species and large infested areas, making it necessary to prioritise management actions (Hiebert 1997; Skinner et al. 2000; Nielsen & Fei 2015). In order to set priorities for management of invasive species in Latvia, a number of preparatory activities are required. Investigations of invasive alien species are required to assess the current situation in Latvia and gain a scientifically-based awareness of the necessary actions for the introduction of invasive species control systems (Priede 2008c).

Latvia and other Baltic countries are situated on the border of the European, Scandinavian and Siberian species distribution ranges, and the Baltic region is an ancient agricultural land with ancient transport routes; this means that the flora is relatively rich here. According to Gavrilova & Šulcs (1999), the flora list of Latvia contained 1937 vascular plant species: 1304 were of native origin, while 633 were alien species. According to the data of Daugavpils University herbarium database (Evarte-Bundere et al. 2019), 1944 species of vascular plants were found in Latvia, at least 640 (33%) of the number of species of flora in Latvia are considered to be alien species. According to NOBANIS – North European and Baltic Network on Invasive Alien Species – list data, 36 alien plant species in Latvia are considered invasive, 12 are potentially invasive and 176 are not considered to be invasive in Latvia. No information has been available about 192 species (Anonymous 2019a). The list of alien species has not been critically revised and edited since 1999, when the last list of Latvian vascular plants (Gavrilova & Šulcs 1999) was published, it needs to be edited and the exact number of species must be published. For example, in Estonia, of the 1441 vascular plant species (Kukk 1999), 787 (55%) are considered to be alien species (Ööpik et al. 2008; Elvisto et al. 2016), while this number is only 548 in Lithuania (Gudžinskas 2011).

Over the past two centuries, Latvia has accumulated a lot of material on alien flora, both in the form of literature and herbarium, and notes, which makes an indispensable base of information for modern research. The first reference to alien flora dates back to the works published in the late 18th century and the beginning of

the 19th century; for example, Fischer (1778), Grindel (1803), Wiedemann & Weber (1852), and others. Since the second half of the 20th century, the interest in this subject and hence the number of studies has increased (Klinge 1887; Lehmann 1895; Kupffer & Lackschewitz 1904; Rothert 1915; Priede 2008c). Compared to Western European countries, few studies on invasive plant species have been conducted in Latvia during the recent decades. A few publications are based on herbarium data, while others merely studied the distribution of species (Cepurīte 2002; Priede 2008a, b, c; Rutkovska et al. 2009, 2011a, b, 2013, 2017; Gavrilova et al. 2011; Evarts-Bunders et al. 2012, 2016a, b). A number of studies have been conducted on *Reynoutria japonica* Houtt. and *Reynoutria sachalinensis* (F. Schmidt) Nakai (Laiviņš 2003), *Bunias orientalis* L. (Laiviņš et al. 2006; Priede & Laiviņš 2007), *Solidago canadensis* L. and *Solidago serotinoides* A. et D. Löve (Priede 2008b) and *Sorbaria sorbifolia* (L.) A. Braun (Laiviņš 2008). One of the latest publications is about the invasive species of the Brassicaceae family (Rūrāne et al. 2018).

Awareness of invasive species distribution is a prerequisite for assessing the invasiveness status and prevalence of invasive species, as well as the potential threat to native plant communities and species (Priede 2008c). The purpose of national-scale monitoring of invasive species is to provide information on changes in the extent of populations of these species in the country, as well as to assess the impact of these invasions on natural and semi-natural ecosystems. After development of the methodology for monitoring of invasive species, it was approbated in 16 (500 x 500 m or 25 ha) quadrates, where data on new populations of invasive species were obtained, population size and the more exposed biotopes to the risk of invasions were determined. Monitoring of invasive species is targeted as non-species specific; all species indicated in the list of invasive species were encountered (identified by the respective method), as well as new invasive species are recorded, thus obtaining data on potential "early warning" species that are just beginning to show invasiveness tendencies, and there is a lack of data on their occurrence in Latvia. The data obtained will be used to determine the effectiveness of various land management measures and activities aimed at semi-natural ecosystem restoration by eradicating and controlling invasive species.

In the Baltic countries, the experience of monitoring invasive organisms is not large. Lists of invasive species in Lithuania (Rašomavičius et al. 2012) and Estonia (Ööpik et al. 2013) have been defined, and plant species have been mapped at national scale, generating the database of species distribution and species atlases; for example, data on invasive species in Estonian flora is collected in the atlas of species distribution (Kukk & Kull 2005), where the mapping of species is repeated every ten years, and mapping in Estonia has taken place again since 2015. In Lithuania, the studies on invasive species occur similarly – mapping of invasive species, exploration of new localities, and monitoring methodology is currently under development. In Belarus, as well as in Russia, research into invasive species is taking place at the level of invasive species evaluation and distribution, with

emphasis placed on the list of invasive plants developed by botanical botanists (Dubovik D., Skuratovich A., personal communication).

The current official list of invasive alien plants in Latvia includes only *Heracleum sosnowskii* Manden. (Anonymous 2008); no other invasive plant species are included in the document. The aim of the research is to compile a list of invasive plant species in Latvia, to define the priority invasive plant species to be monitored, and to elaborate and approbate the methodology of invasive species monitoring.

