Original research article

Prediction of the appearance of tree of heaven in forest communities in western Slovenia

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Abstract

Background and Purpose: *Tree of heaven (*Ailanthus altissima*) is one of the most invasive tree species in Slovenia. Since its invasion into forests is expected, we must raise public awareness and prepare guidelines for forest management in the presence of invasive species. The aim of the research was to predict the potential distribution of tree of heaven, to detect the most endangered forest communities and to discover what characteristics of forest stands make them susceptible.*

Materials and methods: *From databases, literature sources and field observations, we collected all localities in which tree of heaven appears. We assigned these localities geological, geomorphological, soil and climatic data. We then built an ecological model and prepared a map of potential distribution. Based on the modelled future distribution of tree of heaven, we randomly selected and sampled 50 plots in the area in which invasion is expected and outside of this area. We analyzed their morphological and ecological strategies, ecological conditions, origin and social behavior spectrum.*

Results: *We found that tree of heaven has the largest invasive potential in western Slovenia. The model showed that the most susceptible forest communities appear in warm areas with pronounced climatic seasonality. Many differences occur in floristics and plant traits of forest communities in extreme positions, in terms of susceptibility to invasion, but in transitional areas, these differences are not so obvious, only a higher pH of soil and absence of species characteristic of acidophilus communities are an indicator of vulnerability.*

Conclusion: *Susceptibility to invasion by tree of heaven is mainly influenced by macro-climatic conditions; in the transitional zone, communities thriving on shallow soils over carbonate bedrock are more vulnerable.*

INTRODUCTION

TH which is autochtonous in China was first introduced in Europe (Paris) in 1751 *(3)*. It was disseminated because of its ornamental value and was also used for afforestation of dry sites, as well as for some economic purposes (e.g. for silkworm breeding) *(4)*. TH is one of the most invasive species in Europe *(5)*. It has a continuous distribution in the Mediterranean area and spreads along a gradient from the meridional to temperate zone *(6–8)*. In Slovenia, it was first recorded in 1875 and is nowadays spread all over the country *(9)*.

This is a typical pioneer woody species that appears in sites with various disturbances. It can often be introduced in an urban environ-
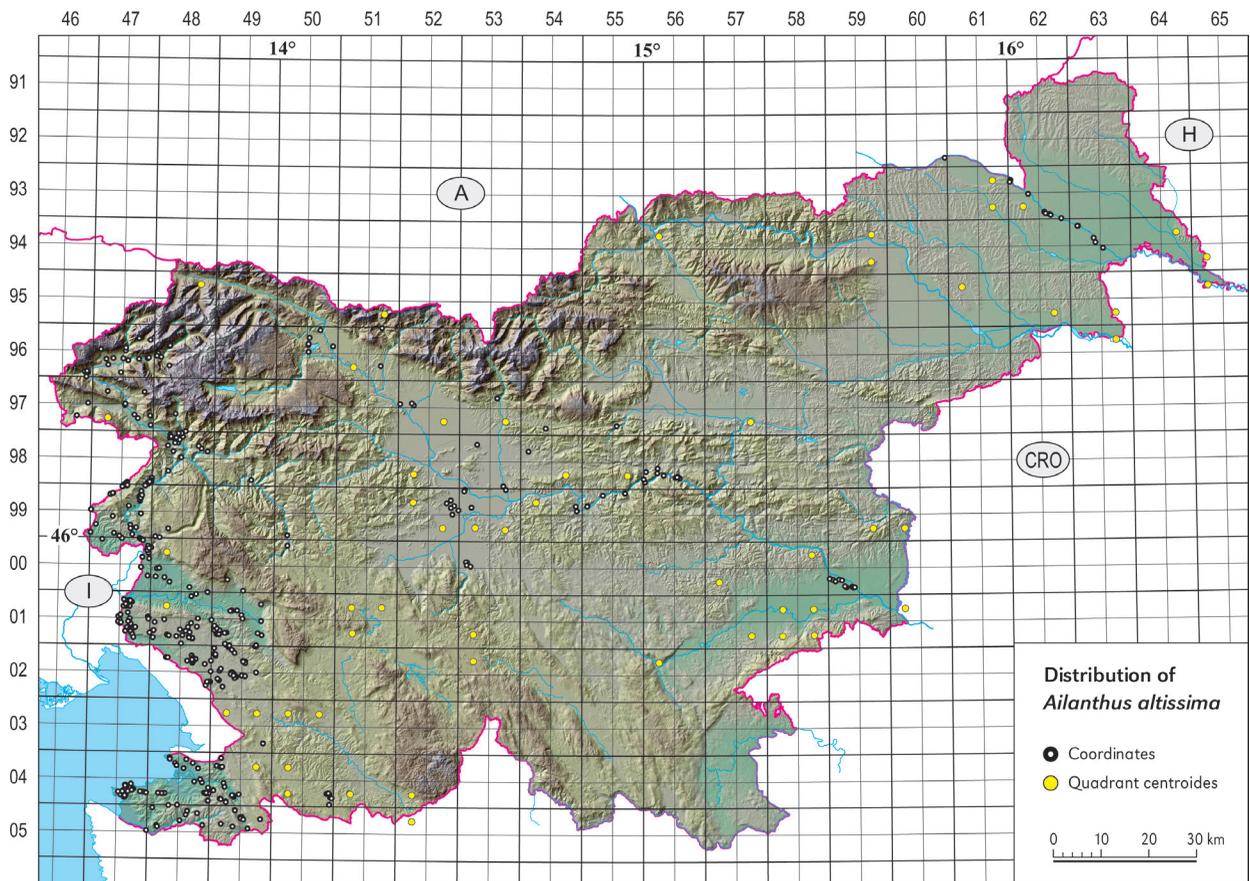
Figure 1. *Map of distribution of TH in Slovenia. Localities with exact coordinates are indicated with black and localities presenting centroids of quadrants by yellow points. The data are presented in MTB grid.*

