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*Tilia maximowicziana* (Malvaceae) is a plant species endemic to the northern part of the Japanese archipelago and Kunashir Island. In Russia, this species is included in the Red Data Book of the Russian Federation with rarity category 1 (taxon near extinction). In 2014–2019, we conducted field surveys of known *Tilia maximowicziana* subpopulations in Russia. We found and considered six locations on Kunashir Island. We further estimated morphometric traits of individuals and vegetation characteristics. On the basis of obtained data, we conducted regional IUCN estimation of *T. maximowicziana* for the Russian territory. We found that *T. maximowicziana* subpopulations inhabited deciduous and mixed forest plant communities, where *Sasa* sp. plants dominated in the herb layer. We demonstrated that the endemic plant species represented lower values of DBH and tree height, while leaf size (length / width), length of petioles and fruits were within the amplitude of their values known in the main part of the species range. According to IUCN Red List categories, *T. maximowicziana* subpopulation demonstrated the ability to seed reproduction of this species in northern limit of the natural range. The obtained results allowed us to estimate the global IUCN status of *T. maximowicziana*, taking into account its subpopulations in the Japanese archipelago.

Key words: endemic, fruit production, IUCN Red List, morphometric traits, plant community, range, threat

#### Introduction

At present, plant extinction rates are increasing under climatic and anthropogenic influence (Cheaib et al., 2012; Le Roux et al., 2019). It especially concerns endemic plants on small islands, having a restricted range and possibility for dispersal. It increases the extinction risk (Harter et al., 2015), which have been demonstrated in biodiversity hotspots (e.g. Ferreira et al., 2016). Endemic plants are more abundant in tropic and subtropic regions (e.g. Ungricht et al., 2005; Kier et al., 2009), while in temperate zone, endemics are rarer (e.g. Kier et al., 2009; Essl et al., 2013). It is especially true for Russia, where endemic plants are both less represented and less studied.

In Russia, the Far East, Southern Siberia and the Caucasus are biodiversity hotspots (Venevsky & Venevskaia, 2005; Griffin, 1999). The Russian Far East represents 2641 vascular plant species inhabiting an area of 229 691 km<sup>2</sup>. Among the island flora of the Kuril Archipelago, Kunashir Island has the highest species richness – 908 taxa (Pietsch et al., 2003).

The genus *Tilia* is included in subfamily Tilioideae of the family Malvaceae s.l., according to Nyffeler et al. (2005). There are about 23 species of *Tilia* worldwide including four species and two hybrids naturally occurring in Europe and Western Asia, four – in North America, and 15 – in Eastern Asia (Pigott, 2002). The natural range of the genus covers temperate regions up to 60-66° N. One of these species is Tilia maximowicziana Shiras. This is a large tree up to 30 m tall with a cylindrical trunk about 1.0-1.5 m in diameter (Pigott, 2012). This species is included in the Red Data Book of the Russian Federation (Bardunov & Novikov, 2008) (rarity category 1 – «at-risk of extinction»), being known only on Kunashir Island at the northern limit of its range. The main part of the native range is located in Japan (islands of Hokkaido and Honshu), where the type locality is situated (Shirasawa, 1900). According to published data (Alekseeva, 1983; Kharkevich, 1987; Barkalov & Eremenko, 2003; Bardunov & Novikov, 2008; Volkova et al., 2015), Russian locations of T. maximowicziana are located on the Okhotsk Sea coast up to 43° N. The species usually grows single or in small groups of trees in remotely situated forests.

We have aimed to study the status of *Tilia maximowicziana* subpopulations known in Russia.

