J Arid Land (2013) 5(4): 434–438
doi: 10.1007/s40333-013-0165-z
jal.xjegi.com; www.springer.com/40333

Forestry activity is one mechanism of invasion by arboreal plants

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Abstract: For a long time, forestry primarily had industrial goals. Volume of wood production was the main criterion of forestry efficacy, and thus rapid-growing arboreal species were cultivated in natural forests. More recently, nature protection has become one of forestry's goals. Unfortunately, some introduced, rapid-growing species became aggressive components of natural ecological systems during the interim. In this paper, we first describe a method that we developed to categorize aggressiveness of invasive arboreal plants in natural forest ecosystems of Kazakhstan. We then apply this new scheme to monitoring data of invasive arboreal plants to provide an insight into the invasion potential of different species in the fruit forests of Southeast Kazakhstan.

Keywords: forest ecosystems; aggressiveness; invasive arboreal plants

Citation: Gulnara SITPAEVA, Sergey CHEKALIN. 2013. Forestry activity is one mechanism of invasion by arboreal plants. Journal of Arid Land, 5(4): 434–438. doi: 10.1007/s40333-013-0165-z

It has long been known that introduced plants become naturalized into ecosystems through a process of "naturalization" (Thellung, 1910, 1915). These alien, naturalized plants can occupy large areas and transform natural ecosystems (Salisbury, 1952; Conolly, 1977). Although these facts were known at the time, they were not taken into account in practical activities. For example, people often purposefully introduced alien plants into natural ecosystems for aesthetic as well as practical reasons, such as to increase forestry activities. For a long time, forestry primarily had industrial goals, and volume of wood produced was the main criterion of forestry efficacy. Consequently, rapid-growing arboreal species were cultivated in natural forests to increase wood production. However, the Handbook of the Convention on Biological Diversity (Secretariat of the Convention of Biological Diversity, 2001) brought a new emphasis on nature protection. One objective of the Convention is to control aggressive invasive plants, which are harmful to natural ecosystems and species and thus to biodiversity. Although protection of nature is now among the goals of forestry, we lack sufficient knowledge to recognize and manage invasive plants.

Investigations of invasive arboreal plants in natural forest ecosystems of Kazakhstan have begun after the signing of the Convention on Biological Diversity. The aims of our study are first to describe a method to categorize invasive arboreal plants and second to use this method to understand the process by which invasive arboreal species disperse in Kazakhstan's fruit forests. Our method to categorize invasive arboreal plants includes accurate definitions of aggressiveness levels for arboreal plants and the manner in which they arrived in natural forest ecosystems. We consider that "aggressiveness" for an invasive species arises from interactions between species traits and the local biotic and abiotic environment. Aggressiveness is expressed as increasing population levels and may include evolutionary changes in species traits.

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Received 2012-11-30; revised 2013-02-16; accepted 2013-03-05

1 Materials and methods

Chekalin and Nurmuratuly (2010) showed that invasive plants cannot be simply divided into aggressive and non-aggressive categories, and we have found that three levels of aggressiveness better describes population growth of invasive species. Introduced species may occur in an ecological system for long time periods without increasing their plant population. We call this condition for an introduced species "latent". The next level of aggressiveness is "potential aggressive". This level occurs when the number of plants of such species is increasing in natural ecosystem, but without any significant effects on the plant populations of other species. In practice, we consider a species "potential aggressive" until its plant population is no more than 5% of the total population of trees in community or of young trees. If population size of the invasive species is greater than 5%, then it is categorized as "aggressive". Thus, 3 levels of aggressiveness are defined for populations of invasive species: "latent" (L); "potential aggressive" (P); "aggressive" (A). Aggressiveness for a species' population was categorized based on the most aggressive level observed in any one plot; our logic was that if the species population growth was aggressive in one location, then it is likely to become aggressive in the others over time. We recognize that this method represents the worst-case scenario.

To establish the level of aggressiveness for invasive species in a community, we need to determine population sizes of arboreal species. Two methods are used to determine population size (Bykov, 1988). If the total population of arboreal plants in the community is not large (e.g. no more than 100–150 plants), a complete census is used where every arboreal plant in the community is enumerated. For larger populations, population size must be estimated. For this method, the territory of the community is divided into subareas with different ecological conditions and with different plant diversities. Within each subarea, census plots that encompass no less than 100 arboreal plants are established. The number of plots needed is dependent on size and variability of the community and encompasses no less than 10% of its arboreal plants.

The ages of plants in both plantation and natural forests are established as well. If the age structure of the introduced arboreal species indicates increasing numbers of progressively younger plants, this species is categorized as "potential aggressive". If such an age structure of the introduced arboreal species is not established, this species is "latent". In addition to age structure, the method of plant dispersal into natural communities (e.g. wind, water, animals, and birds) should be described.

