



Invasion of alien plants in fire-damaged forests at southern boundary of the taiga zone

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Abstract

Aim of the study: Biological invasions are one of the most important areas of forest research. In this study, we revealed invasibility of fire-damaged forests at the southern boundary of the taiga zone.

Area of study: The Mordovia State Nature Reserve (Central Russia).

Material and Methods: Altogether, 11 square plots of each 100 × 100 m were established in different types of fire-damaged forests. To test plant invasion outside the established plots, field researches were carried out by route method in fire-damaged area of the Mordovia Reserve.

Main Results: Six alien species (*Erigeron canadensis*, *E. annuus*, *Oenothera biennis*, *Lactuca serriola*, *Sambucus racemosa*, *Viola arvensis*) were registered within the established plots in 2011–2014. In addition, two alien invasive plants (*Solidago canadensis* and *Bidens frondosa*) were found outside these plots. No differences were detected in invasibility of the tested forest ecosystems.

Research highlights: Among the revealed alien species, *Erigeron canadensis*, *Lactuca serriola* and *Solidago canadensis* are the most invasive plants in forest ecosystems. The first one was observed with a high occurrence frequency and abundance in all forest types tested. The second one has not been differed by abundance, but it characterized by a high competition as well as a large biomass and a large number of seeds. *Solidago canadensis* penetrated to natural forest ecosystem in a short time period due to closest location of its dispersal centers near the boundary of the Mordovia Reserve. These species are the most probable invaders of the forest ecosystems.

Keywords: Invasive plants; invasibility; post-fire successions; Mordovia State Nature Reserve; wildfire; forest ecosystem.

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Introduction

Wildfires are one of the key processes in many biomes worldwide. They are considered as one of the most important ecological factors determining the distribution and composition of many ecosystems (Bond & Keeley, 2005; Pausas & Ribeiro, 2013). Usually the wildfire has a short but powerful damaging effect on the vegetation cover. In the first years, an increasing in the number of species as well as in the total biomass of organisms occur in fire-damaged areas. (Zyryanova *et al.*, 2010; Shugaev *et al.*, 2015). After several years, the speed of this process decreases: revegetation begins, aiming at restoring the vegetation cover that existed before the fire influence (Gromtsev,

2000; Kazantseva & Chernobay, 2011). Some plants are well adapted to post-fire conditions due to improved light conditions, availability of mineral elements and a sharp decline in competition (Calvo *et al.*, 2008). That is why such plants have high parameters of abundance and biomass in fire-damaged areas.

Also alien plant species are involved in the pyrogenic successions. They are able to impact on native plant populations and ecosystem by changing soil stability, contributing to soil erosion, occupying open habitats, affecting the accumulation of litter, salt and other resources of the soil (Vitousek, 1990; Richardson *et al.*, 2000). Forest ecosystems are the most resistant communities against plant invasion (Pearsall, 1959; Weaver *et al.*, 2001; Keeley *et al.*, 2003). One of the

main reasons for tolerance of forests to invasion is the closed canopy which typically provides from 5% to < 2% of incident solar radiation (Canham *et al.*, 1990). Therefore the covered canopy greatly inhibits the growth and development of alien plants (Rejmanek, 1989; Charbonneau & Fahrig, 2004). This is especially important for areas with a special protection regime: e.g. nature reserves and national parks. Protected areas are the most common and important instrument for *in situ* conservation of biodiversity (Scott & Lemieux, 2005). Due to the special protection regime, strict nature reserves (category 1a, according to the IUCN System of Management Categories for Protected Areas (1994)) are withdrawn out of the human use.

This research is aimed at studying the short-term effects of wildfires on the invasion of alien plant species in forest ecosystems at the southern boundary of the taiga zone. As a model object, the Mordovia State Nature Reserve was selected.

