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Possibility of co-protection for populations of steppe and forest plants in alone location: A case study in Republic of Mordovia, Russia

MARIA A. SENCHUGOVA[1], ANATOLIY A. KHAPUGIN[2,3,♥]

[1]Department of Botany, Physiology and Ecology of Plants, Mordovia State University. Bolshevistskaya Street 68, Saransk, Republic of Mordovia, Russia
[2]Joint Directorate of the Mordovia State Nature Reserve and National Park "Smolny", Dachnyi Lane 4, Saransk, Republic of Mordovia, Russia
[3]Tyumen State University. Lenin Street 25, Tyumen, Tyumen region, Russia. ♥email: hapugin88@yandex.ru

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Abstract. *Senchugova MA, Khapugin AA. 2018. Possibility of co-protection for populations of steppe and forest plants in alone location: a case study in Republic of Mordovia, Russia. Biodiversitas 19: 1387-1395.* In conditions of vegetation mosaicity of forest-steppe zone, many threatened plant species from different coenologic groups could growth in spatially close habitats. In this study, we tested whether steppe-related (*Iris aphylla*) and forest-related (*Lilium martagon*) plants could inhabit an alone location in conditions of the Republic of Mordovia, Russia. It would allow a probability to establish a Protected Area for preservation of two target plant species. For this purpose, we studied populations of *I. aphylla* and *L. martagon* in different locations, including habitats typical and atypical for these species. Using Jacquard similarity index and Tsyganov ecological scales, we compared floristic compositions and environmental variables of all studied locations. As a result, we revealed 25.3%-probability of co-habitation of *I. aphylla* and *L. martagon* in conditions of the Republic of Mordovia. Moreover, a proposed habitat was typical for *L. martagon*. This species has not been found in grassland habitats, while *I. aphylla* was registered within forest habitats. Obtained results allow to improve the Protected Areas management in the region by organization of a smaller Protected Area by conserving higher number of threatened plant species.

Keywords: Conservation, *Iris aphylla*, Jaccard's similarity index, *Lilium martagon*, protected area

INTRODUCTION

Forest-steppe biome forms a separate vegetation belt. It ranges from Eastern Europe to the easternmost parts of Asia (Magyari et al. 2010). The Republic of Mordovia is located within the forest-steppe zone in European Russia. Grassland and forest patches are interspersed with each other in this region. It is especially in central and eastern part, while western part is mainly covered by forest vegetation. Due to considerable mosaicity of habitats and unique geographical position, Republic of Mordovia is characterized by wide range of threatened plant species of different coenotical groups (Khapugin and Silaeva 2013; Khapugin et al. 2017). This is consistent with Hoekstra et al. (Hoekstra et al. 2005) noted on extremely high conservation value of the forest-steppe belt. The mosaic vegetation has been considered as one of the most species-rich (Erdős et al. 2017) and also host a high number of red-listed plant species.

A Protected Area network is considered as a key tool for positive contribution to biodiversity conservation component of the global response to environmental changes and degradation (Gaston et al. 2008; Grebennikov 2016). They are contributing positively to biodiversity recovery and conservation (Gebremedihin et al. 2018; Leverington et al. 2010). Establishment of a Protected Area is based on the three consistent criteria: the presence of threatened species, exceptional botanical richness and threatened habitats (Anderson 2002). Therefore, there is a small probability of preserving a location with one-two threatened species. Moreover, a chance for Protected Area establishment to preserve of plant populations of species typically confined to different habitat types is even less. In this study, we selected two near-threatened (Khapugin et al. 2017b,c) forest (*Lilium martagon* L.) and steppe (*Iris aphylla* L.) plant species aiming to test whether it is possible to organize protection of their populations in a single location. We addressed the following questions: (i) What are most favorable conditions for growth of *I. aphylla* and *L. martagon* in the Republic of Mordovia? (ii) What is a probability for co-habitation of two target species?

MATERIALS AND METHODS

Study species

Iris aphylla L. (Iridaceae) is a long-lived, rhizomatous perennial steppe plant species. The centre of its range covers Ukraine, Central and South Russia, the Caucasus and Asia Minor, while peripheral populations are located in Poland, Belorussia, Germany, the Czech Republic, Slovakia, Hungary, Romania (Webb and Chater 1980) In the Middle-Russian Upland, this plant is mostly confined to meadow steppes on slopes or, rarely, to edges of shrub thickets. In addition, *I. aphylla* occurs along forest edges and in open forests, where blooming plants are rare (Kazakova et al. 2015; Khapugin et al. 2018). This Near-Threatened species is included in the Red Data Book of the Republic of Mordovia (Silaeva 2017). It is presented by 45 populations in Mordovia predominantly located in eastern part of the region. However only four of them are located within existing Protected Area Network (Khapugin et al. 2017a).

Lilium martagon L. (Liliaceae) is a bulbous perennial herb. It is distributed in Eurasia, from Portugal eastwards throughout southern Europe all the way into Siberia (Fox 2006). It usually occurs in small clumps in light forests, along forest glades. In Mordovia, *L. martagon* is confined to forest ecosystems, predominantly light deciduous forest types (Khapugin et al. 2018). This Near-Threatened species is included in the Red Data Book of the Republic of Mordovia (Silaeva 2017). It is presented by 33 populations in Mordovia located exclusively in eastern part of the region. However only three of them are located within existing Protected Area Network (Khapugin et al. 2017a).

