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Distribution and environmental impact of alien woody species in lowland riparian forest habitats: Case study in the protected areas of Georgia, South Caucasus

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Abstract: Biological invasions are globally recognised as a significant threat to native biodiversity, as they can change the structure, composition, and functioning of the native ecological system. The riparian forest is considered a habitat highly invaded by invasive plants since rivers serve as corridors for alien species through the terrestrial ecosystem or may simply harbour exotic species that cannot survive elsewhere. The riparian forest, as a high conservation value forest, is an important part of the lowland forests of Georgia. These forests are distributed along large rivers, including the Mtkvari, Alazani, Iori, Aragvi, Ksani, Algeti, and Great and Little Liakhvi rivers. Here, we present a case study that was part of the scientific project titled 'Survey of Potential Invasive Alien Woody Species (PIAWS) in the Protected Areas of Georgia'. Protected areas (PAs) in Georgia play an important role in conserving native biodiversity, including forest ecosystems of distinguished biodiversity. We focused on the lowland riparian forest (LRF) distributed along the Mtkvari and Iori rivers within two PAs – Korugi and Gardabani Managed Reserves (MRs). Six main alien woody species (AWS) were identified in the study areas: *Robinia pseudoacacia*, *Gleditsia triacanthos*, *Ailanthus altissima*, *Acer negundo*, *Amorpha fruticose* and *Morus alba*. Among these AWS, the local status of *R. pseudoacacia*, *G. triacanthos, A. altissima*, *and A. fruticosa* is invasive, while that of *A. negundo* and *M. alba* is naturalised. The environmental impact of AWS on LRF habitat was evaluated using the Environmental Impact Classification for Alien Taxa (EICAT) classification system. A major or moderate impact of AWS on the LRF habitat is evident, which, according to EICAT impact mechanisms, is expressed as apparent competition and physical, structural and indirect impacts. The study revealed that the impact levels of three AWS, *R. pseudoacacia*, *G. triacanthos*, and *A. altissima*, were classified as major or moderate ('harmful' impact), while the remaining AWS, *A. negundo* and *A. fruticosa*, were of minor or minimal concern. AWS in the invaded areas of the LRF are found as an understorey layer or, otherwise, they have already formed the main canopy and replaced native dominant woody species. Therefore, undesirable structural and succession processes in invaded LRFs are evident.

Keywords: conservation; Environmental Impact Classification for Alien Taxa (EICAT); exotic trees; invasion

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Biological invasion is globally recognised as a significant threat to native biodiversity (Drake et al. 1989; Wilcove et al. 1998; Pyšek et al. 2020), as it can change the structure, composition, and functioning of native ecological systems (Hejda et al. 2009; Vilà et al. 2011; Jeschke et al. 2014).

The problem is caused by introduced species, some of which become naturalised and invasive or even transformer in the new habitats (Richardson et al. 2000). Riparian forests are considered a highly vulnerable habitat to invasions due to rivers serving as corridors for alien species through terrestrial ecosystems, providing a rich propagule source, usually being associated with a large number of available nutrients, and providing a wide range of disturbed sites that offer safe space for many exotic species that cannot survive elsewhere (DeFerrari, Naiman 1994).

Lowland forests in Georgia are distributed on swamps, flood plains and riverbanks, where water conditions allow the development of forest vegetation (Grossheim 1948). These lowland forests are distributed along large rivers, such as the Mtkvari, Alazani, Iori, Aragvi, Ksani, Algeti, and Great and Little Liakhvi rivers (Ketskhoveli 1959; Akhalkatsi, Tarkhnishvili 2012). Since the last century, lowland riparian forests (LRFs) in Georgia have experienced significant anthropogenic pressure, leading to a significant reduction in local primary riparian forest formations dominated by *Quercus robur* ssp. *pedunculiflora* and *Ulmus minor*, which have survived only in fragments (Ketskhoveli 1959). In addition to fragmentation and overexploitation, the important challenge for riparian forests is the negative impact of alien woody species (AWS), some of which – *Robinia pseudoacacia*, *Gleditsia triacanthos*, and *Morus alba* – have been cultivated in the past for forestry in plantations or as living fences and windbreaks (Aleksidze et al. 2021).

Here, we present a case study in the protected areas (PAs) of Georgia. PAs in Georgia play an important role in conserving native biodiversity, including forest ecosystems of distinguished biodiversity (Gigauri 2000; CEPF 2003). Currently, approximately 47% of the PAs territory is covered with various types of natural forest. Forests are the prevailing type of vegetation in Georgia and the major ecosystem in the Caucasus hotspot (CEPF 2003; Nakhutsrishvili 2013). The objective of the study was to identify AWS and review their potential environmental impact on invaded LRFs. Using this methodology, an impact assessment was carried out based on the characteristics of the AWS, such as distribution, abundance, regeneration, and competition (growth).

MATERIAL AND METHODS

Study area. The study was conducted in the LRFs of the Gardabani and Korugi Managed Reserves (MRs, IUCN category IV), which are located in Eastern Georgia, along the large Mtkvari and Iori rivers (Figure 1). According to the IUCN definition (Dudley 2007), managed reserves are a category of protected areas that are created for the maintenance, conservation, and restoration of species and habitats. In our case, protected areas at both study sites are created to maintain, conserve, and restore LRF habitats. The Iori Plateau and Gardabani Sanctuary sites, including LRFs, which are in the Korugi and Gardabani MRs, are a part of the Iori-Mingachevir Corridor. This corridor includes most of the globally threatened species and is a significant area of waterfowl and Caucasian endemics (CEPF 2003).