Material and methods

The Mordovia State Nature Reserve is situated in the northwest of the Republic of Mordovia, Russian Federation (54° 42' – 54° 56' N 43° 04' – 43° 36' E; up to 190 m a.s.l., Fig. 1). It lies in the southern boundary of the taiga natural zone. The reserve area is 321.62 sq. km. Forest communities cover 89.3% of total reserve area. The Vascular Flora of the Mordovia Reserve

includes 797 species from 99 families. Among them, alien vascular flora is presented by 108 species (13.5% of the total species number) (Khapugin *et al.*, 2015a). In general, the vegetation cover of the Mordovia Reserve is similar to the taiga complex with a tendency of transfer to nemoral complex under the succession. Participation of forest-steppe elements is typical for this area (Tereshkina, 2006).

Pine (*Pinus sylvestris* L.) is the main forest-forming wood species in the reserve. It forms pure or mixed forest communities in the south, central and western parts of the Mordovia Reserve. Birch (*Betula pendula* Roth) ranks a second place in the area covered by forest in the Mordovia Reserve. Birch forests are encountered by patches together with pine forest areas. It forms predominantly secondary communities at logging sites and at burnt pine forest sites. Lime (*Tilia cordata* Mill.) forests are encountered in the northern part of the Mordovia Reserve. They are predominantly secondary plant communities replacing pine (*Pinetum*) and lime-spruce (*Tilieto-Piceetum*) forests. Nevertheless, they play an important role in the conservation of the endangered plant species *Lunaria rediviva* L., located in the north-eastern border of its range (Khapugin & Chugunov, 2015). Oak (*Quercus robur* L.) forests cover a relatively small area in the Mordovia Reserve. These are distributed in the floodplain of the Moksha river in the western part of the Protected Area. Spruce (*Picea abies* L.) forests are located predominantly in the floodplains of rivers and streams (Pushta, Vyaz-Pushta, Vorsklyay, Arga, etc.) and cover small areas.