Material and Methods

Study area

The climate in Latvia is determined by its location in the temperate climate zone at the shores of the Baltic Sea and the Gulf of Riga. Further away from the sea, continentality become more expressed. The average annual air temperature in Latvia is +5.9°C. The warmest month is July with an average temperature of 17.0°C, while the coldest months are January and February, with average temperatures -4.6°C and -4.7°C, respectively. To date, the highest air temperature in Latvia of +37.8°C was recorded in Ventspils on the 4th of August 2014, while the lowest temperature of –43.3°C was recorded in Daugavpils on the 8th of February 1956. The average annual precipitation is 667 mm, and the average relative humidity is 81%. The sun shines averagely for 1790 hours a year, which is approximately half of the possible sunshine duration (in clear weather). The most frequent wind directions during the year are southern, southwestern and western winds (Anonymous 2019b). Overall, the average temperature in Latvia increased by 1°C in the 20th century. In the recent years of the 21st century, the average air temperature is decreasing. With regard to the annual amount of precipitation during the last 100 years, considerable fluctuations with the tendency to increase from the 2nd half of the 20th century have been observed (Anonymous 2019b).

Latvian geobotanical regions

Geobotanical regions are determined according to the regional vegetation features and are widely used as stratification classes in various flora studies. A geobotanical region is characterised by a certain set of plant communities or phytocenoses and the spatial structure of vegetation. The features of this vegetation depend on environmental factors such as soil, geological and geomorphological structure of the area, climate, as well as the most important types of human economic activity and their intensity (Kabucis 1995). Geobotanical regions are merged into geobotanical provinces, larger units, which reflect differences in vegetation caused by the climate oceanity and continentality. Latvia belongs to the Baltic geobotanical province: the Piejūras geobotanical region – the sub-province of Western Baltic, and the rest of Latvia's geobotanical region – the sub-province of Eastern Baltic. The geobotanical zonation of Latvia was performed at the Institute of Biology of the Academy of Sciences in the 1950-60s (Kabucis 1995). Eight geobotanical regions have been distinguished:

I. the Piejūras geobotanical region extends along the coast of the Baltic Sea, where the altitude is 0-40 m above the sea level. This includes the Piejūras Lowland, Ugāle Plain in Kursa Lowland and Tīreļi and Ropaži Plains of the Viduslatvijas Lowland, where the terrain has been to a great extent formed by the impact of waves and winds at various stages of the Baltic Sea development. The vegetation is diverse, forests (predominantly pine forests) cover more than 50% of the area.

II. the Rietumlatvijas geobotanical region includes the upland of western, eastern and northern Kursa, Vadakste plain of the Viduslatvijas Lowland and Pieventa Plain of Kursa Lowland. Forests cover about 35% of the area, about half of which are pine forests. In the south of the geobotanical region, *Carpinus betulus* grows in small amount. The geobotanical region includes the floristically peculiar valleys of the rivers Venta and Abava.

III. the Zemgale geobotanical region includes Zemgale Plain. Favourable climate and rich soils have resulted in the development of deciduous forests dominated by *Fraxinus excelsior*, *Quercus robur*, *Alnus incana*, *Betula pendula* and *Populus tremula* trees in the remaining forest fragments. They are characteristic with underwood and herb-rich layer. The woods have been cut mostly in ancient times, providing space to fertile fields that currently occupy most of Zemgale Plain.

IV. the Ziemeļvidzeme geobotanical region includes Tālava Lowland and Idumeja Upland, as well as Metsepole Plain, Ērģeme Hills, Aumeistaru Hills and the Gauja Valley. Forests cover about 30% of the geobotanical region. The western part of the geobotanical region is predominantly composed of Oxalidosa and Aegopodiosa spruce forest types. There are many broadleaved forests and broadleaved-spruce forests in the Gauja Valley.

V. the Centrālvidzeme geobotanical region includes Vidzeme and Alūksne Uplands. Most of the area is occupied by agricultural land. Forests cover about 25% of the area. Typically, there are spruce forests. The peatlands are mostly with bogs and transition mires by overgrown lakes. Many lakes (about 400) have diverse aquatic plant species.

VI. the Viduslatvijas geobotanical region includes the Viduslatvijas Slope, Upmale Hilly Plain, Taurkalne Plain and Sēlija Hilly Plain. Spruce forests with species-poor herbaceous layer are typical for the vegetation of the geobotanical region. As a result of human economic activities, secondary birch stands have developed instead of spruce forests. There are few peatlands only around lakes and in valleys of small rivers. The geobotanical region also includes the Daugava Valley, which was flooded while building Pļaviņas Hydropower Plant.

VII. the Ziemeļaustrumu geobotanical region includes the Austrumlatvijas Lowland and Mudava Lowland, Abrene Foothills and Zilupe Plain. The area is characterised by a great diversity of forest plant communities. Large areas of forest are occupied by Hylocomiosa and Vacciniosa forest types, smaller areas by Oxalidosa forest types. Inland dunes, Daugava, Aiviekste and Zilupe valleys are rich in pine forests, mainly Hylocomiosa and Cladinosa-Callunosa forest types. Many large bogs occur here, such as the Teiči Bog and the Švēriņi Bog.