The Gardabani MR (3 484 ha) is located in the territory of Gardabani and Marneuli municipalities, near the border of the Republic of Azerbaijan, at 260–290 m a.s.l. The mean annual temperature is 13 °C, and the mean annual precipitation is 420 mm. The soils are alluvial calcareous – Calcaric fluvisol type (FAO 2014; Urushadze et al. 2019). The LRF is distributed along the lower stream of the Mtkvari River. The prevailing vegetation is a typical alluvial riparian forest comprising the following native tree species: *Populus alba* var. *canescens*, *Populus nigra*, *Salix alba*, *Salix excelsa*, and *Quercus robur* ssp. *pedunculiflora*, *Ulmus minor* and *Juglans regia*; the lower layers are represented by *Crataegus caucasica*, *Tamarix ramosissima*, *Ligustrum vulgare*, and *Hippophae rhamnoides*. Lianas and herbaceous species include *Clematis vitalba*, *Humulus lupulus*, *Hedera helix*, *Althaea* sp., and *Periploca graeca* (Ketskhoveli 1959; Akhalkatsi, Tarkhnishvili 2012; Nakhutsrishvili 2013).

The Korugi MR (16 281 ha) is in Southeast Georgia, in the territory of Sagarejo and Gurjaani municipalities, at 430–500 m a.s.l. The mean annual temperature is 12–14 °C, and the mean annual precipitation is 590 mm. Different types of soils are represented in the area: black calcareous – Calcic Vertisols, cinnamonic calcareous – Calcaric Kasta-

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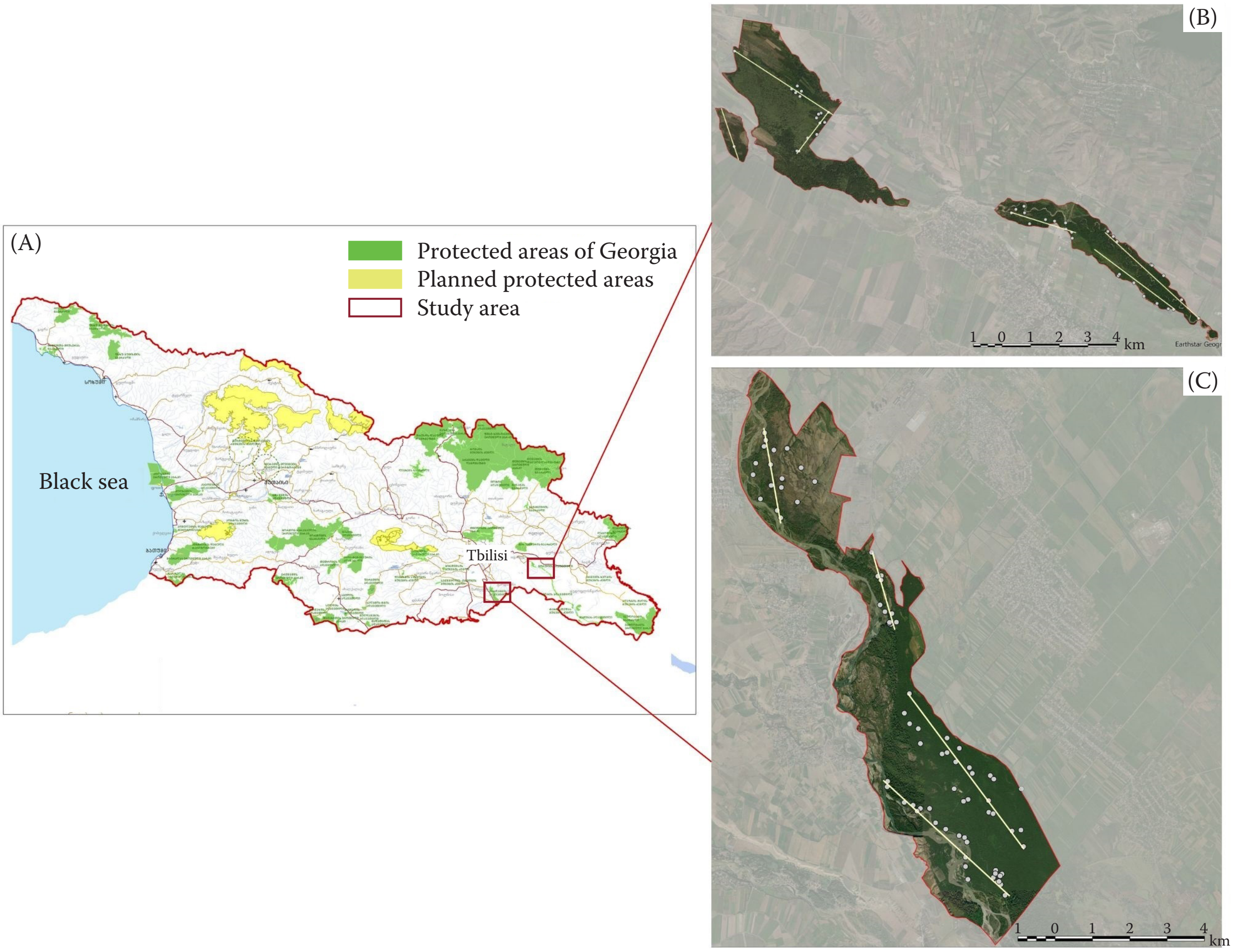