The species aggressiveness classification methods above were applied to data from monitoring invasive plants in fruit forests of the Nature Protected Territories of Transiliyskiy and of Djungarskiy Alatau (Chekalin, 2007). These analyses were conducted for three different community types in Kazakhstan: in forest plantations that contain introduced arboreal species and in both fruit gardens and natural forests near to where introduced abroad species are cultivated. The aim of such analyses is to establish whether an introduced arboreal species can reproduce in areas where it is cultivated.

2 Results and discussion

Results for introduced arboreal plants growing in fruit forests of Ile-Alatauskiy and Djungar-Alatauuskiy State Nature Parks and of Almatinskiy State Nature Reserve are shown in Tables 1–3 for both surveys in 2000 and 2005.

Not all introduced arboreal species currently have aggressive populations. Ile-Alatauskiy State Nature Park has 7 aggressive species (44%), Almatinskiy State Nature Reserve has 5 (46%), and Djungar-Alatauskiy State Nature Park has 4 (33%). Thus, one third to one half of introduced plants have aggressive populations now.

The most aggressive invasive species is *Malus domestica* Borkh. This species has aggressive populations in all protected territories that were investigated. Originally, *Malus domestica* Borkh. was established for plant breeding of new apple-tree cultivars by hybridization with native apple species. Molecular-genetic data that were obtained by Kazakhstan's Institute of Botany and Institute of Biology and Biotechnology revealed that *Malus domestica* Borkh. has largely

Table 1 Aggressiveness for populations of introduced arboreal plants in Ile-Alatauskiy State Nature Park

Species	2000			Level of aggressiveness	2005			Level of aggressiveness
	Fruit garden	Forest plantation	Nature ecosystem		Fruit garden	Forest plantation	Nature ecosystem	
Malus domestica Borkh.	+	+	+	A	+	+	+	A
Ulmus pumila L.		+	+	A		+	+	A
Ulmus laevis Pall.		+	+	A		+	+	A
Acer negundo L.		+	+	A		+	+	A
Fraxinus lanceolata Borkh.		+	+	A		+	+	A
Prunus domestica L.								
Prunus spinosa L.	+		+	A	+		+	A
Juglans regia L.	+		+	A	+		+	A
Cerasus avium (L.) Moench.	+		+	A	+		+	P
Prunus cerasifera	+		+	P	+		+	P
Pyrus domestica Medic								
Robinia pseudoacacia L.	+		+	P	+		+	P
Betula pendula Roth.	+		+	P	+		+	P
Pinus sylvestris L.		+	+	P		+	+	P
Quercus robur L.		+		L		+		L
Aronia melanocarpa (Michx.) Elliott		+		L		+		L

Note: A, aggressive; L, latent; P, potential aggressive. Presence of each introduced arboreal species in each community type is indicated with a "+".

Table 2 Aggressiveness for populations of introduced arboreal plants in Almatinskiy State Nature Reserve

Species	2000			Level of aggressiveness	2005			Level of aggressiveness
	Fruit garden	Forest plantation	Nature ecosystem		Fruit garden	Forest plantation	Nature ecosystem	
Malus domestica Borkh.	+	+	+	A	+	+	+	A
Ulmus pumila L.		+	+	A		+	+	A
Ulmus laevis Pall.		+	+	A		+	+	A
Acer negundo L.		+	+	A		+	+	A
Fraxinus lanceolata Borkh.		+	+	A		+	+	A
Pyrus domestica Medic								
Pinus sylvestris L.	+		+	P	+		+	P
Picea abies (L.) Karst.		+		L		+	+	P
Syringa vulgaris L.		+		L		+		L
Quercus robur L.		+		L		+		L
Amelanchier ovalis Medic			+	L		+	+	L

Note: A, aggressive; L, latent; P, potential aggressive. Presence of each introduced arboreal species in each community type is indicated with a "+".

Table 3 Aggressiveness for populations of introduced arboreal plants in Djungar-Alatauskiy State Nature Park

Species	2000			Level of aggressiveness	2005			Level of aggressiveness
	Fruit garden	Forest plantation	Nature ecosystem		Fruit garden	Forest plantations	Nature ecosystem	
Malus domestica Borkh.	+	+	+	A	+	+	+	A
Ulmus pumila L.		+	+	A		+	+	A
Ulmus laevis Pall.		+	+	A		+	+	A
Acer negundo L.		+	+	A		+	+	A
Armeniaca vulgaris Lam.	+	+	+	P	+	+	+	P
Tilia cordata Mill.		+		L		+	+	P
Quercus robur L.		+		L		+	+	P
Pinus sylvestris L.		+		L		+		L
Picea obovata		+		L		+		L
Larix sibirica Ledeb.		+		L		+		L
Populus nigra L.		+		L		+		L
Malus baccata (L.) Borkh.		+		L		+		L

Note: A, aggressive; L, latent; P, potential aggressive. Presence of each introduced arboreal species in each community type is indicated with a "+".

displaced *Malus sieversii* (Ledeb.) M. Roem. Thus, this introduced species now has established its own populations and has become a "naturalized" species.