VIII. the Dienvidaustrumu geobotanical region includes Latgale and Augšzeme Uplands. Much of the region is occupied by agricultural land. Forests cover less than 25% of the geobotanical region. The largest areas are occupied by secondary birch and aspen stands. Broadleaved and mixed broadleaved-spruce forests have been preserved in valleys of rivers, especially Daugava and its tributaries, and on lake islands. The most common forests are oak or linden dominated or mixed broadleaved forests with rich shrub and herbaceous cover. The terraces of the Daugava Valley are covered of pine forests. The geobotanical region, which is the richest in lakes among Latvian geobotanical regions, has more than 800 lakes (Kabucis 1995). A very diverse vegetation has developed in Daugavpils, with 1085 vascular natural and alien plant species registered in its flora list (Evarts-Bunders et al. 2015)

Selection of invasive plant species to be monitored

The following materials were used in the development of the programme for monitoring invasive plants: herbarium material was checked at the Laboratory of Botany, Department of Biosystematics, University of Daugavpils (Herbarium of Daugavpils University, DAU), Institute of Biology, University of Latvia (LATV), and the Herbarium of the Museum of Botany, University of Latvia (RIG); scientific studies, publications, Bachelor's, Master's, Doctoral thesis); mapping data for semi-natural grasslands, mapping data protected forest habitats; nature conservation plans of specially protected nature areas.

All invasive plant species identified in various literature sources and through mutual communication between experts have been summarised, focusing mainly on those with at least fragmentary studies proving their invasiveness in Latvia.

From the list of alien species of Latvia (Anonymous 2019a), all plant species recognized as being invasive was selected. The highest priority was given to species that satisfy the criteria, described in the European and Mediterranean Plant Protection Organisation (EPPO) methodology of prioritization process for invasive alien plants as well as supplemented with some specialised criteria, selected for local conditions and some additional recommendations for prioritization of invasive plant species for monitoring (Anonymous 2012): 1) negative impact on European Union protected habitats (92/43/EEK Council Directive on the conservation of natural habitats and of wild fauna and flora), 2) invasive plant data not obtained in other monitoring programmes in Latvia, 3) plant reproduces effectively in the wild, 4) massive weed of agriculture, 5) genetic erosion of any native species, 6) considered invasive in neighbouring countries, 7) species assessment has been carried out in Latvia (actual number of localities), 8) widely cultivated plant species and 9) invasion not subsided for concrete species (the species shows the features of mass invasions, species has not found its own ecological niche). Based on the adopted criteria, 35 invasive plant species were found to be appropriate for invasive plant monitoring (Evarts-Bunders et al. 2016a) (Tab. 1.). Species that meet at least seven selection criteria and which are believed to cause the most significant impacts of natural

ecosystems are considered priority invasive plants to be monitored, or so-called Black List species. In total, 15 Black List plant species have been selected.

<u>Principles of location of sample plots for invasive plant species monitoring</u>

Monitoring of invasive species was carried out in certain sample plots. According to the biodiversity monitoring programme of Latvia, the stratified random selection of sample plots was used in this case. According to the developed methodology, a certain number of quadrates was randomly selected, whereby the draw was made in each of the stratification classes in proportion to their occupied area. In this case, Latvian geobotanical regions areas were used for stratification. In order to ensure the systematic and even distribution of sample plots in the territory of the country, 400 5 x 5 km quadrates (39 % from all 1017 quadrates of Latvia) within the Latvian Coordinate System (LKS-92) were drawn (Fig. 1).