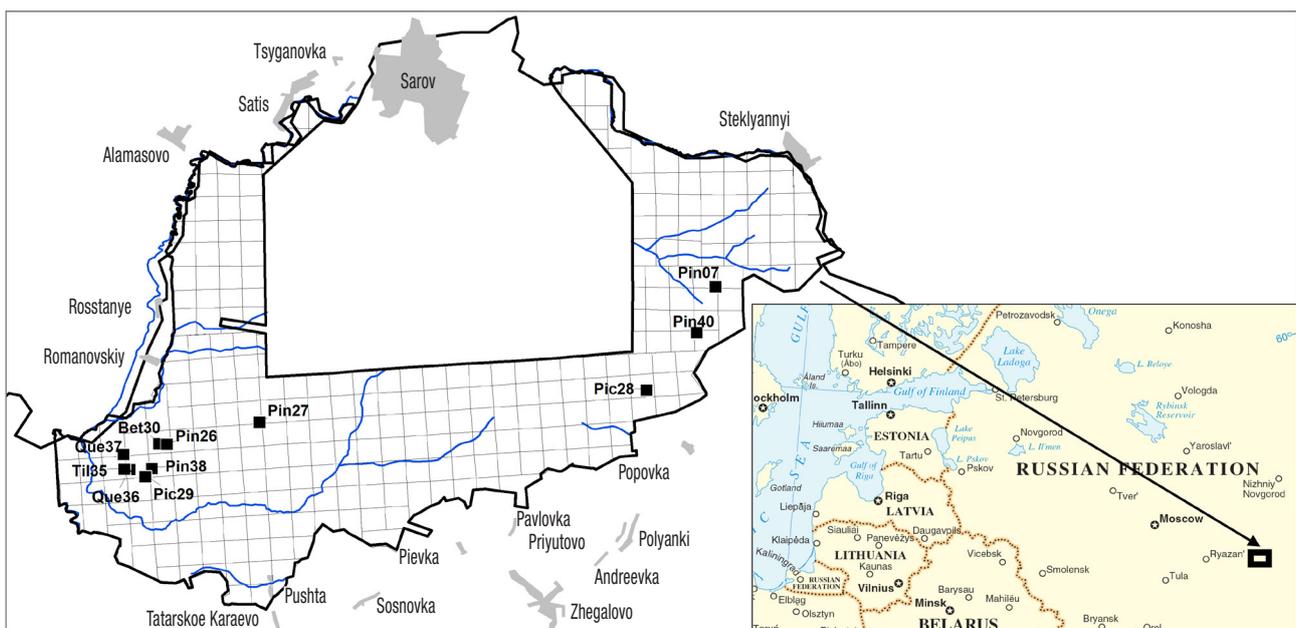


Figure 1. Geographical position of the Mordovia State Nature Reserve in Eastern Europe. Numbers on the map of the Mordovia Reserve indicate the established plots referred to in the list of studied locations (Map with modifications from web-site United Nations Geospatial Information Section: <http://www.un.org/Depts/Cartographic/english/htmain.htm>).

In 2010, a relatively large part of the Mordovia Reserve was on fire; about 37% (120 km²) of the forest was burnt (Grishutkin, 2012). The plot characterization of the wildfire is presented in Table 1. The sample plots were selected by using the forest inventory map of the Mordovia Reserve with habitats damaged by the wildfire of 2010 in the studied Protected Area. The percentage

of the burnt forest area was evaluated through geobotanical survey of each established plot. Fire severity was described following Ryan (2002) and Turner *et al.* (1994) with modifications. The fire intensity was assessed following the Fire Intensity Risk System (BC Wildfire Service, 2015). To study the post-fire dynamics of the vegetation cover in the forests of the Mordovia State

Table 1. Representation of alien species at established plots in fire-damaged forests of the Mordovia State Nature Reserve in 2011–2014 years

Plots	Percent of area burnt, %	Intensity (Severity)	Year	Projective cover (%) and occurrence frequency of alien species					
				<i>Erigeron canadensis</i>	<i>Erigeron annuus</i>	<i>Lactuca serriola</i>	<i>Sambucus racemosa</i>	<i>Oenothera biennis</i>	<i>Viola arvensis</i>
Pin07	90	3(b)	2014	0.5	–	–	–	–	–
			2011	0.5	–	0.5	–	–	–
Pin26	95	3(b)	2012	3.0	–	0.5	0.5	–	–
			2013	2.5	–	1.0	0.5	–	–
			2014	1.5	–	0.5	0.5	–	–
Pin27	100	5(d)	2011	1.0	–	0.5	–	–	–
			2012	2.0	–	1.0	–	–	–
			2013	5.5	–	1.0	–	–	–
Pin38	100	3(b)	2014	7.0	–	1.0	–	–	–
			2011	0.5	–	0.5	–	–	–
			2012	1.5	0.5	0.5	0.5	0.1	–
Pin40	98	3(c)	2013	1.0	0.5	1.0	0.5	–	–
			2014	0.5	–	1.0	0.5	–	–
			2012	2.0	–	–	–	–	–
Pic28	100	4(d)	2014	1.5	0.5	–	–	–	–
			2011	0.5	–	–	–	–	–
Pic29	100	4(d)	2012	1.5	–	0.5	0.5	–	–
			2013	2.0	–	1.0	0.5	–	–
			2014	1.0	–	1.0	0.5	–	–
Bet30	95	4(c)	2011	0.5	–	0.5	0.5	–	–
			2012	2.0	0.5	–	–	–	–
			2013	1.5	0.5	–	–	–	–
Que36	90	2(a)	2014	1.0	0.5	–	–	–	–
			2011	0.5	–	–	–	–	–
			2012	1.0	1.0	–	–	–	–
Que37	90	2(a)	2013	1.0	0.5	–	–	–	–
			2014	0.5	0.5	–	–	–	–
			2011	0.5	–	0.5	–	–	0.5
Til35	100	2(a)	2012	1.5	0.5	0.5	–	–	0.5
			2013	1.0	1.0	1.0	–	–	0.5
			2014	0.5	0.5	0.5	–	–	–
Total number of findings				36	13	24	10	1	3

Note: **Intensity:** 2 – light, low vigorous surface fire; 3 – severe surface burn, moderately vigorous surface fire; 4 – deep burning or crown fire, highly vigorous surface fire, torching (or passive crown fire); 5 – crown fire, extremely vigorous surface fire or active crown fire. **Severity:** a – Light, b – Severe surface burn, c – Deep burning, d – Crown fire.