Study area

Our study area was located in the eastern part of the Republic of Mordovia (Figure 1). Field studies have been carried out during 2016-2017. Three locations per target species were investigated in Mordovia. *I. aphylla* was studied in National Park "Smolny" (location 1: 54º47'20.24"N, 45º14'07.41"E), neighborhoods of Salma Village of Romodanovo District (location 2: 54º24'32.25"N, 45º08'28.57"E), and Natural Monument "Levzha landscape sanctuary" in Ruzaevka District (location 3: 54º06'02.09"N, 45º06'06.95"E). *L. martagon* was studied in neighborhoods of Salma Village in Romodanovo District (location 4: 54º24'53.43"N, 45º08'04.38"E), urban forest in neighborhoods of Saransk (location 5: 54º09'47.33"N, 45º06'04.02"E), in neighborhoods of biological station of the Mordovia State University in Bolshie Berezniki District (location 6: 54º11'07.36"N, 46º10'37.93"E). In each study site, 10 m × 10 m plots were selected ("large plots") where individuals of target species were found. Floristic composition of all vascular plant species was recorded within established large plots. Table 1 presents brief characteristics of all large plots established during fieldwork.

Floristic lists of described large plots were compared using Jaccard's similarity index calculated using the following formula: JS = 100 x C/(A+B-C), where A = number of species in locality A; B = number of species in locality B; C = number of species shared between two (A and B) localities (Jaccard 1901). Plant species names follow The Plant List (2018).

In each study site, 10 m × 10 m plots were selected (large plots) where individuals of target species were found. To reveal differences between environmental conditions of studied large plots, we used the Tsyganov (1983) ecological scale that is most suitable for the Republic of Mordovia. Each environmental factor in the scale is represented by points (gradations) arranged within a range of plant survival. It means that for a certain plant species we can define the range of its existence in relation to a certain factor (for instance, soil nitrogen, moisture etc.). Edaphic and topographic environmental factors of Tsyganov scale (1983) were selected: shading (LC), soil moisture (HD), soil nitrogen (NT), soil pH (RC), trophicity (TR). We calculated the mean point value of an environmental factor per each study plot as a mean of the entire set of species registered there. The following formula was used:

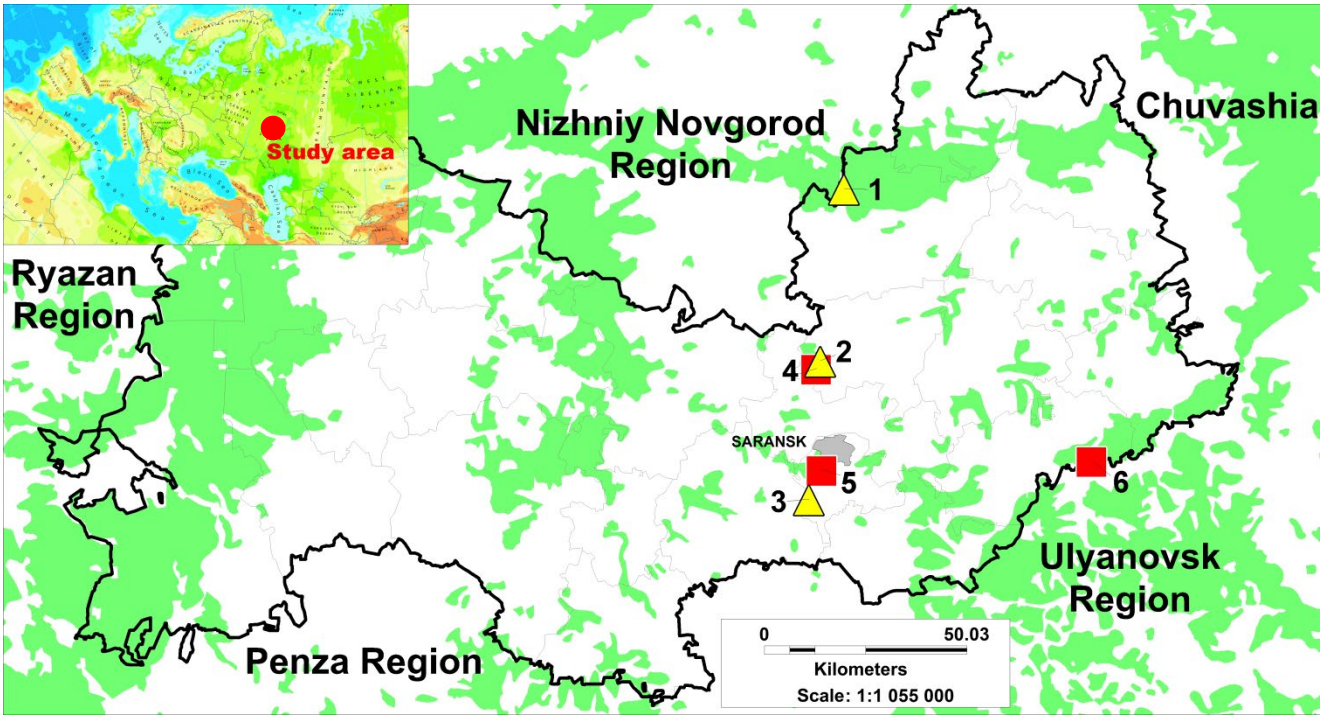

Figure 1. Studt sites in the Republic of Mordovia, Russia and its possition in Europe: location 1 (54º47'20.24"N, 45º14'07.41"E), location 2 (54º24'32.25"N, 45º08'28.57"E), location 3 (54º06'02.09"N, 45º06'06.95"E), location 4 (54º24'53.43"N, 45º08'04.38"E), location 5 (54º09'47.33"N, 45º06'04.02"E), location 6 (54º11'07.36"N, 46º10'37.93"E); red (dark-grey) squares-locations of *Lilium martagon*; yellow (light-grey) triangles-locations of *Iris aphylla*

Table 1. Characteristics of large plots established in study area in the Republic of Mordovia, Russia

Species	Abbreviation used for a large plot	Position number (according to Figure 1)	Characteristics of a habitat position
Iris aphylla	I.NP	1	Glade within the mixed forest
Iris aphylla	I.S1	2	Steppificated deciduous forest (45-55% canopy)
Iris aphylla	I.S2	2	Steppificated deciduous forest (45-55% canopy)
Iris aphylla	I.S3	2	Steppificated deciduous forest (45-55% canopy)
Iris aphylla	I.S4	2	Steppificated deciduous forest (45-55% canopy)
Iris aphylla	I.S5	2	Steppificated deciduous forest (40-50% canopy)
Iris aphylla	I.S6	2	Forest edge (5-10% canopy)
Iris aphylla	I.S7	2	Forest edge (10-15% canopy)
Iris aphylla	I.S8	2	Grassland: meadow-steppe slope
Iris aphylla	I.L1	3	Grassland: meadow-steppe slope
Iris aphylla	I.L2	3	Grassland: meadow-steppe slope
Iris aphylla	I.L3	3	Grassland: meadow-steppe slope
Iris aphylla	I.L4	3	Grassland: meadow-steppe slope
Iris aphylla	I.L5	3	Grassland: meadow-steppe slope
Lilium martagon	L.S1	4	Steppificated deciduous forest (45-50% canopy)
Lilium martagon	L.U1	5	Closed deciduous forest (45-55% canopy)
Lilium martagon	L.U2	5	Closed deciduous forest (45-55% canopy)
Lilium martagon	L.U3	5	Closed deciduous forest (45-55% canopy)
Lilium martagon	L.BB	6	Moist closed alder forest (60-65% canopy)

$$m = \frac{(x_1^{min} + x_2^{min} + \ldots + x_n^{min}) + (x_1^{max} + x_2^{max} + \ldots + x_n^{max})}{2n}$$

Where, mEFV: mean environmental factor point values (e.g., shading), x_n^{min}: the minimal point value of a factor in the Tsyganov scale (1983) for a plant species, x_n^{max}: the maximal point value of a factor in the Tsyganov scale (1983) for a plant species, *n*: number of plant species in the floristic list in a study plot.

Statistical analyses were carried out using PAST 3.15 (Hammer et al. 2001) and Microsoft Excel. The ordination techniques, the principal component analysis (PCA), were used to define the major gradients determining ecological preferences of target species. Mean point values of environmental factors for established plots were plotted onto a PCA ordination diagram as supplementary environmental data.

RESULTS AND DISCUSSION

The accompanying floras were revealed for all large locations with *I. aphylla* and *L. martagon* participation. It included 140 species of vascular plants from 106 genera and 44 families for *I. aphylla* (Table S1), and 63 species of vascular plant moss species from 58 genera and 34 families for *L. martagon* (Table S2). Based on obtained data we calculated the Jaccard's similarity index amongst these accompanying floras. Obtained results are presented using cluster analysis (Figure 2). They show separation of all study plots into two main clusters. They could be conditionally named as cluster of forest habitats (left in Figure 2) and cluster of open habitats (right in Figure 2). It can be seen, that all *L. martagon* habitats were correctly assigned to the "forest cluster", while *I. aphylla* demonstrated duality of its confinement to a certain cluster. Six plots with *I. aphylla* were assigned to the "forest cluster", and other eight plots-to the "grassland cluster".

In order to test this definition of study plots into two groups, we conducted principal component analysis (PCA) of point values of selected environmental factors (Figure 3). All study plots distributed mainly along gradients of soil moisture, habitat shadiness, and soil nitrogen availability. It can be seen, that separation of forest-related and grassland-related plots was clearly noticeable, while plots related to the forest edge (including forest glades) positioned intermediately. However, this is not so clear from Figure 2. Both Figure 2 and Figure 3 showed high similarity in both plant species compositions and environmental conditions between habitats of *I. aphylla* and *L. martagon* in Mordovia.