ment *(10)*. It is a species of early successional stages that can be found in forest stand gaps or in clearings *(11)*. Its ecological strategy is competitor *(12)*. It is rare in closed stands because it is outcompeted by competitive strong species of late successional stages *(13)*. In the region under research, TH has been observed in sites in pole stages of forest development but not in established forest stands.

Several phases can be distinguished in the mechanism of establishment and dissemination of alien and invasive species *(14)*. The longer an invasive species is present in an area, the more probable it is that it will inhabit all potential habitats. The first phase, the so-called lag phase, is the time between arrival and the beginning of fast growth and spread. Among the reasons for this delay can be considered: a lack of habitats propitious for its settlement, their interdependence with other plants or unsuitable genetic diversity. This phase can last decades, or even centuries, but some species can be invasive immediately.

Intensive studies have been performed in the past to discover how invasive plants, their plant functional types and recipient environment interact, in order to determinate the level of impact *(15–17)* and to predict the interrelation between an invasive species and the recipient

community *(18)*. Plant functional types are a non-phylogenetic grouping of species showing close similarity in their response to environmental and biotic factors *(19–20)*. There are two main approaches in the classification of functional types *(21)*; the first is more concentrated on morphological features, such as Raunkier's life forms *(22)*, whereby the morphology of species changes depending on the changing environment. The second approach is based on ecological strategies, for which we used Grime's model of CSR *(23)*. This model is based on how plants or plant communities deal with stress and disturbance. There are main strategies: competitors, stress tolerators and ruderals, and their combinations. The position of each species, as well as of communities, can be determined in a CSR triangle. The community thus gets a functional signature *(24)*.

Since there are still gaps in this knowledge, the aim of our study was to discover which forests are threatened by TH invasion and what their main characteristics are that make them predisposed to invasion. Our task was to ascertain the present distribution of TH in Slovenia. On the basis of the present distribution of TH and variables based on geology, geomorphology, soil data and climate, to prepare an ecological model of its potential distribu-

tion. Our goal was also to discover which forest types are the most endangered by invasion and what makes them vulnerable.

METHODS

Data on existing locations of TH in Slovenia were collected from databases *(25–26)* and from available habitat mapping data *(27)*, and some field observations were also done. The locations from databases and field observations were geocoded, while the coordinates from habitat mapping data were calculated as centroids of polygons in which TH occurs. All the coordinates of TH occurrence in Slovenia were integrated into ArcGIS and a map was prepared.