Figure 1. Study areas of the Korugi and Gardabani Managed Reserves; the map shows (A) their location in Georgia, as well as the individual reserves in the orthophoto maps: (B) Korugi Managed Reserve, (C) Gardabani Managed Reserve (APA 2022)

nozems, alluvial calcareous – Calcaric Fluvisols and grey cinnamomic – Haplic, Calcic Kastanozems (Urushadze et al. 2019). The LRF is distributed along the Iori River. There is a Tugai riparian forest, which is common on the riverbanks of the Iori, Alazani and Mtkvari rivers (Grossheim 1948; Akhalkatsi, Tarkhnishvili 2012). The main primary forest-forming tree species are *Populus nigra*, *Populus alba* var. *canescens*, *Salix alba*, *Quercus robur* ssp. *pedunculiflora* and *Ulmus minor*, and the secondary forest-forming species are *Pyrus communis* ssp. *caucasica*, *Malus orientalis* and *Prunus cerasifera*. Lower layers are formed by *Crataegus caucasica*, *Tamarix ramosissima*, *Hippophae rhamnoides*, *Ligustrum vulgare*, *Prunus spinosa*, *Elaeagnus angustifolia*, *Berberis* sp., and *Euonymus europaeus*. Lianas and herbaceous species include *Hedera helix*, *Clematis vitalba*, *Humulus lupulus*, *Periploca graeca*, *Rosa canina*, and *Althaea* sp.

Considering the forest formations described in the study areas, the forest habitat types were specified according to the EUNIS habitat classification system (Table 1; Chytrý et al. 2020).

Studied alien species. Six AWS were identified in the study areas (Table 2). The distribution of some AWS in the study areas is the outcome of intentional introduction. For instance, *R. pseudoacacia* was planted as a fuelwood plantation in the last century, *G. triacanthos* as a living fence around the PAs or around the cropland near PAs as well as a windbreak, and *M. alba* plantations were established for silkworm feeding. Using AWS in commercial forestry or agroforestry is a common practice, but it causes major problems when AWS act as invaders of natural ecosystems (Richardson 1998). The distribution of the rest of the studied AWS is related to accidental introduction (Aleksidze et al. 2021). To specify the

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Table 1. Habitat types of the studied lowland riparian forest (LRF)

EUNIS habitat type	NATURA 2000 habitat type	References
T11 – temperate *Salix* and *Populus* riparian forest	91E0 Code of Georgia: alluvial forests with adler trees	Akhalkatsi, Tarkhnishvili (2012); Goginashvili et al. (2021); Chytrý et al. (2020)
T13 – temperate hardwood riparian forest	91F0 GE Code of Georgia: riparian mixed forests	

local status of the AWS, we followed the concepts of Richardson et al. (2000).

Data collection and analysis. Field sampling. The study was based on a combination of LRF vegetation analysis and a review of the potential impacts of the identified AWS. To obtain the forest vegetation data, we used a purposive sampling method (Rai, Thapa 2015; Kershaw et al. 2016) and recorded the individual occurrences along the line transects (Kangas, Maltamo 2006; Buckland et al. 2015; Kershaw et al. 2016). In each MR, we allocated four circular sample plots (r = 12.62 m, s = 500 m^2) in different formations of invaded LRF habitat and 20 square subplots (2 × 2 m, s = 4 m^2) within the sample plots (5 in each sample plot, Figure 2). All trees by species with a diameter at breast height (*DBH*) ≤ 8 cm were measured within the inner plot, and regeneration (seedlings, sprouts, saplings) by species was examined in subplots.

Characteristics of understorey vegetation (species composition, relative cover % by species) and seed production of mature trees were visually estimated. The diameter and height were measured using a DP II Computer Calliper and Vertex IV (Haglöf, Sweden), respectively. Invaded stand parameters, which characterise structure [average age, species composition (abundance), frequency, mean diameter and height, density and competitive status], were calculated using the following equations and methodological approaches (Kangas, Maltamo 2006; Kershaw et al. 2016):

The arithmetic mean diameter was determined using the following Equation (1):

$$\bar{d} = \sum_{i=1}^{n} \frac{d^i}{n} \tag{1}$$

where:

d_i – diameter at breast height (*DBH)* of the i^{th} tree species;

n – number of trees measured.

Table 2. Identified alien woody species (AWS) in the study areas (WFO 2022)

Common name	Scientific name	Family	Life form	Native range	Introduction pathway	Local status	Korugi Managed Reserve	Gardabani Managed Reserve
Black locust	*Robinia pseudoacacia*	*Fabaceae*	tree	North America	deliberate	invasive	+	+
Honey locust	*Gleditsia triacanthos*	*Fabaceae*	tree	North America	deliberate	invasive	+	+
Boxelder	*Acer negundo*	*Sapindaceae*	tree	North America	accidental	naturalised	+	+
Tree of heaven	*Ailanthus altissima*	*Simaroubaceae*	tree	temperate Asia	accidental	invasive	–	+
False indigo	*Amorpha fruticosa*	*Fabaceae*	shrub	North America	accidental	invasive	+	+
White mulberry	*Morus alba*	*Moraceae*	tree	temperate Asia	deliberate	naturalised	+	+