Discussion

Issues of preservation of plants (Ge et al. 2017; Khapugin 2018; Lisetskii et al. 2016), invertebrates (Ruchin and Grishutkin 2018; Weking et al. 2016), vertebrates (Rusin et al. 2013), their habitats (Erdős et al. 2014, 2017) under conditions of vegetation mosaicity in forest-steppe belt are discussed in many countries. Our data on relation of *I. aphylla* and *L. martagon* to the certain habitats of forest-steppe belt of European Russia did not show clear distinguishing into two types-forests and grasslands. Several clumps of *I. aphylla* were registered in atypical (forest) habitats. This demonstrated its wider ecological requirements in compare with second target species. At the same time, no one population of *L. martagon* was registered in grassland habitats. Despite a lack of flowering individuals in *I. aphylla* populations registered in the forest (Khapugin et al. 2018), plants are able to successful vegetative reproduction in such conditions. The appearance and further growth of a perennial steppe plant within a forest ecosystem became to

be possible due to the afforestation processes occurred in Russia during the post-Soviet period (Sieber et al. 2013). Results of recent investigations proposed that there are several co-located populations of *I. aphylla* and *L. martagon* in the Republic of Mordovia (Khapugin and Senchugova 2018). Further studies should be aimed to determine, are there other cases of co-habitation of these target species in a certain alone habitat. This will allow determining the most important areas, which need to be protected in Mordovia.

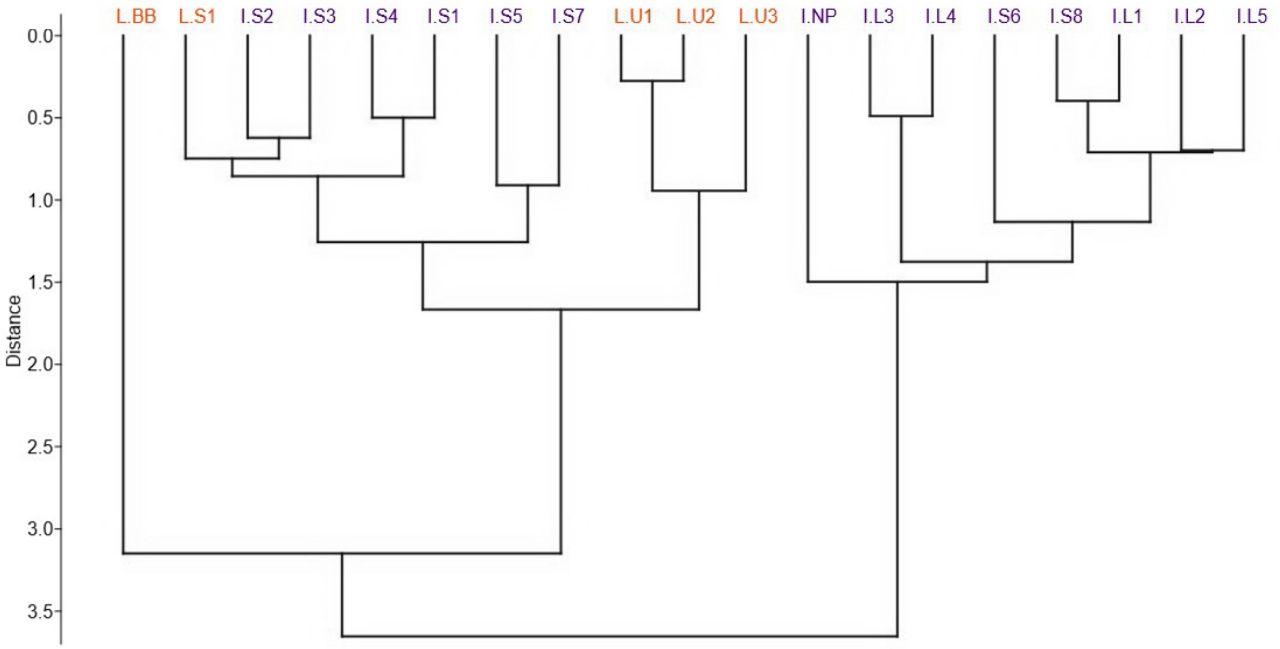

Figure 2. Cluster analysis dendrogram of plant species composition of 19 study plots with participation of *Iris aphylla* (prefix "I.) and *Lilium martagon* (prefix "L.) in the Republic of Mordovia, based on Jaccard's similarity indices