Since TH is distributed only sporadically in eastern and central Slovenia, our research was focused on the western part of Slovenia. A model of TH potential distribution was constructed for this area. In recent decades, modelling techniques have been developed that enable the production of relatively exact maps of the potential distribution of species and communities based on present species localities, environmental factors and accurate modelling techniques *(28–29)*.

The basis for the preparation of the model was data on localities in which TH occurs (346 points) and localities in which TH was not found (1124 points) *(29)*. We assigned to each locality information on bedrock *(30)*, geomorphological conditions extracted from digital model of relief *(31)*, soil type *(32)* and climate extracted from WorldClim database *(33)*. As the main transport corridor in the region is valley of the river Soča that correlates with climatic corridor for penetration of the Mediterranean climate towards the Alps, we did not take a transporation network as input data for the analysis. Correlated variables were excluded anyway. In order to ascertain the conditions that allow the appearance of TH we used the program package WEKA *(34–35)*. Within this program we produced a classification decision tree by using algorithm J4.8. We increased the values of the minimum number of instances in a leaf while other parameters of the algorithm were set to their default values (minimum number of instances in a leaf: 2, use of unpruned trees: no, confidence factor used in postpruning: 0.25, subtree raising operation in postpruning: yes, use of binary splits: no). Several potential models were thus obtained. The final selection of the model was based on the qualitative predictive performance estimated with 10-fold cross validation. The model with the highest percentage of correctly classified instances was selected (Fig. 2).

For visualization of the results and preparation of the map of potential distribution of TH in western Slovenia, we determined in ArcGIS systematic points over the entire selected region at a distance of 100 m. We then used the decision rules of the classification tree to define whether the conditions at a particular point are suitable or unsuitable for TH occurrence. A map of potential distribution of TH was thus obtained.

In order to determine which are the most endangered forest communities for TH invasion, we first did field sampling. We randomly selected 25 points within the area
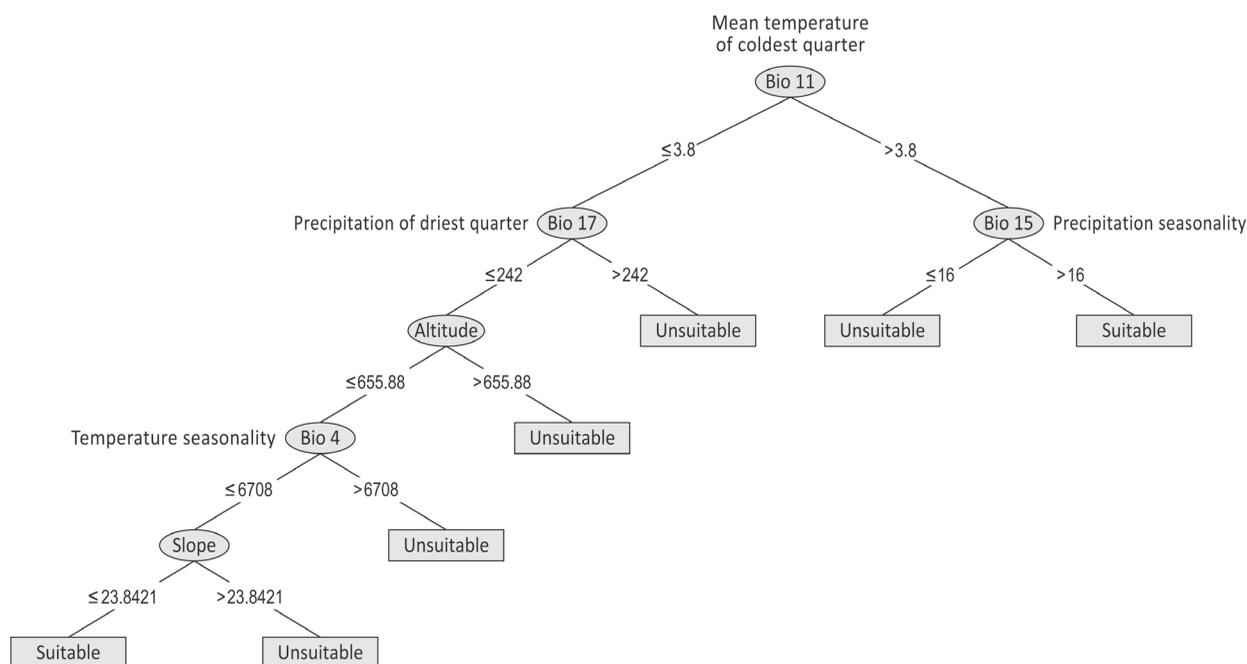
Figure 2. *Model prepared by WEKA program.*

of potential distribution of TH and the same number in the area outside potential distribution of this species. We used the shape of forest surfaces to ensure that points were located within forest *(36)*. On these locations, we sampled 200 m² large plots according to the standard procedure: floristic inventory of each plot, plant species abundance and cover were estimated by a seven grade scale and the general characteristics of the stand were estimated *(37)*.