Ulmus pumila L., *Ulmus laevis* Pall., and *Acer negundo* L. are species with aggressive populations as well. They are aggressive on all mountain territories that we surveyed. Some introduced species (*Fraxinus lanceolata* Borkh., *Prunus domestica* L., and *Prunus spinosa* L.) are not aggressive in all surveyed territories but have aggressive populations only in local territories. Our results also indicate that the level of population aggressiveness changed through time. This observation is illustrated by *Quercus robur* L. in Djungar-Alatauskiy State Nature Park and *Pinus sylvestris* L. in Almatinskiy State Nature Reserve.

Pinus sylvestris L. was used to create forest plantations in Transiliyskiy Alatau more than 100 years ago. After this initial introduction, populations of *Pinus sylvestris* L. were "latent". However, current surveys indicate that it has become "potential aggressive" now in both Ile-Alatauskiy and Almatinskiy State Nature Reserves. In both territories, plants of *Pinus sylvestris* L. likely dispersed from forest cultures into natural communities. Similary, *Quercus robur* L. was used for forest cultures in Djungarskiy Alatau more than 50 years ago. For long time, it too was "latent". Now, its populations are "potential aggressive".

We suspect that changes in population aggressiveness of introduced arboreal species are at least partially related to climate change. For example, recent invasions of introduced arboreal plants into upper mountainous areas are likely due to increasing global temperature (Chekalin et al., 2007). However, differences in aggressiveness at the same elevation are not likely due to increasing global temperature. Because temperature at any one elevation is also influenced by aspect (Proskurakov, 2012), plants at the same elevation often experience different ecological conditions. Thus, the levels of aggressiveness of introduced arboreal plants would differ depending on aspect as well. Of course, changes in aggressiveness are also affected by other changes in ecological conditions or simply due to the lag in species response that often occurs during plant invasions (Mack et al., 2000).

Introduced arboreal plants likely disperse into nature forest ecosystems of Transiliyskiy and Djungarskiy Alatau from either forest plantations or fruit gardens. When an introduced arboreal species occurs in one of the cultured areas (i.e. fruit gardens and forest plantations) and in nearby natural ecosystems, we infer that the species dispersed into the natural ecosystem from the cultivation area. This inference is supported by comparison of the age structure of plants in the cultivation and natural areas. If arboreal plants have seeds in the cultivation area and if the maximum age of plants in the cultivation area is greater than that in the natural area, age structure data reinforce the inference that the introduced arboreal species dispersed into natural areas from the cultivation area. Among all introduced arboreal species, 62%–100% of them likely dispersed from forest plantations and 17%–35% likely dispersed from fruit gardens. If we analyze only species with aggressive populations, then 71%–100% of species dispersed from forest plantations and 25%–44% dispersed from fruit gardens. Clearly, forest plantations are the main source for aggressive invasive arboreal plants in natural forests.

An unresolved question is: Do populations of an invasive arboreal species in one particular community type have to reach higher levels of aggressiveness before it can spread into additional community types? If the species is growing only in culture, then we suspect that the change in aggressiveness has to occur in culture before that species is able to spread into natural ecosystems. But if the species is present in natural ecosystems, then the change in aggressiveness level from "latent" to "potential aggressive" may occur first in nature then in culture or first in culture then in nature. We suspect that local ecological conditions will determine where these latter changes in aggressiveness first occur.

3 Conclusions

Our investigations of introduced arboreal species in Kazakhstan's mountain fruit forest ecosystems show that (1) the level of population aggressiveness for invasive arboreal plants changes. These changes through time are likely related to changes in ecological conditions, although these relationships need further investigation. Because population aggressiveness changes,

monitoring of invasive plants should be completed regularly, such as every 5 years, in order to detect and then control the levels of their aggressiveness. (2) The main source populations for invasive arboreal plants that are currently found in natural forests in the mountain ecosystems of Kazakhstan are from forestry plantations near the territories of nature reserves.

Acknowledgements

Thanks to the organizers and supporters of the International Symposium on Invasive Plants and Global Change in Urumqi, China in 2012 for their heroic work in building a successful meeting.

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