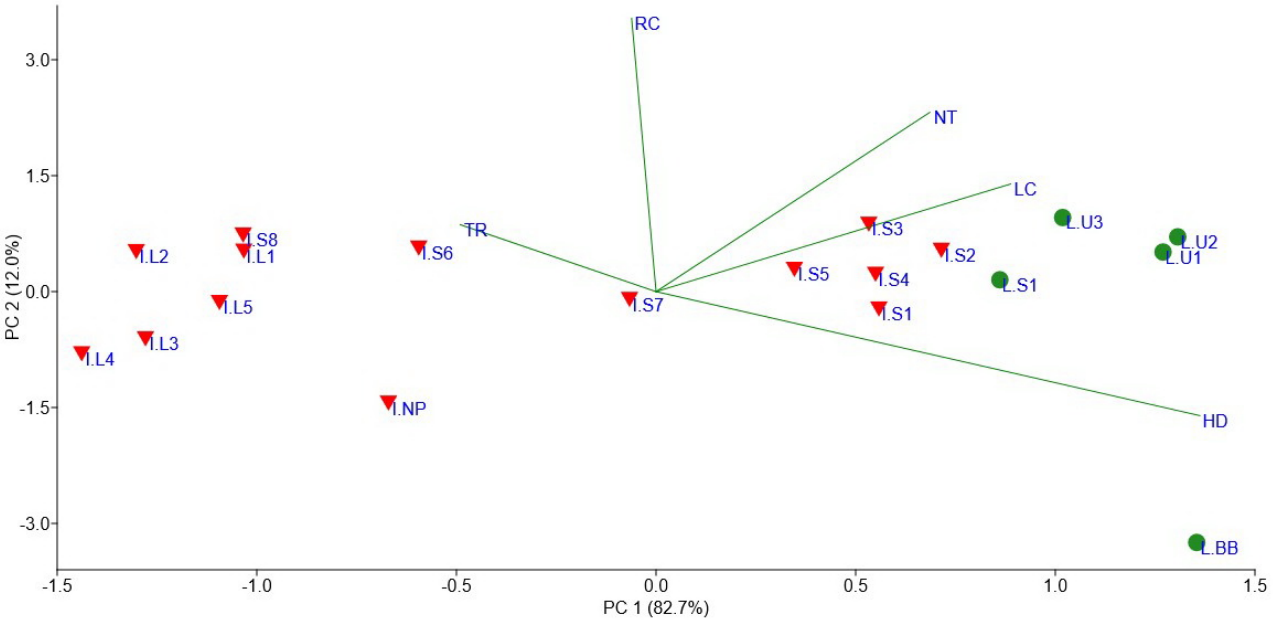

Figure 3. Principal component analysis (PCA) ordination diagram of plots with participation of *Iris aphylla* (prefix "I.") and *Lilium martagon* (prefix "L.") in the Republic of Mordovia. Symbols: red triangles-locations of *Iris aphylla*, green dots-locations of *Lilium martagon*. Environmental factors: LC-shading, HD-soil moisture, NT-soil nitrogen, RC-soil pH, TR-trophicity. To reveal ecological gradients, mean point values of environmental factors were plotted onto PCA ordination diagram as supplementary environmental variables

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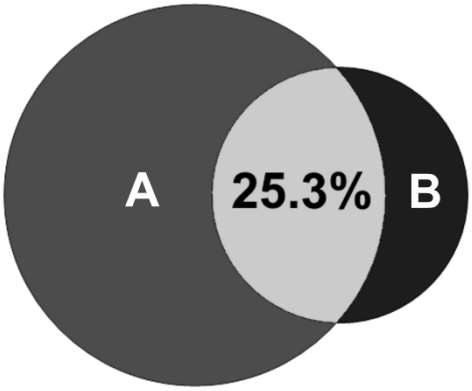

Figure 4. Area-proportional Venn-diagram of the plant species of floras accompanying to *Iris aphylla* (A: 140 species) and *Lilium martagon* (B: 63 species) in the Republic of Mordovia, Russia

Thus, we can assume that co-habitation of forest and steppe threatened plants, *I. aphylla* and *L. martagon*, is possible in conditions of vegetation mosaicity of forest-steppe belt in European Russia. Moreover, this is possible in forest plant communities, typical to *L. martagon*, but not vice versa. Nevertheless, the question remains, how likely is the cohabitation of these two species? To answer it based on obtained results, we supposed that plant species composition could be used as a tool. Using Jacquard similarity index, we compared the whole compositions of floras accompanying to *I. aphylla* and *L. martagon* in the study area (Figure 4).

As it can be seen, these floras have 25.3% similarity. Therefore, we can conditionally assume 25.3% probability of co-habitation of *I. aphylla* and *L. martagon* in conditions of vegetation mosaicity of the Republic of Mordovia, Russia.

Thus, we can conclude that cohabitation, and thus preservation, of steppe-related (*I. aphylla*) and forest-related (*L. martagon*) plant species is possible in conditions of forest-steppe belt of European Russia. This probability is about 25% with the proviso that environmental conditions would be similar to our conducted research. In conditions of high level of agricultural pressure on natural ecosystems, is it highly difficult to exclude a habitat from agriculture for organization of a Protected Area. This is consistent with a few principal external problems facing protected areas formulated by Bishop et al. (Bishop et al. 1995) as "the failure to integrate protected areas requirements into wider policies, such as agriculture" and "the inadequate recognition of the needs, interests and knowledge of local people within protected areas". Therefore, conservation of two co-inhabiting plant species in alone location allows organizing protection by using smaller area of natural habitats and by facing smaller difficulties with local people.