We entered the data into the Turboveg program *(38)* and elaborated them in the program package Juice *(39)*. We then performed clustering, Detrended Correspondence Analysis (DCA) with passively projected bioindicator values, comparison of bioindicator values, chorotypes, morphological and ecological functional types between clusters to detect the floristic, ecological, structural and other features and to discover differences in communities that thrive in the area of potential distribution of TH and outside. In this way we estimated the characteristics of invaded and non-invaded stands, and from the differences tried to establish the main characteristics that make communities susceptible to invasion of TH.

Floristic similarities among communities were compared using cluster analysis. We eliminated the relevé with SD higher than 2 calculated on the basis of relative Euclidean distance from further analysis. We prepared a dendrogram, in which the original seven graded scale was transformed to percentages and square rooted. We used Euclidean distance and the Ward method for grouping the samples. These data were also subject to Detrended Correspondence Analysis (DCA) prepared in R software *(40)* using the *vegan* package *(41)*. Bioindicator values were passively projected onto the two-dimensional ordination space of DCA.

We calculated the characteristic species for each cluster with a fidelity measure and the Fisher test *(42)*. The fidelity measure was set to 0.5 in order for a species to be diagnostic.

In addition to the traditional approach to determine the characteristic features of communities, we also performed analysis of bioindicator values, chorotypes, plant functional types (morphological and ecological) and species behavior types, which reflect the ecological conditions, origin, structure and functionality of communities. We calculated all values on the basis of presence/absence data. The results are presented by Box-plot diagrams and differences between groups were calculated by Kruskal-Wallis test. We used Pignatti ecological bioindicator values reflecting ecological conditions in the community and they were set for each species according to Pignatti *(43)*. The data for the analysis of chorotypes, morphological features and ecological strategies were provided by the BiolFlor database *(44)*, Flora d`Italia *(45)* and local flora *(1)*.

We also calculated social behavioral type, which is estimated according to the accepted phytosociological placement of each species in the syntaxonomic system *(46)*. Its structure in an individual forest type reflects ecological conditions, dynamics and relationship within the community *(47)*. We considered the following types: species of mesophilous forests *Carpino-Fagetea*, species of thermophilous deciduous forests *Quercetea pubescentis*, forest edge *Trifolio-Geranietea,* dry grassland *Festuco-Brometea*, shrub and mantle species *Rhamno-Prunetea*, species of acidophilous forests *Vaccinio-Picetea* and *Quercetea roboris* and species of forest clearings *Epilobietea*.

RESULTS

We collected all available information about appearance of TH and prepared the map of distribution (Fig. 1). It shows that TH can only be found sporadically in the central and eastern part of Slovenia, mostly along rivers, whereas in the western part of the country, the distribution of TH is denser.

The model, prediction of which can be accepted with 87.96 % probability, shows (Fig. 2) that the most discriminating variable for identification of TH habitat is the mean temperature of the coldest quarter (winter). Based on the structure of the model suitable conditions for TH distribution are there where the mean temperature of the coldest quarter is higher than 3.8 °C and precipitation occurs seasonally or where the mean temperature of the coldest quarter is lower than 3.8 °C, and the precipitation of the driest quarter (summer) is low, altitude is below 655 meters, temperature seasonality is low and inclination is less than 23.8°.

The model visualization (Fig. 3) showed that TH appears in the south-western part of Slovenia (at the Adriatic coast), below the Karst edge, on the Karstic plateau, in the Vipava Valley and in the southern part of Goriška brda. It is also distributed along rivers in more alpine regions.

The *Alnus glutinosa* dominated community was eliminated from further analysis, because it was an outlier. The classification (Fig. 4) revealed that relevés can be classified within four clusters (groups). The first and the second groups were mainly sampled in areas in which TH is potentially distributed, whereas groups 3 and 4 were sampled in the area beyond it.