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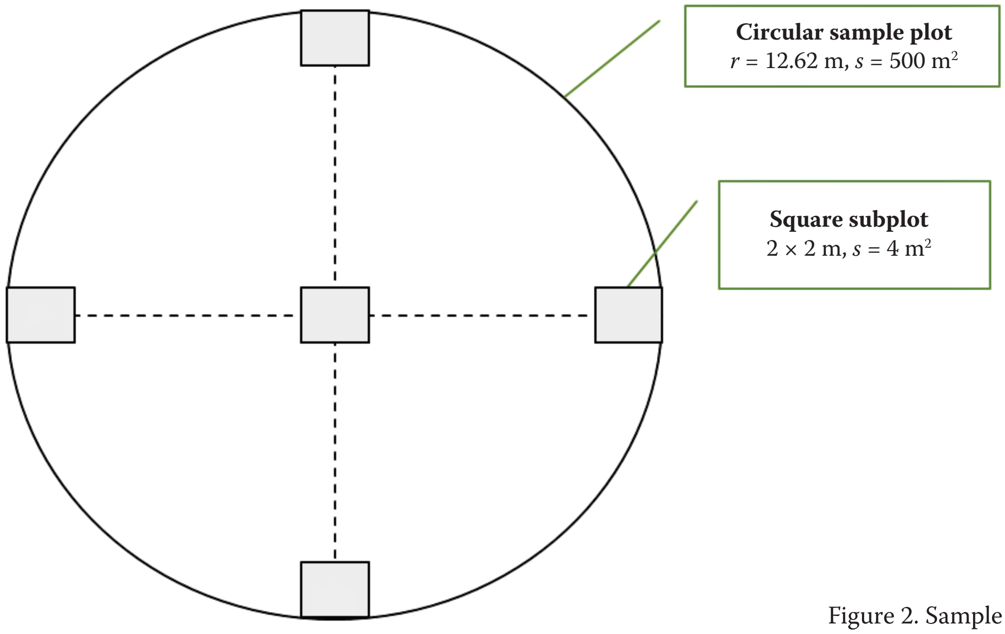

Figure 2. Sample plot design

Average height by species was calculated using the following Equation (2) (Lorey's mean height):

$$n_L = \frac{n_1 g_1 h_1 + n_2 g_2 h_2 + \ldots + n_n g_n h_n}{G} = \frac{\sum_{i=1}^{n} n_i g_i h_i}{\sum_{i=1}^{n} n_i g_i} \quad (2)$$

where:
G – total basal area per sample plot;
n_i – number of trees in the i^{th} diameter class;
g_i – average basal area of the i^{th} diameter class;
h_i – average height of the trees in the i^{th} diameter class.

Species composition K (%) was expressed using several individuals (abundance) in a population using Equation (3):

$$K = \frac{n_i \times 100}{N} \quad (3)$$

where:
n – number of individuals of the i^{th} species present in the sample population;
N – total number of individuals in the sample population.

The average age was determined by bore core analyses of sample trees in the plot (by species).

Stand density (frequency) was calculated using the following Equation (4):

$$P = \frac{\sum G_{obs}}{\sum G_{norm}} \quad (4)$$

where:
G_{obs} – observed basal area of the stand;
G_{norm} – basal area of a normal stand of the same age and site index.

The stocking (plot-count) method was used for the regeneration study. All individuals on each subplot by species were counted. Counts are then converted into per ha using the appropriate expansion factor [Equation (5)]:

$$N = 10\,000 \frac{n}{s} \quad (5)$$

where:
n – total number of individuals per subplot;
s – total area of the subplot.

Finally, regeneration conditions (very good, good, satisfactory, weak, and very weak) were determined and assessed.

The competitive status of an AWS relative to all trees in the invaded stand was determined using the following Equation (6):

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$$G_i = \frac{\pi\left(\frac{D_i}{2}\right)^2}{\pi\left[\left(\frac{\sum_{i=1}^{n}\frac{D_i}{n}}{2}\right)\right]^2} = \frac{D_i^2}{\overline{D}^2} \tag{6}$$

where:

G_i – basal area index for the i^{th} tree;

D_i – diameter of the i^{th} tree;

$\overline{D}$ – mean plot diameter.

In addition, in both MRs, we collected more than 120 records (more than 50 in Korugi, 75 in Gardabani) along the transects (Figures 3, 4). We have described some characteristics of the invaded sites or individual occurrences, including dispersal (massive, fragmented, nested) and abundance (number of individuals); composition (species and cover %, including understorey and regeneration); disturbance (e.g. erosion, deadwood, fallen wood, pests and diseases, grazing) seed production and growth [height, *DBH*, age (bore cores of the largest and/or new invaded trees].