Nature Reserve, we established 11 square plots (100×100 m) in the five aforementioned types of forest affected by wildfire: 5 plots were established in pine forests (Pin07, Pin26, Pin27, Pin38, Pin40), 2 in spruce forests (Pic28, Pic29), 2 in oak forests (Que36, Que37), 1 in birch forest (Bet30) and 1 in lime forest (Til35) (Khapugin *et al.*, 2012; Shugaev *et al.*, 2015). The geobotanical methodic follows Aleksandrova (1964). Eight of the established plots were studied from 2011 to 2014. Plots Pin07 and Pin40 were established only in 2014. Plot Pic28 was studied in 2012 and 2014 years.

In addition, we could not ignore the obviously high rate of invasion of some plants outside the abovementioned established plots. Therefore we studied the penetration of these plants in burnt forest communities outside fixed plots.

Results and Discussion

Alien plants found within the established plots in fire-damaged forests

During the four years of the research, only 6 alien plant species have been found within the established plots. They are presented in Table 1 and Figure 2:

Three of them (*Erigeron canadensis* L., *Erigeron annuus* (L.) Desf., *Oenothera biennis* L.) are included in the Black Data Book of Central Russia (Vinogradova *et al.*, 2010) as the most invasive alien plant species of European Russia.

Erigeron canadensis (Compositae) Giseke) has the highest occurrence frequency and abundance within all

established plots. This species was found in all established plots with an occurrence frequency of 100% (Fig. 2). Moreover, *Erigeron canadensis* is the most widely distributed plant species invaded the fire-damaged forests in the whole area of the Mordovia Reserve. *Erigeron canadensis* is one of the first and abundant (together with *Epilobium angustifolium* L.) ruderal plants (according to Grime, 1979) in fire-damaged forests of the Mordovia Reserve during the early stages of pyrogenic succession (Khapugin *et al.*, 2012). By 2014 its projective cover had decreased at most studied plots except for Pin27, despite the fact that this species is annually observed in all plots established during the study period. Due to xerophilous conditions of habitat Pin27 and stringent conditions of fire in 2010 (Table 1), the growth rate of undergrowth of *Betula pendula* Roth has decreased at this plot. Under these favourable conditions *Erigeron canadensis* is characterized by a high abundance, annual flowering and fruiting. Dominance or presence of this species in the vegetation cover during the early stages of pyrogenic successions is in line with the results of other researchers (Dymova, 2014; Malinovskikh, 2014). Thus, we conclude that this alien species is the most invasive plant in natural ecosystems of the Mordovia State Nature Reserve.

Erigeron annuus (Compositae) is a less competitive species than the previous alien plant. It was first found only in 2012 year at most parts of the established plots (except plot Bet30) (Fig. 2). *Erigeron annuus* was presented by isolated individuals scattered throughout the areas of the established plots, without thicket forming. By 2014, *Erigeron annuus* was observed only in