Figure 5 shows bi-plot of four groups of forest communities with passively projected bioindicator values on first two ordination axes of the DCA analyses. The main gradient is along the first axis, representing the transition between communities classified by cluster 1, susceptible to invasion of TH, to cluster 4 communities that are not expected to be invaded. The position of clusters 2 and 3 along this axis is not so distinct but they can be distinguished on the second axis.

According to floristic analysis (Tab.1), diagnostic species for clusters 1 and 2 are *Hedera helix, Sesleria autum-*

Figure 3. *Map of potential distribution of TH in the western Slovenia.*
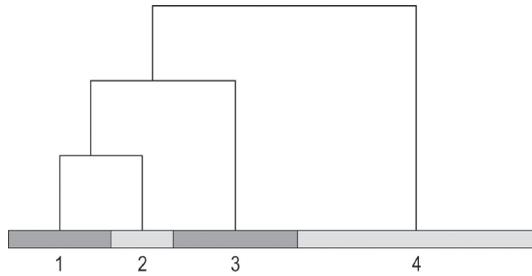
Figure 4. *Dendrogram of sampled forest communities revealed four clusters (groups). Clusters 1 and 2 are susceptible for TH invasion and cluster 3 and 4 are not.*
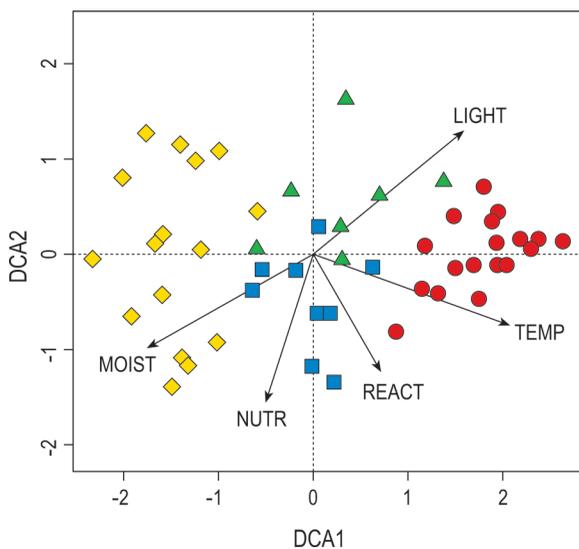
Figure 5. *DCA analysis of forest communities with passively projected bioindicator values. Legend: red circles – group 1, blue squares – group 2, green triangle – group 3, yellow diamond – group 4. Groups correspond to Fig. 4.*

nalis and *Ruscus aculeatus;* diagnostic species for cluster 3 and 4 are *Oxalis acetosella, Prenanthes purpurea, Maianthemum bifolium, Athyrium filix-femina* and *Polytrichum formosum.* Diagnostic species for cluster 1 are *Cotinus coggygria, Vincetoxicum hirundinaria, Ligustrum vulgare* and *Crataegus monogyna;* for cluster 2 are *Asarum europaeum* and *Galium laevigatum,* for cluster 3 are *Carex montana, Fragaria viridis, Euonymus europaeus, Festuca heterophylla* and *Cephalanthera longifolia*; and for cluster 4 are *Ctenidium molluscum, Cardamine trifolia, Isothecium alopecuroides, Neckera crispa* etc.

The dominant tree species in cluster 1 are *Carpinus betulus, Quercus cerris, Fraxinus ornus, Pinus nigra, Pinus sylvestris, Robinia pseudoacacia, Quercus petraea, Ostrya carpinifolia* and *Castanea sativa*; in cluster 2 are *Fagus sylvatica, Ostrya carpinifolia, Robinia pseudoacacia, Tilia cordata* and *Ulmus glabra*; in cluster 3 are *Fagus sylvatica, Castanea sativa, Pinus sylvestris* and *Quercus petraea*; and in cluster 4 are *Fagus sylvatica, Picea abies* and *Abies alba*.