#### **Material and Methods**

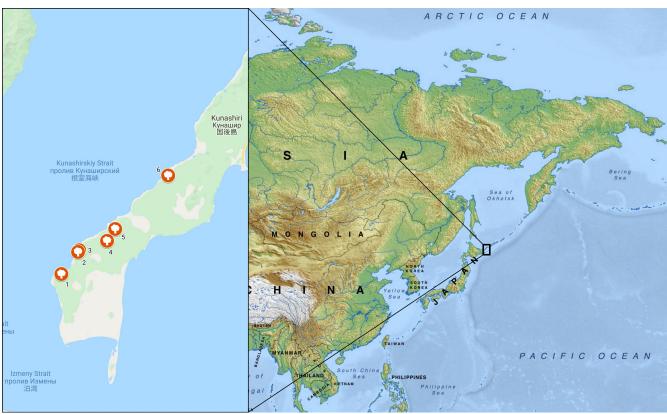
## Study area

The study was confined to Kunashir, the southernmost island of the Kuril Archipelago, including more than 56 islands (Fig. 1). It is located at 43.666667– 44.500000 N, 145.416667–146.333333 E. The precipitation ranges between 600 mm and 1300 mm per annum. The climate is oceanic, moderately cold. The summer is cool, rainy with a temperature not higher than +20°C (June). The winter temperature is not lower than -10°C. The relief is middle-mountainous, volcanic, represented by three acting volcanoes and mountain massifs connected by low-lying isthmuses. The sea coast is rocky, steep or gently sloping with sand dunes shores.

# Site selection

In 2014–2019, we have carried out research and field investigation of *T. maximowicziana* subpopulations, including our data and literature sourc-

es (Grishchenko et al., 2018) on Kunashir Island (Table 1). These subpopulations were considered to be a representative sample of the *T. maximowicziana* population on both Kunashir Island and in Russia. In relation to the IUCN Red List categories and criteria the subpopulations are defined as geographically or otherwise distinct groups in the Russian population between which there is little demographic or genetic exchange (IUCN, 2019). However we must note that the subpopulations selected in our study do not fit completely this definition as genetic exchange is highly likely. The term is used here for convenience to mean a portion of the Russian population.



**Fig. 1.** The locations in which *Tilia maximowicziana* is located in Russia (Kunashir Island) on map of Asia. Designations: 1 - location A, 2 - location B, 3 - location C, 4 - location D, 5 - location E, 6 - location F.

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Locations	Description	Altitude, m a.s.l.	Slope exposure	Distance to sea coast, m	Number of mature (fruiting) individuals	Number of saplings
A. Ivanovskiy cape	Left bank of River Krivonozhka	60	NW	340	6 (0)	5
B. Golovnin volcano caldera	Right bank of stream Ozernyi	126	NW	400	12 (3)	4
C. Golovnin volcano caldera	The top of mud volcano Magnolie- vaya northwest of the stream Ozernyi		W	420	1 (0)	2
D. Alekhina cape	Upper reaches of the stream Po- granichnyi, left bank	50	NW	1275	8 (0)	_
E. Alekhina cape	Right bank of stream Alekhina	62	S	1550	1 (0)	_
F. Stolbchatyi cape	Upper slope part of in 250 m from the mouth of the stream Zmeinyi	90	W	140	3 (1)	_

**Table 1.** Locations in which we confirmed the occurrence of *Tilia maximowicziana* on Kunashir Island, Russia, with geo 

 graphical coordinates, altitude, slope exposure, distance to sea coast, number of mature individuals, and saplings

#### Study design

A complete count of individuals was conducted in each subpopulation within four  $100 \times 100$  m plots. Each plant found was recorded and marked to prevent being counted more than once. Apart of mature individuals, we accounted saplings. Because of inaccessibility of some subpopulations, field population- and habitat-based studies have been carried out in relation to locations A, B, E, F. In them, we estimated width / length of leaves, length of petioles (N = 25 for each parameter), while only in selected subpopulations, the length of bracts (locations B and F, N = 25) and fruits (location F, N = 25) were estimated. For mature individuals, the diameter at breast height (DBH) and tree height were estimated. The Nikon Laser Forestry Pro laser rangefinder was used to determine the tree height and the least distance to the sea coast. The nested quadrate method was used to determine the species composition and projective coverage of species in the plant community associated with the T. maximowicziana subpopulation within four  $100 \times 100$  m plots. Scientific names are standardised according to The Plant List (2013).