Each selected sample plot is planned to be surveyed every four years, with 100 sample plots surveyed each year. In total, the 400 quadrates were located evenly across the territory of Latvia, with each containing one sample plot. Four hundred monitoring sample plots is a sufficient number of plots for representative and objective data. The position of the monitored quadrates is shown in Fig. 1
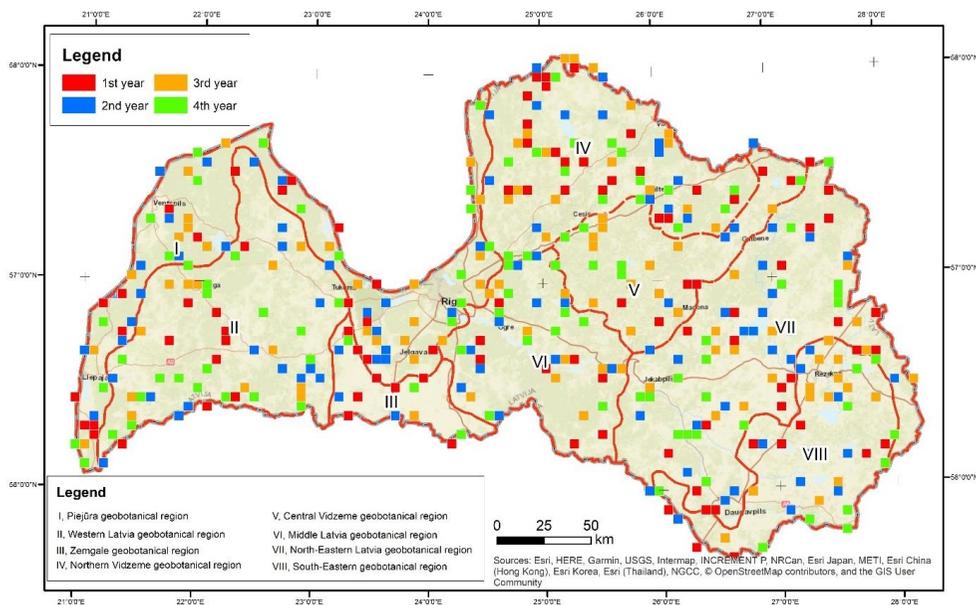
Fig. 1 Recommended principle of quadrate selection while undertaking invasive plant species monitoring. The figure shows all 400 quadrates of one accounting period divided by years.
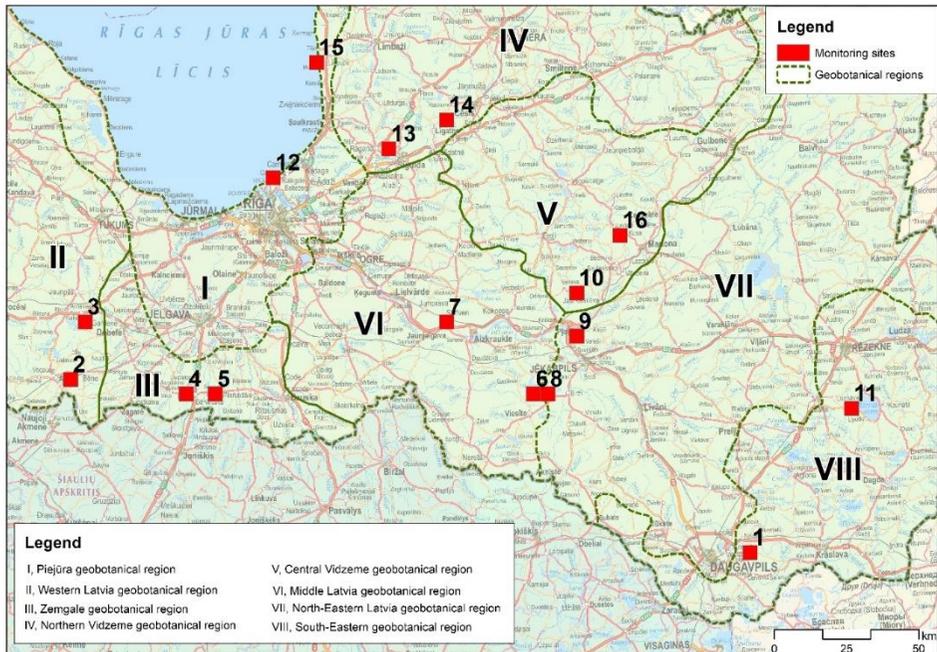
Fig. 2 Sites of the monitoring approbation on the map of Latvian geobotanical regions.
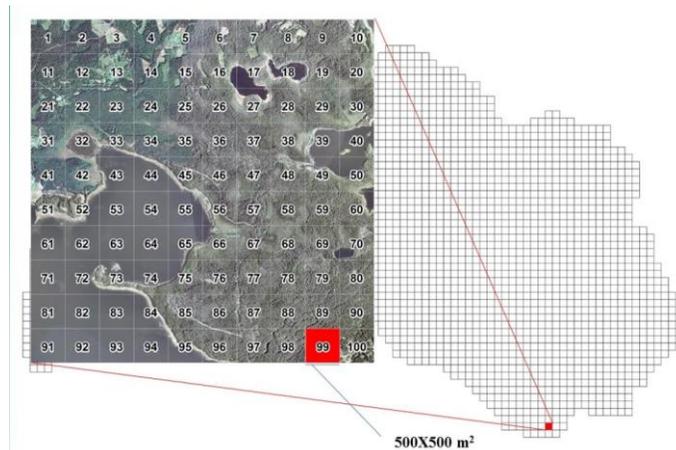
Fig. 3 Principles of selection of sub-quadrates in 5 x 5 km quadrates. In this case, the 99th 500 x 500 m monitoring sub-quadrate is marked in the 99th quadrate.

Tab. 1 Primary list of invasive plant species and its evaluation according to selection criteria. Species, selected as a priority to be monitored or so called Black List species marked with grey.

Alien plants	Criterion								
	1	2	3	4	5	6	7	8	9
Acer negundo L.	x	x	x			x	x	x	x
Amelanchier spicata (Lam.) K. Koch.	x	x	x			x	x	x	x
Aronia prunifolia (Marshall) Rehder	x	x	x			x	x		x
Aster salignus Willd.	x	x	x			x	x	x	x
Bunias orientalis L.		x	x			x		x	x
Cotoneaster lucidus Schultdl.	x	x	x			x	x	x	x
Echinocystis lobata (Michx.) Torr. & A. Gray	x	x	x			x	x	x	x
Elaeagnus argentea Pursh.	x	x	x			x	x		x
Elodea canadensis Michx.	x	x	x			x			x
Epilobium adenocaulon Hausskn.	x	x	x			x			x
Gypsophila paniculata L.	x	x	x			x	x		x
Helianthus tuberosus L.		x	x			x	x	x	x
Hippophaë rhamnoides L.	x	x	x				x		x
Impatiens glandulifera Royle	x	x	x			x	x	x	x
Impatiens parviflora DC.	x	x	x			x	x	x	x
Lactuca tatarica (L.) C.A.Mey.	x	x	x			x			x
Ligustrum vulgare L.	x	x	x			x	x		x
Lupinus polyphyllus Lindl.	x	x	x			x	x	x	x
Malus domestica Borkh.	x	x	x		x		x		x
Parthenocissus quinquefolia (L.) Planch.	x	x	x	x		x			x
Petasites hybridus (L.) P. Gaertn., B. Mey. & Scherb.	x	x	x				x	x	x
Reynoutria japonica Houtt.	x	x	x			x	x	x	x
Reynoutria sachalinensis (F. Schmidt) Nakai	x	x	x			x	x	x	x
Robinia pseudoacacia L.	x	x	x			x			x
Rosa rugosa Thunb.	x	x	x			x	x	x	x
Rumex confertus Willd.	x	x	x			x		x	x
Sambucus nigra L.	x	x	x			x	x		x
Sambucus racemosa L.	x	x	x			x	x	x	x
Solidago canadensis L.	x	x	x			x	x	x	x
Solidago gigantea Aiton	x	x	x			x	x	x	x
Sorbaria sorbifolia (L.) A. Braun	x	x	x			x	x	x	x
Spiraea chamaedryfolia L.	x	x	x				x		x
Swida alba (L.) Opiz	x	x	x				x		x
Swida sericea (L.) Holub	x	x	x				x		x

Tab. 2 Randomly selected sample quadrates for monitoring approbation, two from each geobotanical region. Abbreviation: Q - quadrate; GR - geobotanical region.