The analysis showed clearly that TH can be expected in forests forming cluster 1, composed of sub-Mediterranean lowland hornbeam forests, secondary black and scots pine forests, turkey oak forests, sessile oak forests and pubescent oak and hop-hornbeam forests. Cluster 2 is still susceptible to TH invasion and is composed of submontane and thermophilous beech forests, as well as ravine forests. Cluster 3, which is less susceptible for TH invasion, is composed of montane beech forests, chestnut forests, sessile oak forests and scots pine forests. Cluster 4 is also less susceptible to TH invasion and is dominated by beech, Norway spruce and silver fir forests. In all these forests the shelterwood management system is applied.

The ecological conditions represented by bioindicator values in these communities are given in Fig. 6. In the cases of light, temperature, humidity and nutrients, a maximum difference ($p < 0.001$) can be found at two extreme positions in cluster 1 and cluster 4, whereas clusters 2 and 3 are in-between. Soil reaction shows that clusters 1 and 2, representing susceptible communities for invasion, show a higher soil reaction than the other two clusters.

The origin of species (Fig. 7) shows that forest communities originating from the Mediterranean area (clusters 1 and 2) are more susceptible to invasion. On the other hand, forests originating from colder areas (boreal, mountains) are less vulnerable.
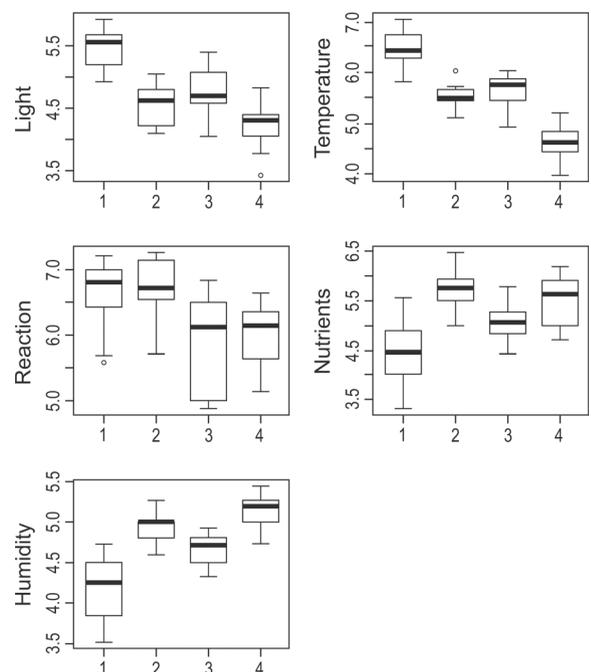
Figure 6. *Box-plots of Pignatti bioindicator values for light, temperature, reaction (pH), nutrients and humidity. Box plots present median, interquartile range, maximum, minimum and outliers. Legend: numbers on y axis present mean bioindicator values, samples are grouped as in Fig. 5.*

Table 1. *Synoptic table of relevés. Species with fidelity value higher than 0,5 are presented, as well as some most common species.*