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Table S1. List of plant species registered in study plots with participation of *Iris aphylla* in the Republic of Mordovia, Russia

Species	Study plots													
	I.S1	I.S2	I.S3	I.S4	I.S5	I.S6	I.S7	I.S8	I.L1	I.L2	I.L3	I.L4	I.L5	I.NP
Acer negundo L.	-	-	-	-	-	-	+	-	+	-	-	-	-	-
Acer platanoides L.	+	+	+	+	+	-	-	-	-	-	-	-	-	-
Acer tataricum L.	+	-	-	+	-	+	+	-	-	-	-	-	-	-
Aconitum septentrionale Koelle	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Adonis vernalis L.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Aegopodium podagraria L.	+	+	-	+	+	-	+	-	-	-	-	-	-	-
Agrimonia eupatoria L.	-	-	-	-	+	+	+	+	+	+	+	+	+	-
Anemone ranunculoides L.	+	-	+	+	-	-	-	-	-	-	-	-	-	+
Anthriscus sylvestris (L.) Hoffm.	-	-	+	-	+	-	-	-	-	-	-	-	-	-
Artemisia vulgaris L.	-	-	-	-	+	-	+	-	-	-	-	-	-	-
Asarum europaeum L.	-	+	+	+	+	+	+	-	-	-	-	-	-	-
Asparagus officinalis L.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Berteroa incana (L.) DC.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Bromus inermis Leyss.	-	-	-	-	-	+	-	+	+	+	+	-	-	-
Calamagrostis epigejos (L.) Roth	-	-	-	-	-	-	+	-	+	+	+	+	+	-
Campanula latifolia L.	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Campanula persicifolia L.	+	-	+	-	-	-	-	-	-	-	-	-	-	-
Campanula trachelium L.	+	+	-	+	+	-	-	-	-	-	-	-	-	-
Carex caryophyllea Latourr.	-	-	-	-	-	-	-	-	+	+	-	-	-	-
Carex praecox Schreb.	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Carex spicata Huds.	+	-	+	-	+	-	+	-	-	-	-	-	-	-
Centaurea scabiosa L.	-	-	-	-	-	-	-	+	-	+	-	-	-	-
Chamaecytisus ruthenicus (Fischer ex Woloszczak) Klásk.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Chelidonium majus L.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Cirsium arvense (L.) Scop.	-	-	-	-	+	+	+	-	-	-	-	-	-	-
Clinopodium vulgare L.	-	-	+	+	-	-	-	-	-	-	-	-	-	-
Conium maculatum L.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Convallaria majalis L.	+	+	+	+	+	-	-	-	-	-	-	-	-	-
Corydalis solida (L.) Clairv.	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Corylus avellana L.	+	+	+	+	+	-	-	-	-	-	-	-	-	-
Dactylis glomerata L.	-	-	-	-	-	-	+	-	-	-	-	-	+	-
Dracocephalum ruyschiana L.	-	-	-	-	-	+	-	-	-	-	-	-	-	+
Dryopteris filix-mas (L.) Schott	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Epilobium angustifolium L.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Epipactis helleborine (L.) Crantz	+	+	+	+	+	-	-	-	-	-	-	-	-	-
Erigeron annuus (L.) Pers.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Euonymus verrucosus Scop.	+	+	+	+	-	-	-	-	-	-	-	-	-	-
Euphorbia microcarpa (Prokh.) Krylov	-	-	-	-	-	-	-	-	-	+	+	+	-	-
Euphorbia semivillosa (Prokh.) Krylov	-	-	-	-	-	-	-	-	-	-	+	+	-	-
Falcaria vulgaris Bernh.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Festuca gigantea (L.) Vill.	+	+	-	+	+	-	-	-	-	-	-	-	-	-
Festuca pratensis Huds.	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Filipendula vulgaris Moench	-	-	+	+	+	+	+	+	+	+	+	+	+	+
Fragaria vesca L.	+	+	+	+	-	+	+	-	-	-	-	-	-	-
Fragaria viridis Weston	-	-	-	-	-	-	-	+	+	+	+	+	+	-
Fraxinus excelsior L.	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Galium boreale L.	-	+	-	-	-	+	+	-	+	-	+	-	-	-
Galium mollugo L.	+	-	+	-	+	+	+	-	+	+	+	-	-	+
Galium tinctorium (L.) Scop.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Galium verum L.	-	-	-	-	-	-	-	+	+	+	+	+	+	-
Geranium pratense L.	-	-	-	-	-	-	-	-	+	+	+	+	+	-
Geranium sanguineum L.	-	-	-	-	+	+	-	-	+	-	+	+	+	-
Geranium sylvaticum L.	+	-	+	-	+	-	-	-	-	-	-	-	-	-
Geum urbanum L.	+	+	+	+	+	+	+	+	-	-	-	-	-	-
Glechoma hederacea L.	+	+	+	+	-	-	+	-	-	-	-	-	-	-
Helictotrichon pubescens (Huds.) Schult. & Schult.f.	-	-	-	-	-	+	-	+	-	-	-	-	-	+
Heracleum sphondylium subsp. *sibiricum* (L.) Simonk.	+	-	-	+	+	-	-	-	-	-	-	-	-	-
Hieracium umbellatum L.	-	+	+	-	-	-	-	-	-	-	-	-	-	-
Hierochloe odorata (L.) P. Beauv.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Hypericum perforatum L.	+	-	-	-	+	+	+	-	+	+	+	+	+	-
Hypochaeris maculata L.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Inula helenium L.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Inula hirta L.	-	-	-	+	-	+	-	-	-	-	-	-	-	-
Iris aphylla L.	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Knautia arvensis (L.) Coult.	-	-	-	-	-	-	-	-	-	+	+	+	-	+
Larix sibirica Ledeb.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Lathyrus pratensis L.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Lathyrus sylvestris L.	+	-	-	-	-	+	-	-	-	+	-	-	+	-
Lathyrus vernus (L.) Bernh.	+	+	+	+	+	-	-	-	-	-	-	-	-	-
Leonurus quinquelobatus Gilib.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Leucanthemum vulgare (Vaill.) Lam.	-	-	-	-	-	+	-	-	-	-	-	-	-	-