# IUCN estimation of Tilia maximowicziana

For the definition of the threat status of *T. maxi-mowicziana*, we used the recently revised evaluation criteria adopted by the IUCN (2012a, 2012b, 2019), focusing on the extent of occurrence (EOO), area of occupancy (AOO), number of locations, and subpopulation size.

# **Results and Discussion**

## Locations of Tilia maximowicziana in Russia

Before 2019, four *T. maximowicziana* locations were reliably known in Russia (Table 1, locations A, C, D, E). These were situated on the west coast of Kunashir Island (Fig. 1). Most of them are located in hard-to-reach areas of the Kurilskiy State Nature Reserve. It is supported by data of some authors (e.g. Volkova et al., 2015). In July 2019, we found two new locations (B and F, Table 1) *T. maximowicziana* near the Golovnin volcano caldera and Stolbchatyi cape on Kunashir Island, respectively. Noteworthy, location F is thenorthernmost subpopulation of *T. maximowicziana* within its total range.

#### Morphometric traits of Tilia maximowicziana

On the basis of population-based studies on Kunashir Island, morphometric traits of *T. maximo-wicziana* individuals have been estimated (Table 2). We found about 2-fold excess of DBH and mature tree height between all locations studied. At the same time, the values of these parameters are lower than found in the main range in Japan (Pigott, 2012), where the average tree height and DBH were 30 m and 1.0–1.5 m respectively. It might be explained by the peripheral situation of the studied subpopulations, as deviations from a norm are known in peripheral plant populations (Khapugin & Chugunov, 2015; Volis et al., 1998). At the same time, leaf size, length of petiole, bract and fruit were within the range of known values within the main range (Pigott, 2012).

Characteristics of Tilia maximowicziana habitats We found that T. maximowicziana inhabits plant communities in deciduous and mixed forests. In deciduous forests, Quercus dentata Thunb. and/or Q. mongolica subsp. crispula (Blume) Menitsky dominated in forest stand, sometimes with participation of Acer pictum Thunb. or Betula ermanii Cham. (Table 3). In location A, a shrub layer was absent, while it was poorly developed in location E. The projective cover of the shrub layer had the highest value in location F (Table 3). The herb layer was represented predominantly by Sasa sp. with participation of Matteuccia struthiopteris (L.) Tod., Dryopteris sp. or Maianthemum dilatatum (Alph. Wood) A.Nelson & J.F.Macbr. Noteworthy, on Kunashir Island, T. maximowicziana was associated with other plant species than in the Japanese Archipelago (central part of the species range) (see Pigott, 2012). The similarity concerned to predominance of Sasa sp. in the herb layer, while the forest stand was represented by other tree species. It highlights the need to take into account information on T. maximowicziana habitats on Kunashir Island to obtain complete data on this endemic plant species.

Table 2. Morphometric traits of Tilia maximowicziana individuals in island Kunashir

Locations Average tree height, m	DBH, cm	Leaf length,	Leaf width,	Leaf petiole,	Bract length,	Fruit length,	
Average tree height, in		cm	cm	cm	cm	cm	
Location A	$7 \pm 0.3$	$13.5 \pm 1.0$	$12.3\pm0.5$	$11.3 \pm 0.5$	$6.3 \pm 0.3$	—	_
Location B	$10 \pm 0.4$	$13.2 \pm 1.9$	$9.4\pm0.8$	$7.7 \pm 0.3$	$5.0 \pm 0.3$	$8.9 \pm 0.3$	_
Location C	$10 \pm 0.0$	$24.0\pm0.0$	_	—	_	—	-
Location E	$13 \pm 0.0$	$26.3\pm0.0$	$7.7\pm0.3$	$8.3 \pm 0.3$	$4.3 \pm 0.2$	_	_
Location F	$15 \pm 3.9$	$20.7 \pm 6.1$	$16.3\pm0.8$	$16.4 \pm 0.8$	$6.7 \pm 0.2$	$12.4 \pm 0.4$	$1.0 \pm 0.03$

Table 3. Vegetation	on characteristics of p	plant communities with	h Tilia maximowicziana	(projective cover, %)