Running number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Estimation of presence of TH	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Dominant tree species																																																		
Carpinus betulus	3	3	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Quercus cerris	.	.	4	+	.	.	2	.	.	.	.	.	.	.	.	2	2	.	1	r	.	.	.	.	.	1	.	1	2	+	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Fraxinus ornus	2	2	3	3	2	3	2	2	4	4	2	3	3	3	2	2	+	2	1	.	1	1	2	2	+	+	+	+	+	3	3	.	+	+	2	.	.	1	2	.	.	r	.	.	+	.	2	.	.	.
Pinus nigra	.	.	.	2	3	.	.	.	.	+	2	.	3	.	.	.	.	.	.	.	.	.	.	2	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pinus sylvestis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4	.	.	.	.	.	.	.	.	.	.	1	.	3	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Robinia pseudoacacia	.	.	.	.	.	.	.	.	.	.	.	2	2	.	.	.	.	.	.	.	.	.	.	.	3	2	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Quercus petraea	.	+	.	.	+	3	.	.	.	.	.	.	.	.	+	2	2	2	.	.	.	.	.	.	.	.	.	2	1	+	3	.	5	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ostrya carpinifolia	.	2	1	.	+	3	3	5	2	+	1	2	2	3	2	.	.	2	2	+	4	4	+	2	1	.	.	1	2	2	2	3	+	.	+	.	.	.	+	r	r	r	.	.	.	2	2	r	.	.
Quercus pubescens	.	.	.	.	.	.	.	2	+	1	2	2	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Castanea sativa	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	.	2	3	.	.	.	.	.	.	.	1	.	.	+	3	+	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Fagus sylvatica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	5	5	5	2	2	2	2	.	.	4	3	+	3	3	4	+	3	5	4	5	5	5	5	4	3	5	5	5	+	3	2	.
Tilia cordata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	2	.	.	3	3	.	2	2	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ulmus glabra	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	.	2	.	.	1	1	.	+	.	.	.	2	2	+	.	r	.	.	.	.	.	.	2	2	2	2	.
Picea abies	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	.	.	4	+	+	.	+	+	+	+	3	.	2	+	.	.	2	2	3	2	2	3	3	+	5	4
Abies alba	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	+	.	.	2	2	2	2	r	.	3	2	.	.
Diagnostic species for cluster 1 and 2																																																		
Hedera helix	2	1	+	2	+	3	1	2	2	.	+	2	1	1	.	1	.	.	+	+	+	.	+	+	2	+	1	.	.	.	.	+	.	.	.	.	.	r	r	1	1	.	.	.	.	2	.	.	1	.
Sesleria autumnalis	.	3	4	3	+	+	1	4	5	5	5	4	3	5	3	3	5	.	4	3	.	2	.	.	.	.	.	.	.	+	+	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Ruscus aculeatus	1	1	1	+	.	.	+	2	2	.	.	.	+	.	.	.	.	+	.	.	+	.	.	2	.	2	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diagnostic species for cluster 3 and 4																																																		
Oxalis acetosella	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1	+	+	+	.	.	+	1	2	+	+	+	+	1	4
Prenanthes purpurea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	+	.	.	.	.	+	2	2	+	1	1	1	+	+	.	+	+	+	+	1	.
Maianthemum bifolium	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	+	+	+	+	.	.	.	.	.	.	+	+	+	+	.	+
Athyrium filix-femina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	+	+	+	.	.	+	.	+	+	1	1	+	+	+
Polytrichum formosum	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	+	2	1	+	.	+	+	.	.	.	1	.
Diagnostic species for cluster 1																																																		
Cotinus coggygria	.	.	.	.	.	.	.	3	3	3	3	3	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Vincetoxicum hirundinaria	.	+	+	+	+	+	+	+	1	+	1	.	.	+	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.

Running number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Ligustrum vulgare	1	1	2	2	.	2	2	.	2	2	.	2	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crataegus monogyna	1	.	1	+	2	+	2	.	+	.	1	2	r	1	2	+	.	.	.	.	.	.	.	.	+	.	.	.	+	+	+	.	.	+	.	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.
Diagnostic species for cluster 2																																																		
Asarum europaeum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	1	+	+	2	2	+	+	+	.	1	.	.	.	.	.	.	.	1	+	+	.	.	.	.	+	.	.	.	.
Galium laevigatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.
Diagnostic species for cluster 3																																																		
Carex montana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	2	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Fragaria viridis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	+	+	+	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Rubus fruticosus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	.	2	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Euonymus europaea	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Festuca heterophylla	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	2	+	.	.	1	+	.	.	r	r	.	.	.	.	.	.	.	.	.	.	.
Cephalanthera longifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diagnostic species for cluster 4																																																		
Ctenidium molluscum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	1	1	2	+	.	.	.	+	.	2
Cardamine trifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	2	.	.	1	.	+	+	2
Isothecium alopecuroides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	+	.	+	1	1	1	.	1	1	.	+	+	+
Neckera crispa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	+	+	1	2	.	1	.	.	.	.	.
Schistidium apocarpum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	+	+	+	1	1	+	1	1	.	.	1	+
Anemone nemorosa	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	r	.	.	1	.	.	1	.	1	+	.	1	+
Veronica urticifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	1	1	+	1	1	.	+	+	.	.	.	.
Luzula nivea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	1	2	1	+	.	.	.	.	.
Paris quadrifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	+	1	1	.	+	.	+
Asplenium viride	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	1	1	+	+	.	+	+	.	.
Phyteuma ovatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	+	+	.	+	+	.	.	+	.	.	.
Homogyne sylvestris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	1	1	1	1	.	.	.	.	+	.	.
Thuidium tamariscinum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	2	.	+	2	+	.	+	.	+	.
Gymnocarpium dryopteris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	2	+	+	+	.	.	.
Daphne mezereum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	r	.	r	.	+	.	r	+	+	+	+	.	.	.	.
Most common species																																																		
Acer pseudoplatanus	1	.	.	.	.	2	+	.	.	.	.	.	.	.	.	.	.	.	2	2	1	2	2	+	+	2	2	+	.	+	+	+	1	+	2	+	2	+	+	1	1	.	+	+	.	2	2	+	2	2
Dryopteris filix-mas	.	.	.	+	.	.	.	.	.	r	.	.	.	.	.	.	.	.	+	1	1	+	.	.	.	.	+	.	+	+	+	.	2	.	+	+	+	+	+	+	+	.	r	1	+	1	.	2	1	+
Mycelis muralis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	.	.	.	.	.	.	+	.	1	1	+	.	+	+	.	+	.	+	.	+	.	+	1	.	+	.	+	.	+