Lonicera xylosteum L.	+	-	-	+	+	-	+	-	-	-	-	-	-	-
Malus sylvestris (L.) Mill.	-	+	-	-	-	-	+	-	-	-	-	-	-	-
Melampyrum nemorosum Baumg.	+	+	-	-	+	+	+	+	-	-	-	-	-	-
Melica nutans L.	+	+	-	-	-	-	+	-	-	-	-	-	-	-
Mentha arvensis L.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Myosotis arvensis (L.) Hill	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Nepeta cataria L.	-	-	-	-	-	-	-	-	+	+	+	+	-	-
Origanum vulgare L.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Peucedanum alsaticum L.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Phleum phleoides (L.) H.Karst.	-	-	-	-	-	-	-	+	-	+	-	-	-	-
Phleum pratense L.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Phlomoides tuberosa (L.) Moench	-	-	-	-	-	-	+	+	+	+	-	+	-	-
Pimpinella saxifraga L.	-	-	-	-	-	-	+	-	-	-	-	-	-	+
Pinus sylvestris L.	-	-	-	-	-	+	+	+	-	-	-	-	-	-
Poa nemoralis L.	-	+	-	-	+	+	-	-	-	-	-	-	-	-
Poa pratensis L.	-	-	-	-	-	+	-	+	-	+	+	+	+	-
Polygala comosa Schkuhr	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Polygonatum multiflorum (L.) All.	+	-	-	+	-	-	-	-	-	-	-	-	-	-
Populus tremula L.	+	-	-	+	+	-	-	-	-	-	-	-	-	-
Potentilla alba L.	-	+	-	-	+	+	-	-	-	-	-	-	-	-
Potentilla argentea L.	-	-	-	-	-	+	-	+	-	+	-	-	+	-
Potentilla thuringiaca Bernh.	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Primula veris L.	-	-	+	-	-	+	+	+	-	+	-	-	-	-
Prunella vulgaris L.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Prunus fruticosa Pall.	-	-	+	-	-	-	-	-	+	+	-	-	+	-
Prunus padus L.	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Pulmonaria obscura Dumort.	+	+	+	+	-	-	+	-	-	-	-	-	-	-
Pyrethrum corymbosum (L.) Scop.	+	+	+	+	+	+	-	-	-	-	+	+	-	-
Quercus robur L.	+	+	+	+	+	+	+	-	-	-	-	-	-	-
Rhamnus cathartica L.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Rosa majalis Herrm.	+	+	-	-	-	+	-	-	-	+	-	-	-	-
Rubus idaeus L.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Rubus saxatilis L.	-	+	-	+	+	-	-	-	-	-	-	-	-	-
Salix caprea L.	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Salvia dumetorum Andrz. ex Besser	-	-	-	-	-	+	-	+	+	+	-	-	+	-
Sanguisorba officinalis L.	-	-	-	-	+	+	-	-	-	-	-	-	-	-
Scrophularia nodosa L.	+	+	-	-	+	-	-	-	-	-	-	-	-	-
Silene nutans L.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Silene viscaria (L.) Jess.	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Sonchus arvensis L.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Sorbus aucuparia L.	+	+	-	+	-	-	+	-	-	-	-	-	-	-
Stachys annua (L.) L.	-	-	-	-	-	-	-	-	+	+	-	-	-	-
Stachys officinalis (L.) Trevis.	+	+	-	+	+	+	+	+	-	-	-	+	-	-
Stellaria graminea L.	-	-	-	-	-	-	-	+	-	-	-	+	-	-
Stellaria holostea L.	+	+	+	+	+	-	+	-	-	-	-	-	-	-
Stipa pennata L.	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Tanacetum vulgare L.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Thalictrum minus L.	-	-	-	-	-	-	-	-	-	+	-	-	+	-
Thalictrum simplex L.	-	-	-	-	+	-	-	-	+	-	-	-	-	-
Thymus pulegioides subsp. *pannonicus* (All.) Kerguélen	-	-	-	-	-	-	-	-	-	+	+	+	+	-
Tilia cordata Mill.	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Torilis japonica (Houtt.) DC.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Tragopogon orientalis L.	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Trifolium alpestre L.	+	-	-	-	-	+	-	-	+	-	-	-	-	-
Trifolium medium L.	-	-	-	-	+	-	-	+	-	-	-	-	-	-
Trifolium montanum L.	-	-	-	-	-	+	-	+	-	-	-	-	-	-
Trifolium pratense L.	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Trollius europaeus L.	-	+	+	+	-	-	-	-	-	-	-	-	-	-
Urtica urens L.	+	-	-	-	-	-	+	-	-	-	-	-	-	-
Verbascum nigrum L.	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Veronica austriaca subsp. *teucrium* (L.) D.A. Webb	-	-	-	-	+	+	+	-	+	+	+	-	+	+
Veronica chamaedrys L.	-	-	-	-	-	-	-	+	+	+	-	-	-	+
Viburnum opulus L.	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Vicia cracca L.	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Vicia sylvatica L.	-	-	+	+	-	-	-	-	-	-	-	-	-	-
Vincetoxicum laxum Gren. & Godr.	-	+	-	-	-	+	-	-	-	-	-	-	-	-
Viola canina L.	+	-	-	-	-	+	-	-	-	-	+	+	+	-
Viola collina Besser	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Viola mirabilis L.	+	-	+	+	-	-	+	-	-	-	-	-	-	-