Species	Location A	Location B	Location C	Location E	Location F
Forest	stand				·
Abies sachalinensis (F.Schmidt) Mast.	-	5	60	50	_
Acer pictum Thunb.	30	5	10	5	25
Betula ermanii Cham.	-	20	30	10	-
Kalopanax septemlobus (Thunb.) Koidz.	-	5	_	5	10
Magnolia obovata Thunb.	_	10	_	10	-
Picea jezoensis (Siebold & Zucc.) Carrière	-	10	_	5	5
Prunus sargentii Rehder	_	_	_	_	10
Quercus dentata Thunb.	20	5	_	_	20
Quercus mongolica subsp. crispula (Blume) Menitsky	50	40	_	15	30
Shrub	layer				
Actinidia arguta (Siebold & Zucc.) Planch. ex Miq.	-	10	_	-	10
Hydrangea paniculata Siebold	_	30	10	10	10
Hydrangea petiolaris Siebold & Zucc.	-	-	_	40	-
Ribes latifolium Jancz.	-	_	_	_	10
Sambucus miquelii (Nakai) Kom.	_	10	_	10	10
Toxicodendron orientale Greene	-	-	_	_	50
Toxicodendron trichocarpum (Miq.) Kuntze	_	10	10	_	-
Vitis coignetiae Pulliat ex Planch.	-	10	_	_	10
Herb I	layer				
Aralia cordata Thunb.	-	_	_	_	2
Aruncus dioicus (Walter) Fernald	-	-	_	-	2
Aconitum kunasirense Nakai	-	_	_	_	2
Chloranthus japonicus Siebold	-	-	_	_	2
Dryopteris sp.	20	-	_	20	10
Hemerocallis esculenta Koidz.	-	-	_	-	14
Laportea bulbifera (Siebold & Zucc.) Wedd.	-	-	-	-	2
Maianthemum dilatatum (Alph.Wood) A.Nelson & J.F.Macbr.	-	-	_	20	10
Matteuccia struthiopteris (L.) Tod.	20	-	-	-	15
Petasites japonicus (Siebold & Zucc.) Maxim.	-	-	-	-	5
<i>Poa</i> sp.	-	-	_	30	5
Polygonatum odoratum var. maximowiczii (F.Schmidt) Koidz.	-	-	-	-	2
Sasa sp.	60	90	90	30	20
Solidago virgaurea subsp. dahurica (Kitag.) Kitag.	-	-	-	-	2
Thalictrum sachalinense Lecoyer	-	-	-	-	5
Trillium camschatcense Ker Gawl.	_	_	_	_	2

*IUCN status of Tilia maximowicziana in Russia* The extent of occurrence (EOO) of *T. maximowicziana* was defined as area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon (IUCN, 2019). We found that the EOO was 32.11 km<sup>2</sup>. The area of occupancy (AOO) was defined as the area within its EOO, which is occupied by a taxon, including areas which could be occupied by this species in future (IUCN, 2019). We found that the AOO was 20 km<sup>2</sup>. Below we present a detailed description of the IUCN estimation.

# **Criterion B:**

AOO: 20.00 km<sup>2</sup> calculated with a  $2 \times 2$  km-cell fixed grid by GeoCAT (Bachman et al., 2011).

EOO: 32.11 km<sup>2</sup> calculated with minimum convex hull by GeoCAT (Bachman et al., 2011).

a) All subpopulations represent a single location according to definition of IUCN (2019), according to which the term «location» defines a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present.

b) Decline in quality and extent of habitat (iii). Criterion C:

Population size estimated to 31 mature individuals and (2) no subpopulation estimated to contain more than 50 mature individuals (ii).

#### **Criterion D:**

Population size estimated to number fewer than 50 mature individuals.

Thus, in Russia, *T. maximowicziana* occurs only in six sites close to each other, located on the western coast of Kunashir Island with an AOO of 20 km<sup>2</sup>. As the species has a low degree of fruiting trees and high vegetative reproduction (Table 1), the elimination of fruiting individuals might be a reason of significant decrease in the effective size of the *T. maximowicziana* population. The possible decline in habitat quality and in the number of mature individuals support the classification of the species as Critically Endangered at a regional level (Russia) according to the formula CR B1ab(iii); C2a(i); D.