Q	GR	Nearest geographic landmarks	Centre coordinates of monitoring quadrate		Date
			X	Y	
1.	VIII	Daugavpils county, Tabores parish, Elerne	674121	195364	18th August 2016
2.	II	Auces county, Bēnes parish, Vecmiķeļi	439210	255277	7th October 2016
3.	II	Dobeles county, Annenieku parish, Slagūne	444223	275266	7th October 2016
4.	III	Jelgavas county, Elejas parish, Eleja	479282	250337	6th October 2016
5.	III	Jelgavas county, Sesavas parish, Sesava	489237	250190	4th October 2016
6.	VI	Viesītes county, Šveriņu bog	599270	250251	25th August 2016
7.	VI	Jaunjelgavas county, Jaunjelgava	569175	275271	5th October 2016
8.	VII	Salas county, Melnais bog	604283	250182	25th August 2016
9.	VII	Krustpils county, Krustpils parish, Kaķīši	614248	270268	22th August 2016
10.	V	Pļaviņu county, Aiviekstes parish, Vesetnieki	614168	285268	27th August 2016
11.	VIII	Rezeknes county, Mākoņkalna parish, Berezņīki	709810	246736	29th August 2016
12.	I	Carnikavas county, Kalngale	509329	325200	23th September 2016
13.	IV	Siguldas county, Siguldas parish, Brūveri	549296	335219	21th September 2016
14.	IV	Amatas county, Drabešu parish, Zvārtas rock	569276	345219	22th September 2016
15.	I	Salacgrīvas county, Liepupes parish, Duntes scool	524214	365252	22th September 2016
16.	V	Madonas county, Aronas parish, Zelgavska	629231	305217	1th September 2016

<u>Selection of sample plots for approbation of methodology of invasive plant species monitoring</u>

Approbation of invasive plant species monitoring was performed in certain sample plots (Fig. 2; Appendix 3). In this case, Latvian geobotanical regions (Kabucis 1995) were used for stratification.

In order to ensure a systematic and even distribution of sample plots in the territory of the country, 16 5 x 5 km quadrates of Latvian coordinate system (LKS-92) were drawn, from which the 99th small quadrate was selected, where the field monitoring of invasive species took place; the size of the monitoring plot is 500 x 500 m (Fig. 3; Appendix 1). In the course of the monitoring approbation, two types of

field data form were filled in, where the information gained during the fieldwork was summarised (Appendix 1, 2). In the additional fieldwork data form on each priority invasive plant species, its distribution in small quadrates of the sample plot was noted separately, the impact on invasive species (including land management) was noted, and whether the respective impact mitigates or promotes the spread of invasive species was evaluated. Cover of invasive species were evaluated visually within a 10-point scale (Rašomavičius et al. 2012; Evarts-Bunders et al. 2016b) (Appendix 2). Likewise, the additional field data form also identified the habitat types affected by the invasive species and assessed the representativeness of each affected habitat group.

Results

Having developed the monitoring methodology, it was also necessary to approbate it in order to understand whether it enables obtaining quantitative and qualitative data on invasive species in the future. For approbation of our developed monitoring methodology we chose only 16 sample quadrates or 4% of all monitored quadrates, which was sufficient for understanding whether methodology and field data forms work or not, if it is possible to collect comparable data about distribution of invasive plants in small quadrates, and assessing the need to revise or supplement the methodology so that the obtained data are as representative as possible, and realistic. Of course, the data obtained from such an approbation study cannot be considered as complete monitoring data, although it provides a fairly good reflection of some key problems.

Species numbers and taxonomic composition of invasive plant monitoring approbation

In Latvia, the actual list of alien plant species includes 640 taxa or 33% of the whole flora of Latvia with very different levels of invasiveness – casual alien plants, arboreal trees with episodic escaping from cultivation, local invasions etc. Of these, 35 (15 Black List and 20 Grey List) are included in the inventory of priority invasive species (Table 1).

During the monitoring approbation, 34 species were identified in 16 monitoring approbation sites or sample plots: ten priority or Black List species, ten potentially monitorable or Grey List species and 14 other invasive species. Of the 15 priority monitorable species, 10 species were identified in monitoring approbation: *Acer negundo* L., *Amelanchier spicata* (Lam.) K. Koch., *Aster salignus* Willd., *Cotoneaster lucidus* Schultdl., *Impatiens glandulifera* Royle, *I. parviflora* DC., *Sambucus racemosa* L., *Solidago canadensis* L., *S. gigantea* Aiton, and *Sorbaria sorbifolia* (L.) A. Braun.