Impact assessment. To evaluate the invasiveness and environmental impact of the AWS, we used the Environmental Impact Classification for Alien Taxa (EICAT) (Blackburn et al. 2014; Hawkins et al. 2015; IUCN 2020). The scheme is based on twelve impact mechanisms and five categories of impact strength. We used the following seven of the twelve mechanisms for the AWS impact assessment: (*i*) competition – the alien taxon competes with native taxa for resources (e.g. food, water, space), leading to deleterious impacts on native taxa; (*ii*) hybridisation – the alien taxon hybridises with native taxa, leading to deleterious impacts on native taxa; (*iii*) transmission of disease – the alien taxon transmits diseases to native taxa, leading to deleterious impacts on native taxa; (*iv*) poisoning/toxicity – the alien taxon is toxic or allergenic by ingestion, inhalation or con-

Figure 3. Study sites in the Korugi Managed Reserve (MR)

Yellow lines – transects; white dots – the main location where AWS were recorded and/or allocated sample plots; AWS – alien woody species

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Figure 4. Study sites in Gardabani Managed Reserve (MR)

Yellow lines – transects; white dots – the main location where AWS were recorded and/or allocated sample plots; AWS – alien woody species

tact, or allelopathic to plants, leading to deleterious impacts on native taxa; (*v*) physical impact on ecosystem – the alien taxon causes changes to the physical characteristics of the native environment (e.g. disturbance or light regimes), leading to deleterious impacts on native taxa; (*vi*) structural impact on ecosystem – the alien taxon causes changes to the habitat structure (e.g. changes in architecture or complexity), leading to deleterious impacts on native taxa; (*vii*) indirect impacts through interactions with other species – the alien taxon interacts with other native or alien taxa (e.g. through any mechanism, including pollination, seed dispersal, apparent competition, etc.), facilitating an indirect deleterious impact on native taxa. These seven mechanisms are the most relevant to assessing the environmental impacts of AWS.

The level of impact was assessed according to the following EICAT impact categories: minimal concern (MC) – negligible impacts, and no reduction in performance of a native taxon's individuals; minor (MN) – performance of individuals reduced, but no decrease in population size; moderate (MO) – native taxon population decline; major (MR) – native taxon local extinction (i.e. change in community structure), which is naturally reversible; and massive (MV) – naturally irreversible local or global extinction of a native taxon (i.e. change in community structure). The Data Deficient (DD) category highlights taxa for which evidence suggests that alien populations exist but for which current information is insufficient to assess their level of impact. Not Evaluated (NE) is a taxon that is categorised as not evaluated when it has not yet been evaluated against the EICAT impact categories. These last two categories do not reflect the impact status of a taxon. Impacts that fall within the categories of moderate, major, or massive are termed 'harmful'. For assessment of the impacts, field data from our observations were used as well as a search in the literature. The list of species that were assessed for EICAT covered all the main AWS found in the field.

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RESULTS AND DISCUSSION

In the study areas, we found five main AWS: *Robinia pseudoacacia*, *Gleditsia triacanthos*, *Acer negundo*, *Ailanthus altissima*, and *Amorpha fruticosa*. These species were covered by the EICAT assessment. During the field survey, we recorded AWS *Morus alba*, and this species was found in both study sites in only a few localities. There are reports of this species escaping gardens to semi-natural habitats (Aleksidze et al. 2021); it can become invasive and have a strong negative effect on LRFs.

The main AWS found in the MRs are listed in Table 2. According to the study data, among these AWS, *R. pseudoacacia*, *G. triacanthos*, *A. altissima*, and *A. fruticosa* have local invasion status. *A. negundo* is considered naturalised, while *M. alba* can also be classified as naturalised but subspontaneous.

The identified AWS in the study areas are characterised by good growth rates, seed production and wide distribution, including considerable distance from the mother trees and/or primary sites (> 100 m). Based on the growth parameters, the identified AWS were characterised by a good growth rate under the conditions of Eastern Georgia, considering growth in the natural or well-acclimatised range (Table 3).

The growth parameters of the study AWS are as follows:

R. pseudoacacia is found in the study areas at the age of 20–25 years (average of trees in the plot), 14–16 m in height and 16–20 cm in *DBH*. The average annual increment in height is 0.6–0.7 m, and in *DBH* it is 0.8 cm. Growth parameters in the natural or well-acclimatised range under favourable conditions are an average annual increment in height of 0.5–0.8 m and in *DBH* of 0.5–1.9 cm (Nicolescu et al. 2020).

G. triacanthos is mainly represented by young trees in both study areas, although single mature trees were also recorded (*DBH* = 93 cm, *H* = 18 m). The height of a young, 32-year-old tree (average tree) is 16.6 m, and the *DBH* is 22.4 cm. The average annual increment in height is 0.51 cm and the average annual increment in *DBH* is 0.7 cm. Growth parameters in the natural or well-acclimatised range under favourable conditions are an average annual increment in height of 0.6–0.8 m and in *DBH* of 0.8–1.3 cm (Blair 1990).

A. negundo in the study areas, at the age of 16 years (average tree), is 13.5 m in height and 22.8 cm in *DBH*. The average annual increment in height is 0.84 m, and the average annual increment in *DBH* is 1.42 cm. Growth parameters in the natural or well-acclimatised range under favourable conditions are an average annual increment in height of 0.4–0.8 m and in *DBH* of 2.5 cm (Maeglin, Ohmann 1973; Overton 1990).