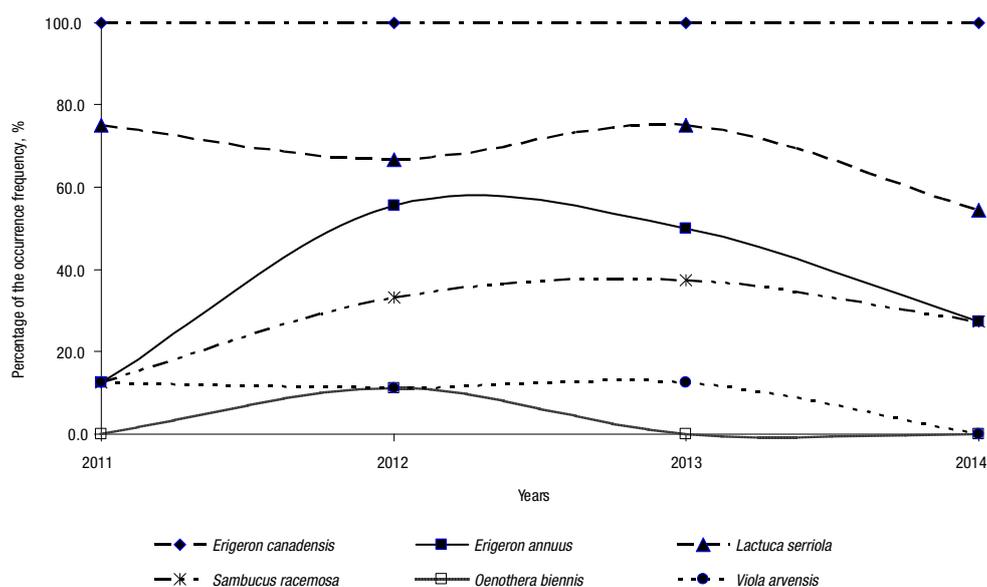


Figure 2. Percentage of occurrence of alien species found at established plots in fire-damaged forests of the Mordovia State Nature Reserve in 2011-2014.

two studied plots (Bet30 and Que36) as few isolated plant individuals. Apparently, *Erigeron annuus* is able to penetrate into natural ecosystems of the Mordovia Reserve, but it cannot compete with native perennial plants (e.g. *Pteridium aquilinum* (L.) Kuhn, *Calamagrostis epigejos* (L.) Roth, undergrowth of *Betula pendula* and *Populus tremula* L.) recovering after a forest fire.

The Western European-Ancient Mediterranean species *Lactuca serriola* L. (*Compositae*) was observed in most parts of the studied plots in both coniferous and deciduous forest communities. The species was found as single individuals scattered throughout the areas of the studied plots. However, the plants are clearly visible because of their tall stems with numerous inflorescences. Last fact promotes active dissemination of *Lactuca serriola*. Also, high seed germination (Mikulka & Chodová, 2003) and its better effect in shade conditions (Kapeluszny *et al.*, 2011) were shown. All these facts provide establishing of *Lactuca serriola* in conditions of high competition with other plants. Because of the high competitiveness of this species and resistance to shading, *Lactuca serriola* is able to exist in the shade of the undergrowth of pioneer deciduous tree species. Thus, this species is a sustainable forest ecosystem component which can be considered as one of the invasive species that deserve special attention.

The finding of a single generative individual of *Oenothera biennis* (*Onagraceae* Juss.) in studied plot Pin38 in 2012 suggests that the seeds of this biennial plant were introduced into the area of this plot immediately after or during the wildfire in 2010 along forest roads and narrow clearings. Apparently, this biennial plant has not been found during the study of this plot in 2011, because the plant was found with a basal rosette of leaves. In warm and humid spring an average of 30% of seeds of *Oenothera biennis* are able to germinate within 4–5 days (Gladunova *et al.*, 2014); that is why we expect new findings of this plant in this established plot and adjacent areas in the future. In addition, we do not exclude the possibility of further dissemination of *Oenothera biennis* in the other areas

of the Mordovia Reserve either, especially along forest roads and narrow clearings in areas damaged by the fire in 2010.

Among all the alien species revealed in the Mordovia Reserve fire-damaged forests, *Viola arvensis* Murr. (*Violaceae* Batsch) and *Sambucus racemosa* L. (*Caprifoliaceae* Juss.) belong to archaeophytes which have been known in the Republic of Mordovia since the sixteenth century. They do not show a high invasive behaviour. Apparently, their findings are caused by random drift of seeds along the forest narrow clearings, which are located in the immediate vicinity of the findings of these plants. We have to say that the *Sambucus racemosa* bushes were depressed despite annual flowering and fruiting. *Viola arvensis* has been observed only in the established plot Que37 since 2011, but it was not found there in 2014. Thus, these two alien species have the lowest invasive activity. Their new findings are possible in disturbed habitats: narrow clearings, forest roads, neighborhoods of forest lodges, etc.