Of the 20 Grey List species, 10 species were identified: *Aronia prunifolia* (Marshall) Rehder, *Bunias orentalis* L., *Elodea canadensis* Michx., *Epilobium adenocaulon* Hausskn., *Helianthus tuberosus* L., *Malus domestica* Borkh., *Parthenocissus quinquefolia* (L.) Planch., *Rumex confertus* Willd., *Sambucus nigra* L. and *Spiraea chamaedryfolia* L. In a further survey, 14 alien species showing signs of invasiveness

were found in the sample plots: *Armoracia rusticana* P. Gaertn., B. Mey. et Scherb., *Brassica napus* L., *Conyza canadensis* (L.) Conquist, *Caragana arborescens* Lam., *Grossularia reclinata* (L.) Mill., *Juncus tenuis* Wild., *Lactuca serriola* L., *Phalacroloma septentrionale* (Fernald & Wiegand) Tzvelev, *Prunus cerasifera* Ehrh., *Quercus rubra* L., *Ribes rubrum* L., *Rosa pimpinellifolia* L., *Syringa vulgaris* L. and *Spiraea alba* (L.) Opiz (Appendix 3). The presence of the identified invasive species in 16 randomly selected monitored approbation quadrates indicates the mass invasion of these species in the country and the need to evaluate the extent of the invasion, the rate of spread and possible means of elimination in the entire country.

Thirty four of the species identified belong to 15 families: Rosaceae (9 or 26.5%), Asteraceae (7 or 20.6%), Brassicaceae (3 or 8.8%), Balsaminaceae (2 or 5.9%), Caprifoliaceae (2 or 5.9%) and Grossulariaceae (2 or 5.9%); the rest of families included one species identified. In this study, all nine species found in the rose family (Rosaceae) are woody plants.

<u>Plant traits</u>

The majority of alien plants are perennial (27 or 79.4%); annuals are also greatly represented (6 or 20.6%). Of the annual plants, the one that was most frequently encountered in the monitored plots was *Impatiens parviflora* included in the Black List, which was identified in five sample plots (Bereznīki, Brūveri, Jaunjelgava, Kalngale, Zvārtas rock); *Impatiens glandulifera* was only encountered in one plot in the form of a small spot on the forest edge (Zelgavska). These species were grown in the 19th century in European botanical gardens as decorative plants. The first herbarium of *I. glandulifera* in Latvia was collected in 1898 at Pape Lake, while *I. parviflora* was collected in 1907 in Riga on Bastejkalns (Appendix 3). Both species spread by explosive opening of the seed capsule, seeds are thrown up to 3 m in the case of *Impatiens parviflora* and 3 - 5 m for *Impatiens glandulifera*, species' distribution is promoted by proximity to watercourses, seeds are transferred along water, road transport also plays an important role, seeds are also transferred by animals (Priede 2008c). Both species are capable of forming monodominant stands in natural habitats of Latvia. A small stand of *Epilobium adenocaulon* from the Grey List was found in one sample plot (Duntes School).

Among the other non-listed invasive species the most frequently encountered were *Phalacroloma septentrionale* in three plots (Bereznīki, Vesetnieki, Zelgavska), *Conyza canadensis* in two plots (Bereznīki, Jaunjelgava) and *Brassica napus* and *Lactuca serriola* in one plot.

Among perennials, the most common life form is phanerophytes, i.e. woody plants – 17, or 50%. Slightly more than a half, nine species, belong to the Rosaceae. Of these, there are three species listed in the Black List: *Amelanchier spicata*, *Coteneaster lucidus* and *Sorbaria sorbifolia*, identified once during each monitoring approbation. *Sorbaria sorbifolia* formed a 1 ha dense stand under the power line in the Eleja polygon. *Malus domestica*, from Rosaceae family, which has been mentioned in the Latvian territory since 1778, has been encountered most often

(three times). Other Rosacea family species mentioned in the article were introduced in Latvia in the 19th century and to date have been used in landscape gardening. Consequently, the spreading of these species into the wild is related to the frequency of cultivation of the species – the donor territories and their spatial distribution, in combination with habitats suitable for the invasive species, play an important role. The examples are small gardens and suburban forests, parks, cemeteries and adjacent areas, etc. Of the perennial herbaceous plants, *Solidago canadensis* was found most frequently in five polygons (Brūveri, Eleja, Slagūne, Vecmiķeļi, and Vesetnieki). Originally introduced in Europe as a decorative plant, it is now characterised as one of the most aggressive, most widely distributed alien species (Priede 2008c). Among the alien aquatic plants, *Elodea canadensis*, included in the Grey List, has been found in four polygons (Bereznīki, Jaunjelgava, Kaķīši, and Slagūne).

Vectors listed are the known or most likely means of introduction to the Latvia. 53.0% of the identified invasive plants dispersed from horticulture, 14.7% as human foodstuffs, including herbs and spices, as plants, seeds or fruits, and 17.6% as or with fodder or other foodstuffs or straw for animals and 14.7% other vectors (Appendix 3).