A. altissima in the Gardabani MR (not recorded in the Korugi MR) at the age of 10 years (average

Table 3. Growth parameters of AWS in the study areas

Species	Growth parameters				Age (yr)	Stem number in the invaded area (per ha)	Notes
	DBH (cm)	*H* (m)	mean increment in *H* ($m \cdot yr^{-1}$)	mean increment in *DBH* ($cm \cdot yr^{-1}$)			
Korugi MR							
Robinia pseudoacacia	45.5	22.2	0.38	0.78	58	120	middle-aged (large) tree
Robinia pseudoacacia	16.0	16.4	0.71	0.69	23	220	young (average) tree
Gleditsia triacanthos	22.4	16.6	0.51	0.70	32	60	young (average) tree
Acer negundo	22.8	13.5	0.84	1.42	16	160	average tree
Gardabani MR							
Gleditsia triacanthos	18.5	13.5	1.12	1.50	12	60	young (average) tree
Acer negundo	10.6	10.3	1.17	1.14	9	120	young (average) tree
Ailanthus altissima	13.1	9.7	0.97	1.31	10	120	young (average) tree
Robinia pseudoacacia	52.0	19.8	0.48	1.27	41	30	middle-aged (large) tree
Robinia pseudoacacia	19.2	14.8	0.59	0.77	25	60	young (average) tree

AWS – alien woody species; *DBH* – diameter at breast height; *H* – height; MR – Managed Reserve

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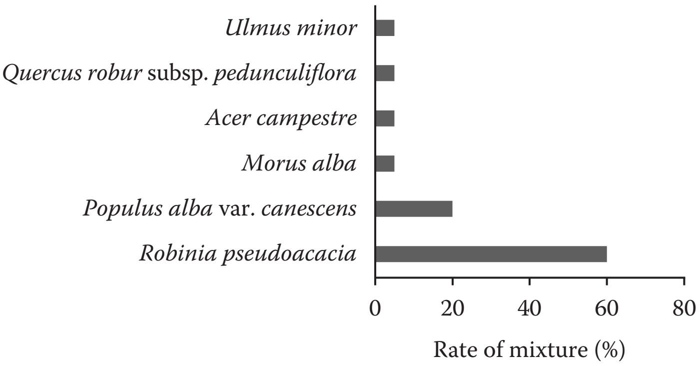
(A)



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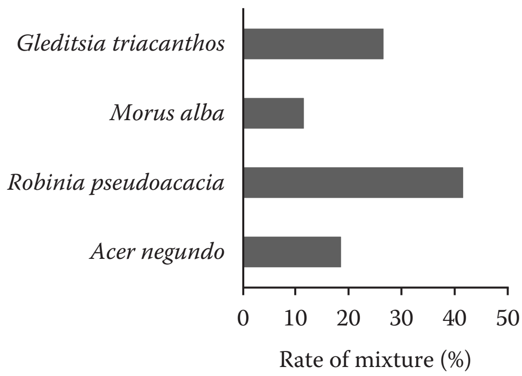


Figure 5. Stand composition of the invaded LRF in the Korugi Managed Reserve: (A) Stand composition that has been partly replaced by AWS, (B) stand composition that has been completely replaced by AWS

AWS – alien woody species; LRF – lowland riparian forest

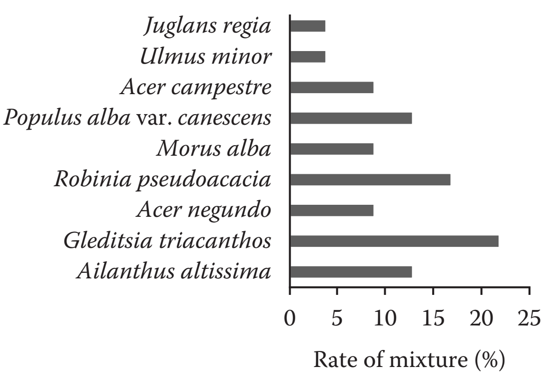
tree) is 9.7 m in height and 13.1 cm in *DBH*. The average annual increment in height is 0.97 m, and the average annual increment in *DBH* is 1.31 cm. Growth parameters in the natural or well-acclimatised range under favourable conditions are an average annual increment in height of 0.52 m and in *DBH* of 1.0 cm (Kowarik, Säumel 2007).

The good growth parameters of the AWS reveal their successful acclimatisation-adaptation in this area, as well as their high competitiveness with local woody species in LRFs, which increases their impact and invasion range.

High rates of mixture and abundance of AWS in LRF habitats are also indicators of high competition and impact (Pyšek et al. 2020). The invaded area in the Korugi MR is more than 30% of the total area. In the invaded part of the LRF, the rate of mixture of AWS is higher than that of native species, which is 68% (Figure 5A). There are some parts of the invaded area where only AWS are distributed, and native woody species are not recorded (Figure 5B). The main invaders in the Korugi MR are *R. pseudoacacia* and *G. triacanthos*. Additionally, unlike in the Gardabani MR, there are non-invaded areas, where still well-preserved riparian forest stands with native woody species can be found.

In the Gardabani MR, the invaded area is more than 80% of the total area. Unlike in the Korugi MR, the invasion-free (non-invaded) area in the Gardabani MR is fragmented. In the invaded LRF, the rate of mixture of AWS in this MR is also higher than that of native species and consists of 60–70% (Figure 6A, B). The main invaders in the Garda-

(A)



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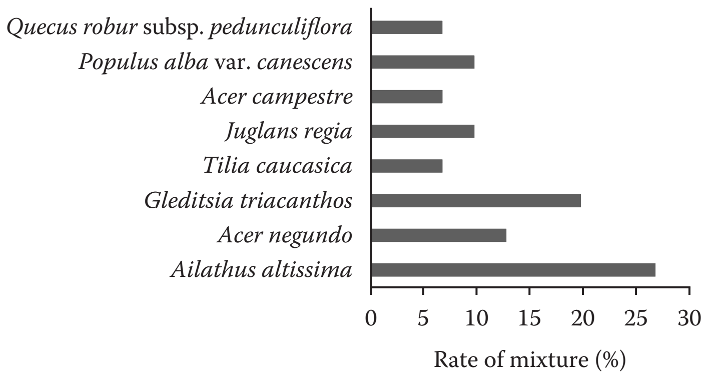