All studied plots are located in one of these types of forest: *Pinetum* (Pin07, Pin26, Pin27, Pin38, Pin40), *Piceetum* (Pic28, Pic29), *Quercetum* (Que36, Que37), *Betuletum* (Bet30), *Tilietum* (Til35). Of these, the deciduous forest ecosystems are the least resistant to plant invasion (Table 2). Coniferous forests were invaded by an average of 1.75 invasive species per established plot. Nevertheless, differences between deciduous and coniferous forest types are minimal.

Alien plants found outside the established plots in fire-damaged forests

In addition to the abovementioned alien plants, two invasive species included in the Black Book of Central Russia Flora (Vinogradova *et al.*, 2010) were found in the Mordovia Reserve outside the plots listed above. These are *Solidago canadensis* L. and *Bidens frondosa* L. from the *Compositae* family.

Despite the long history of the study of the Mordovia State Nature Reserve flora (since 1936), the

Table 2. Average number of invasive plant species found per established plot in different type of forest

Parameters	<i>Pinetum</i>	<i>Piceetum</i>	<i>Quercetum</i>	<i>Betuletum</i>	<i>Tilietum</i>
<i>M</i>	1.75	1.75	2.25	2	2
<i>min</i>	1	1.5	1.75	2	2
<i>max</i>	2.75	2	2.75	2	2

M – mean value, *min* – minimal value, *max* – maximal value; For this calculation, we did not consider the two alien non-invasive species *Sambucus racemosa* and *Viola arvensis* because of their findings are accidental within studied plots.

first locations of *Solidago canadensis* in this area were found at first in 2012. These were located along a railway in the northeastern part of the Mordovia Reserve (Khapugin *et al.*, 2013). In 2013, only one individual was recorded at the roadside nearby Pushta settlement. But in 2014 and 2015, new findings of *Solidago canadensis* were found relatively far away from the settlements, deep in the forests. *Solidago canadensis* penetrates in new localities predominantly along forest roads and narrow clearings. This is confirmed by the observation that all known localities of this invasive species are presented at roadsides and forest glades. We suggest that invasive plant diaspores penetrated into the Mordovia Reserve from the south, where abandoned arable lands are located. These abandoned areas are occupied by individuals of *Solidago canadensis* which not infrequently form a yellow aspect during flowering. The high level of penetration of *Solidago canadensis* along forest roads and narrow clearings coupled with its high invasiveness and closest location of its dispersal center (abandoned arable lands) are the main reasons to foresee a wide penetration of this invasive species in natural forest ecosystems in near future. In our opinion, the wildfire of 2010 was the main factor which provided *Solidago canadensis* to start its invasion due to a wide range of invasion ways as well as thinning of the forest stand, promoting the penetration of the anemophilous seeds of this plant.

Newly revealed locations of *Bidens frondosa* are few. It was first found in the Mordovia Reserve in 2013 (Khapugin *et al.*, 2015b). This locality is placed between the established plots Pic29 and Que36 in alder-spruce forest damaged by the fire. Another locality of *Bidens frondosa* was found on the shores of Malaya Valza Lake. Here, the invasive plant was presented by single individuals scattered throughout the hygrophytic vegetation. We expect that new findings of *Bidens frondosa* in the Mordovia Reserve in future will be found predominantly near water bodies often used by human (e.g. ponds in the Pushta settlement and near the Steklyannyi cordon, the lakes Picherki, Inorki, the rivers Pushta, Satis).

Thus, despite the resistance of forest ecosystems to plant invasions (Pearsall, 1959; Keeley *et al.*, 2003), eight alien plant species were registered in different types of forest damaged by a wildfire in 2010. No differences in invasibility of tested forest ecosystems were detected.

In conclusion, *Erigeron canadensis*, *Lactuca serriola* and *Solidago canadensis* are the most invasive plants in the Mordovia Nature Reserve and these species are the most probable invaders of studied forest ecosystems in the future. These preliminary findings

point out the potential effect of fire to exacerbate the invasibility of some ruderal species in the taiga zone.

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