Most of the 34 alien taxa introduced to Latvia have native ranges in North America (44.1%), Europe (23.5%), Eurasia (17.6%), Mediterranean (8.3%), Western Europe, Asia (3%). 3% are cultivars, decorative varieties, hybrids and other taxa without natural area (Appendix 3). The situation is similar in Europe and Asia Minor (Turkey), where 44% of all invasive plant species are of North American origin (Pyšek et al. 2009; Uludağet al. 2017) (Appendix 3).).
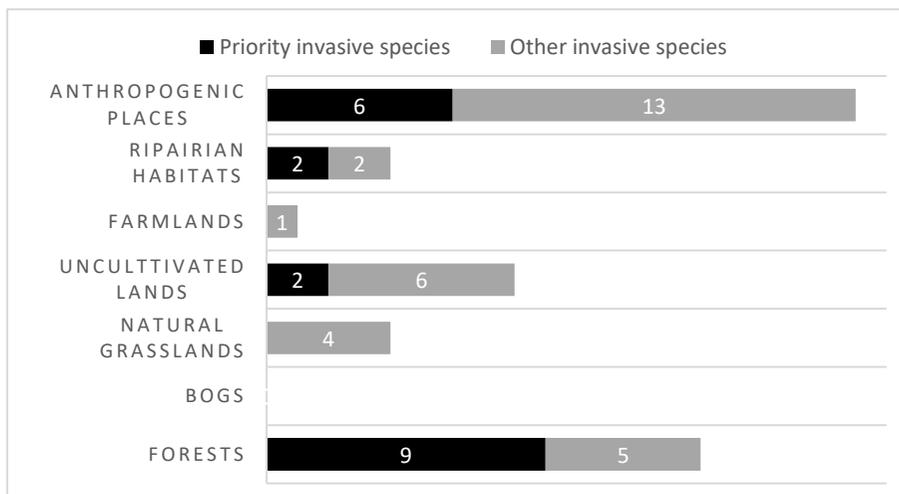
Habitats in monitoring approbation sites

As a result, two of the 16 sites were situated in the protected nature areas (see Fig. 2): Švēriņu purvs Nature Reserve and Melnais purvs Nature Reserve, where no invasive species were found. One invasive species was found in each of the four sites in Vecmiķeļi, Galamuiža, quadrates of Kaķīši and Dunte School. The land intensively used in agriculture is located in Galamuiža and Kaķīši sites. In the sites of Vecmiķeli and Dunte School, forests, new stands and middle-aged stands are developed. Three species were found in the sites of Eleja, Vesetnieki and Brūveri. In anthropogenic sites (power line and gas pipeline) in Eleja site, dense stands of *Sorbaria sorbifolia* and *Solidago canadensis* were found. Four species were identified in Salgūne site. In disturbed areas with the presence of ruderal habitats, more invasive species were identified. Five species were found in Elerne, and six species in the sites of Zvārtas rock and Zelgavska. Seven species were found in Bereznīki and Kalngale. The majority, eight species, were found in Jaunjelgava, where the Daugava flood-lands with the river were included in the site, and it is in the flood-lands where two monitorable species of *Impatiens parviflora* and *Aster salignus* (Fig. 4) were identified.

The first results obtained show that the majority of invasive species were found in anthropogenic sites (19), forests (14) and fallow land (8). Fewer invasive species have been found in semi-natural grasslands (4) and arable lands (1). Preliminary results show that dry forest (8) and shrubs (6) are important growth plots for invasive species. On the other hand, the roadside habitats dominate among the anthropogenic sites with 15 identified invasive species (Fig. 5). All invasions in the sample plots were evaluated only at 1 point (very rare, <1% of the total affected area), except for *Sorbaria sorbifolia* in Eleja site which scored 5 on the 10-point scale within 10-point scale points (not rare, 20-25% of the total affected area).
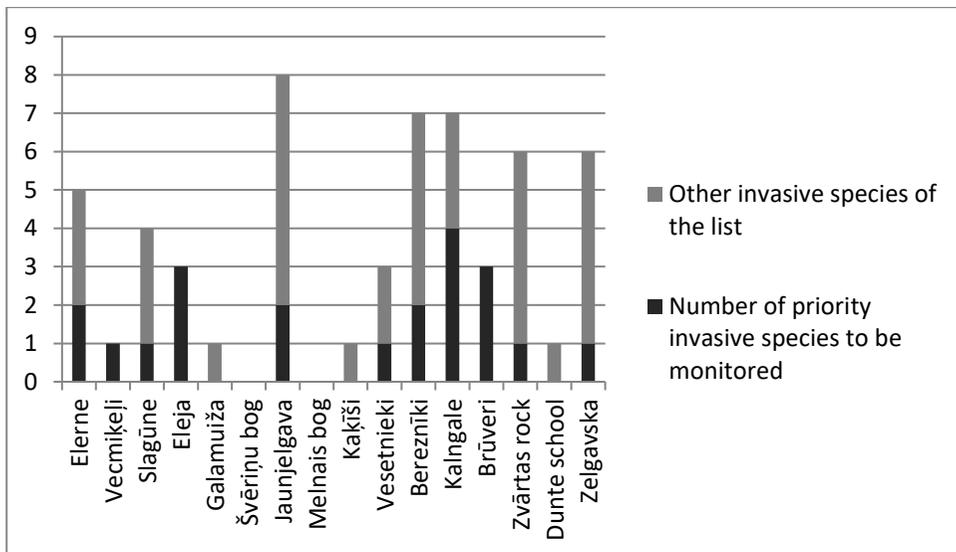
Fig. 4 Number of alien species found in monitored research plots.

Fig. 5 Habitats in which the alien plant taxa are found in monitoring sites.

Discussion

This paper provides the first assessment of alien species in Latvia in terms of their environmental impact. The introduction and naturalisation of a new species is a dynamic process (Blackburn et al. 2011; Richardson & Pyšek 2012; Lokwood et al. 2013; Pergl et al. 2016); therefore, the published lists of this kind are not and cannot be definitive. This published list of priority species can also be called the Black List, while the list of species to be monitored can be called the Grey List. They are equated to similar lists in other countries; for example, the list of priority monitorable species in Estonia includes 13 species, but 38 species are recognised as problematic (Ööpik et al. 2013). In Lithuania, 42 are considered to be monitorable invasive species (Rašomavičius et al. 2012). The Czech Republic has 78 species on the Black List, 47 on the Grey List and 25 on the Watch List (Pergl et al. 2016). The list for Latvia has been compiled based on information in the literature and certain studies of their environmental and socio-economic impacts and is intended to monitor 15 priority monitorable species and another 20 monitorable species in the territory of Latvia.