#### Conservation actions

All subpopulations of *Tilia maximowicziana* in Russia are under protection in the core and buffer zones of the Kurilsky State Nature Reserve. We suggest the further monitoring and searching of new locations of T. maximowicziana both on Kunashir Island and on other islands of the Kuril Archipelago. Each known subpopulation needs to be investigated in terms of status of population and habitat of the species. Consequently, it seems to be necessary to assess the global IUCN Red List status of T. maximowicziana with involving the estimation of species populations known in Japan. It concerns many plant species in worldwide regions, as regional IUCN estimation is a necessary step and tool to obtain data on the global IUCN status (Khapugin et al., 2017; Kestemont, 2019).

#### Conclusions

Nowadays, Tilia maximowicziana is represented by six subpopulations in Russia. All these are situated on the Okhotsk Sea coast. Four of these locations (66.7%) are situated 139-403 m away from the sea coast, while two other locations are 1450-2020 m distant from the sea coast, being, thus, the most hard-to-reach forinvestigating. On Kunashir Island, the T. maximowicziana subpopulations inhabit deciduous (dominated by Quercus dentata, Q. mongolica subsp. crispula, and / or Acer pictum and Betula ermanii) or mixed (dominated by Abies sachalinensis (F.Schmidt) Mast. and Betula ermanii) forests, where Sasa sp. dominated in the herb layer. We found that in the northernmost subpopulations, T. maximowicziana individuals had lower values of DBH and tree height, while other studied morphometric traits were consistent with published data concerning the main part of the species' range. According to IUCN Red List categories and criteria, T. maximowicziana has the regional (Russia) status of CR B1ab(iii); C2a(i); D. Data we obtained could be applied to conduct the assessment of global IUCN Red List status of T. maximowicziana taking into account its subpopulations in the Japanese Archipelago. We also recommend maintaining the endemic plant species on the main list of the Red Data Book of the Russian Federation (Bardunov & Novikov, 2008) with rarity category 1 (near extinction in Russia), once it will be re-edited.

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# СТАТУС TILIA MAXIMOWICZIANA (MALVACEAE S.L.) В РОССИИ

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*Tilia maximowicziana* (Malvaceae) – растение-эндемик северной части Японского архипелага и о. Кунашир. В России этот вид включен в федеральную Красную книгу с категорией редкости 1 (находящийся на грани исчезновения). В 2014-2019 гг., были проведены полевые исследования субпопуляций Tilia maximowicziana, известных в России. Обнаружено и рассмотрено шесть местообитаний вида на о. Кунашир. Затем были изучены морфометрические параметры особей и характеристика растительности в этих локалитетах. На основе полученных данных мы провели оценку угрожаемости Т. maximowicziana на территории России, согласно методологии МСОП. Нами обнаружено, что в известных местообитаниях Т. maximowicziana произрастает в широколиственных и смешанных лесах с доминированием видов рода Sasa в травянистом ярусе. Нами показано, что на о. Кунашир данный эндемик представлен особями с меньшим диаметром ствола на уровне груди и высотой особей, чем в основной части ареала. В то же время значения размера (длина / ширина) листовой пластинки, длины черешка и плодов соответствовали таковым, указанным в основной части ареала вида. Согласно категориям Красного списка МСОП, Т. maximowicziana в России имеет статус угрожаемости CR Blab(iii); C2a(i); D. Находки плодоносящих особей в популяциях T. maximowicziana показали способность вида к семенному размножению в северной части природного ареала. Полученные результаты позволяют провести глобальную оценку угрожаемости T. maximowicziana согласно критериям Красного списка МСОП, принимая во внимание субпопуляции вида на территории Японского архипелага.

**Ключевые слова:** ареал, Красный список МСОП, морфометрические признаки, плодообразование, растительное сообщество, угроза, эндемик