Figure 6. Stand composition of the invaded LRF in the Gardabani Managed Reserve: (A) Stand composition of *Populus* forest formations, (B) stand composition of mixed forest formations

LRF – lowland riparian forest

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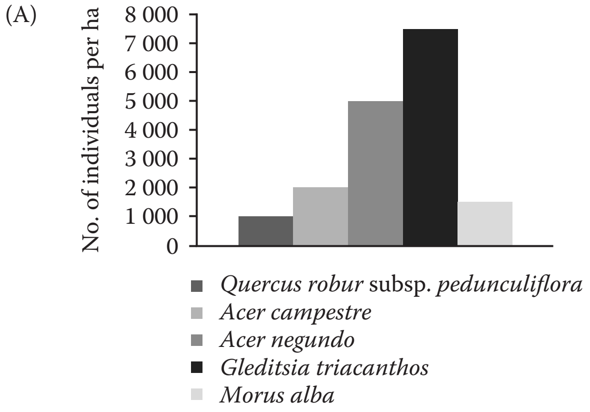


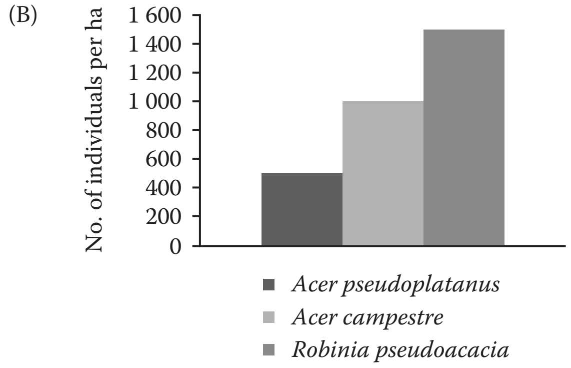


Figure 7. Characteristics of natural regeneration in different LRF formations in the Korugi Managed Reserve: (A) LRF formation that has been completely replaced by AWS, (B) invaded mixed forest formation

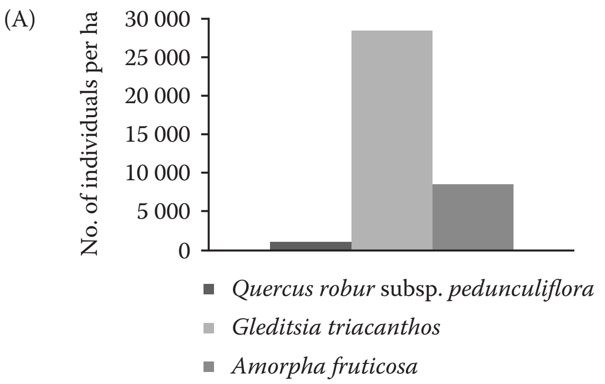
AWS – alien woody species; LRF – lowland riparian forest

bani MR are *G. triacanthos*, *A. altissima*, and *R. pseudoacacia*. *A. negundo* also poses a high potential threat.

We observed that high rates of mixture and abundance of the AWS affect microclimatic characteristics such as temperature and light regimes, which in turn affect the natural regeneration of native woody species. The rate of natural regeneration of AWS in the invaded territory significantly exceeds the rate of natural regeneration of local woody species.

According to the study data, in the invaded LRF habitat in the Korugi MR, where AWS have completely replaced the composition of the native stand, the condition of natural regeneration is weak. Although most individuals recorded are of AWS, local woody species are also found (Figure 7A). In the part of the LRF where the canopy layer is formed by local woody species – *P. alba* var. *canescens*, *P. nigra*, *Q. robur* ssp. *pedunculiflora*, *A. campestre*, and *U. minor* – *R. pseudoacacia* has invaded, and the condition of natural regeneration is weak. Although regeneration of local species is recorded here, the rate of regeneration of individuals of *R. pseudoacacia* still exceeds that of all local species (Figure 7B).

In the LRF habitat of the Gardabani MR, the non-invaded areas are very small and fragmented. In these areas, the rate of natural regeneration of local woody species was assessed as weak. In the invaded areas, the proportion of abundance (number of individuals) of AWS is high, exceeding 60% of the total at all locations (Figure 8B), and at some locations, this proportion reaches almost 100% (Figure 8A). It should be noted that the rate of natural regeneration of woody species



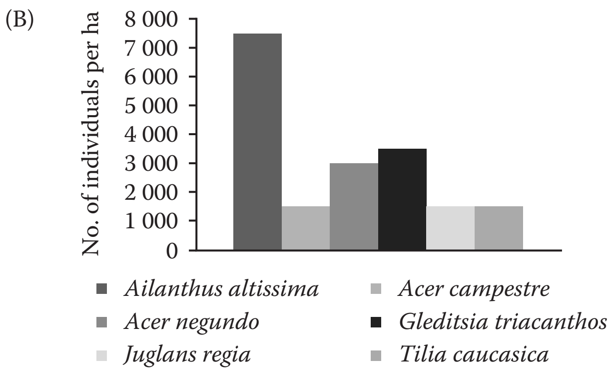


Figure 8. Characteristics of natural regeneration in different LRF formations in the Gardabani Managed Reserve: (A) invaded formations of *Q. robur* ssp. *pedunculiflora*; (B) invaded formations of *Populus* (*P. alba* var. *canescens*, *P. nigra*)