During the approbation of the invasive plant species methodology, 16 randomly selected 500 x 500 m plots were surveyed in 2016, two in each Latvian geobotanical area. During the survey period, 15 selected monitorable priority invasive species were found in 11 quadrates, while the presence of these species was not noted in five quadrates. The number of invasive species found is not large, mainly one or two species, only in three monitoring approbation quadrats (Eleja, Krimulda and Kalngale), where the number of monitorable species reached 3-4. It can be concluded that the quadrates which are most abundant in invasive species in this study are dry forest areas located near inhabited places. Suburban forests are particularly prone to anthropogenic impact, with a large number of alien species found, e.g. 281 anthropophytes had been identified in Daugavpils area by year 2012 (Evarts-Bunders et al. 2012).

The least number of invasive species occur in natural, undisturbed raised and transition mire areas. Alien species have not been found at all in two raised and transition marshlands (Melnais bog and Švēriņu bog) surveyed during the monitoring methodology approbation. These sites are in the protected nature areas. The spread of alien plants into protected areas is strongly influenced by the presence of trails or roads (Arévalo et al. 2010; Otto et al. 2014), and by the number of visitors (Allen et al. 2009; Pickering & Mount 2010; Rutkovska et al. 2017). Analysis of invasive plant diversity was carried out in territories of three nature protected reserves in southeastern Latvia (Evarts-Bunders & Evarte-Bundere 2018). There is no infrastructure for recreation in Pašuliene Forest Nature Reserve (7 alien species) (Evarts-Bunders & Evarte-Bundere 2017), while only a small part of the territory has been suitable for visitors in Eglone Nature Reserve (9 alien species) (Evarts-Bunders et al. 2013), while the anthropogenic impact in Sasaļi Forest Nature Reserve is long-lasting, evidenced by the trenches left after World War I, the bathing area close to the lake, the Daugavpils-Warsaw railway line, the old soviet-time recreation facility, etc. (26 alien species) (Evarts-Bunders et al. 2017).

Having evaluated the data of vegetation season 2016, the following recommendations for the successful implementation of monitoring methodology in the territory of Latvia have been provided:

1) The most common invasive species of the 15 selected (see Tab. 2) were: *Solidago canadensis* and *Impatiens parviflora* (five quadrates, or 33% of all observed during the approbation), *Sambucus racemosa* (three quadrates), *Acer negundo* (two quadrates) and *Amelanchier spicata*, *Aster salignus*, *Cotoneaster lucidus*, *Impatiens gladulifera*, *Solidago gigantea* and *Sorbaria sorbifolia* (in one quadrate each). The presence of such invasive species in randomly selected quadrates indicates the massive invasion of these species in the country and the need to assess the extent of invasion, the speed of spread and possible methods of combating invasive species in the whole country.

2) Five monitorable species (33% out of all priority monitorable species) were not identified during the approbation (*Echinocystis lobata* (Michx.) Torr. & A. Gray, *Lupinus polyphyllus* Lindl., *Reynoutria japonica* Houtt., *R. sachalinensis* (F. Schmidt) Nakai and *Rosa rugosa* Thunb.). Such results show that randomly selected sites do not always effectively reflect the real situation in the nature; therefore, it is necessary to improve the monitoring methodology by selecting 50% of the monitoring quadrates randomly according to the descriptions given in the monitoring methodology, while another 50% should be selected from the already known localities of invasive species in proportion to their number, yet still observing the principles of sites distribution according to geobotanical regions.

3) In the intensively used agricultural lands (Kaķīši and Galamuiža sites) with cultivated grasslands or agricultural crops (rape plants and winter crops), invasive species were not found. When selecting monitoring sites for further work, such quadrates should be avoided, being replaced with adjacent quadrates that have at least a small mosaic structure and habitat diversity – bog edges, mosaic landscapes, and so on.

4) During the approbation of the monitoring methodology, no alien species have been found in the two raised bog and transition mire sites surveyed. When planning the location of monitoring quadrates, in order to save time and resources, it is advisable to avoid natural, undisturbed raised and transition bog areas and leave certain areas of disturbed, degraded bogs where invasions are more probable.

According to the additional findings obtained during the approbation of the monitoring methodology, corrections were made to the monitoring methodology, the data on the habitat section were specified, additional criteria were introduced in the field data forms (e.g. the level of invasiveness) and the cartographic material of the monitoring sites was improved and made more convenient (Evarts-Bunders et al. 2016b).

The difficulties with gaining research funding for basic monitoring activities and the fact that research targets early invasion stages may not allow for quantitative analyses resulting in research articles; however, for descriptive short notes the resulting data is important (Pietzsch et al. 2006; Scholte et al. 2009; Versteirt et al.

2009; Schindler et al. 2015). In Latvia, the methodology of invasive species monitoring has also been development and approbated, however, for the time being, due to a lack of funding, it has not yet been implemented in the planned 400 quadrates with the observation time of four years.

Acknowledgement

Electronical supplementary materials

Appendix 1. Invasive plant monitoring. Field data form
Appendix 2. Invasive plant monitoring. Additional field data form (fill for each detected priority invasive plant species in polygon)
Appendix 3. Analysis of invasive species identified during monitoring approbation

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