Note: Explanations of study plot abbreviations-see Table 1; "+"/"- : presence/absence of a species in a study plot

Table S2. List of plant species registered in study plots with participation of *Lilium martagon* in the Republic of Mordovia, Russia

Species	Study plots				
	L.BB	L.S1	L.U1	L.U2	L.U3
Acer platanoides L.	-	+	+	+	+
Aegopodium podagraria L.	+	+	+	+	-
Alnus glutinosa (L.) Gaertn.	+	-	-	-	-
Asarum europaeum L.	-	+	-	-	-
Betula pendula Roth	+	-	-	-	-
Calamagrostis canescens (Web.) Roth	+	-	-	-	-
Campanula patula L.	-	-	+	-	-
Carex digitata L.	-	+	-	-	-
Carex pallescens L.	-	-	+	-	-
Carex pilosa Scop.	-	+	+	+	+
Convallaria majalis L.	+	+	+	+	+
Corylus avellana L.	-	+	+	+	+
Dryopteris filix-mas (L.) Schott	-	-	+	-	-
Epipactis helleborine (L.) Crantz	-	+	-	-	-
Euonymus verrucosa Scop.	-	+	+	+	+
Festuca gigantea (L.) Vill.	-	+	-	+	-
Filipendula ulmaria (L.) Maxim.	+	-	-	-	-
Filipendula vulgaris Moench	-	+	-	-	-
Fragaria vesca L.	-	+	-	-	-
Fraxinus excelsior L.	-	-	+	-	-
Galium palustre L.	+	-	-	-	-
Galium rivale (Sibth. et Smith) Griseb.	+	-	-	-	-
Geum urbanum L.	-	+	-	-	+
Glechoma hederacea L.	-	-	+	+	-
Heracleum sibiricum L.	-	+	-	-	-
Hieracium umbellatum L.	-	+	-	-	-
Lathyrus vernus (L.) Bernh.	+	+	+	+	+
Lilium martagon L.	+	+	+	+	+
Lonicera xylosteum L.	-	+	+	+	+
Lysimachia europaea (L.) U.Manns & Anderb.	+	-	-	-	-
Majanthemum bifoliun (L.) F. M. Schmidt	+	-	-	-	-
Malus sylvestris Mill.	-	-	+	-	+
Melampyrum nemorosum L.	+	-	-	-	-
Melampyrum pratense L.	-	+	-	-	-
Melica nutans L.	-	+	+	+	+
Mercurialis perennis L.	-	+	+	+	+
Milium effusum L.	-	-	+	+	-
Phragmites australis (Cav.) Trin. ex Steud.	+	-	-	-	-
Pinus sylvestris L.	+	-	-	-	-
Platanthera bifolia (L.) Rich.	-	-	-	+	-
Poa nemoralis L.	-	+	+	+	-
Polygonatum multiflorum (L.) All.	-	+	+	+	-
Polytrichum commune Hedw.	+	-	-	-	-
Populus tremula L.	-	+	+	-	-
Potentilla alba L.	-	+	-	-	-
Potentilla erecta (L.) Raeusch.	+	-	-	-	-
Primula veris L.	-	+	-	-	-
Pulmonaria obscura Dumort.	-	+	+	+	-
Pyrethrum corymbosum (L.) Scop.	-	+	-	-	-
Quercus robur L.	+	-	-	-	-
Ranunculus cassubicus L.	-	+	-	-	-
Rosa majalis Herrm.	-	+	-	-	-
Rubus saxatilis L.	+	-	+	+	+
Sanguisorba officinalis L.	-	+	-	-	-
Scrophularia nodosa L.	-	-	+	+	+
Serratula tinctoria L.	-	+	-	-	-
Sorbus aucuparia L.	+	-	-	-	-
Stellaria holostea L.	-	+	+	+	+
Tilia cordata Mill.	-	+	+	+	+
Vaccinium myrtillus L.	+	-	-	-	-
Viburnum opulus L.	-	-	-	-	+
Vicia sylvatica L.	-	+	-	-	-
Vincetoxicum laxum (Bartl.) Gren. & Godr.	-	+	-	-	-
Viola mirabilis L.	-	+	+	+	+

Note: Explanations of study plot abbreviations-see Table 1; "+"/"- : presence/absence of a species in a study plot