LRF – lowland riparian forest

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Table 4. Impact level of AWS according to EICAT impact mechanisms* in the Gardabani and Korugi Managed Reserves

Impact mechanisms	*Robinia pseudoacacia*		*Gleditsia triacanthos*		*Acer negundo*		*Ailanthus altissima***	*Amorpha fruticosa*	
	Gardabani	Korugi	Gardabani	Korugi	Gardabani	Korugi	Gardabani	Gardabani	Korugi
Competition	MO	MO	MR	MO	MN	MN	MO	MN	MN
Poisoning/toxicity	MO	MC	MN	MC	MN	MC	MO	MN	MC
Physical impact on ecosystem	MO	MO	MR	MO	MN	MN	MO	MN	MN
Structural impact on ecosystem	MO	MO	MR	MO	MN	MN	MO	MN	MC
Indirect impacts through interactions with other species	MO	MN	MO	MO	MC	MC	MO	MC	MC

* EICAT (Environmental Impact Classification for Alien Taxa) impact categories: massive (MV), major (MR), moderate (MO), minor (MN), minimal concern (MC); impacts that fall within the categories moderate, major or massive are termed 'harmful'; ** *A. altissima* was not identified in the Korugi Managed Reserve; AWS – alien woody species

in the invaded territory is generally good, and the total number of individuals exceeds 10 000 per ha and even reaches 30 000 in some locations (Figure 8A).

Along with the mentioned factors, the allelopathic effect of alien plants on other tree species should also be considered. Studies have confirmed that the leaves and roots of *A. altissima* contain phytotoxic components that inhibit the development of natural regeneration (Heisey 1990; Csiszár 2009; Bostan et al. 2014). The following species are also characterised by allelopathic effects: *A. negundo*, *M. alba*, *R. pseudoacacia*, and *A. fruticosa* (Csiszár 2009; Grabić et al. 2022), while *G. triacanthos*, *R. pseudoacacia*, and *A. fruticosa* are also nitrogen-fixing tree species (Rice et al. 2004; Kamlesh et al. 2007; Nuñez, Dickie 2014).

The invasive range and environmental impact of AWS on LRF habitats were assessed considering the discussed complex factors in accordance with the EICAT impact mechanisms (Table 4). It should be noted that due to the lack of pertinent research data in the ecoregion, the impact caused by hybridisation could not be assessed. Additionally, the spread of diseases or pests from AWS to native woody species has not been described (neither was recorded during our study).

A major or moderate impact of AWS on the LRF habitats is evident, which in accordance with the EICAT impact mechanisms is expressed as apparent competition and physical, structural and indirect impacts.

Finally, the impact levels of three AWS, *R. pseudoacacia*, *G. triacanthos*, and *A. altissima*, in the study areas were assessed as major or moderate, while those of *A. negundo* and *A. fruticosa* were assessed as minor or minimal (Table 5). The impact of *M. alba* at this stage of the study was not evaluated (NE) against the EICAT impact categories.

Table 5. EICAT impact level* of AWS in the Gardabani and Korugi Managed Reserves

Managed Reserve	*Robinia pseudoacacia*	*Gleditsia triacanthos*	*Acer negundo*	*Ailanthus altissima*	*Amorpha fruticosa*
Gardabani	MO	MR	MN	MO	MN
Korugi	MO	MO	MC	–	MC

* EICAT (Environmental Impact Classification for Alien Taxa) impact categories: massive (MV), major (MR), moderate (MO), minor (MN), minimal concern (MC); impacts that fall within the categories moderate, major or massive are termed 'harmful'; AWS – alien woody species

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CONCLUSION

Our study revealed that the following AWS have a 'harmful' impact on the LRF habitats: *Gleditsia triacanthos*, *Ailanthus altissima*, and *Robinia pseudoacacia*. Among them, *G. triacanthos* is the most impactful taxa in the LRF, as it is characterised by an equal distribution and high abundance. The natural conditions of the LRF of the South Caucasus biogeographical region are suitable for the bioecological characteristics of *G. triacanthos*, which are similar to the environmental conditions in the native range.

The main reason for the high negative impact and high invasion potential of *A. altissima* is its ability to grow in a wide range of environmental conditions and its resistance to herbivores and pathogens (Sladonja et al. 2015). *R. pseudoacacia* is a less competitive species in the LRF than *G. triacanthos* and *A. altissima;* however, it remains a species with high impact potential. The main reason why *R. pseudoacacia* occurs so frequently in PAs in Georgia is its popularity among foresters in cases where remnant past plantations are still found.

Other identified AWS are not assessed as 'harmful' but are identified as potentially dangerous, especially in some vegetation layers. For instance, *A. fruticosa* has a negative impact on the understorey and forest floor layers along rivers or flooding areas, which is a hindering factor for the natural regeneration process (Maeglin, Ohmann 1973; Overton 1990; Saccone et al. 2013).

AWS in the invaded areas of the riparian forest are widely present in the understorey layer or already completely replace the main layer of native dominant woody species in some areas.

Using EICAT, we identified several main mechanisms of AWS impact: competition, physical, structural, and indirect.

Our study clearly shows that the undesirable structural and succession processes in invaded LRFs are apparent. We also identified some of the species (*M. alba*) that must be monitored in the future due to their estimated negative impact.

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