Species table (Running number 1–50):

- Clematis vitalba
- Corylus avellana
- Cyclamen purpurascens
- Viola reichenbachiana
- Brachypodium sylvaticum
- Salvia glutinosa
- Primula vulgaris
- Anemone trifolia
- Sorbus aria
- Asplenium trichomanes
- Cornus mas
- Acer campestre
- Prunus avium
- Rosa arvensis
- Carex digitata
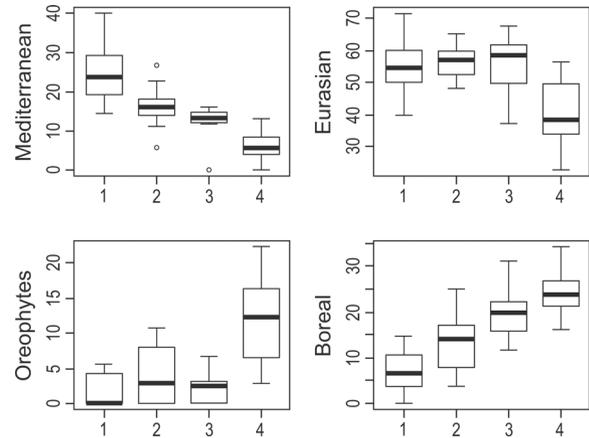- Senecio ovatus
- Brachypodium rupestre

Figure 7. *Box-plots of origin of species (chorotypes) in each group. Legend: numbers on y axis present percentage of each chorotype, samples are grouped as in Fig. 5.*
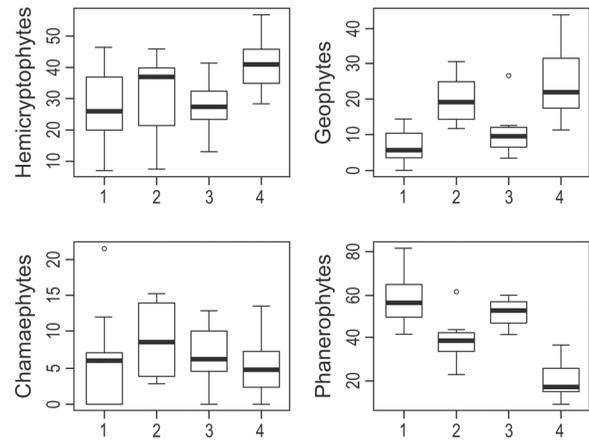

Figure 8. *Box-plots of morphological functional types. Therophytes are not present in most of samples (76%) in the other they have a minor presence. Legend: numbers on y axis present percentage of morphological functional types, samples are grouped as in Fig. 5.*

Morphological functional types (Raunkier's life forms) (Fig. 8) show that there are more phanerophytes in polidominant (sub)Mediterranean forests and more hemicryptophytes and geophytes in montane forests.

Ecological strategies (Fig. 9) show that most of plots are situated in the CS part of the CSR space. The separation of relevés in the plot is hardly possible, but we can detect more plots from cluster 1 and 2 with more pronounces competitor strategy and cluster 3 and 4 with more stress tolerators.

Social behavioral types (Fig. 10) show the predominance of species from thermophilous deciduous forest, forest edges and grassland communities in the (sub)Mediterranean influenced forests in cluster 1; clusters 2 and 3 are in-between, and cluster 4 is dominated by species of mesophilous and acidophilous forests.
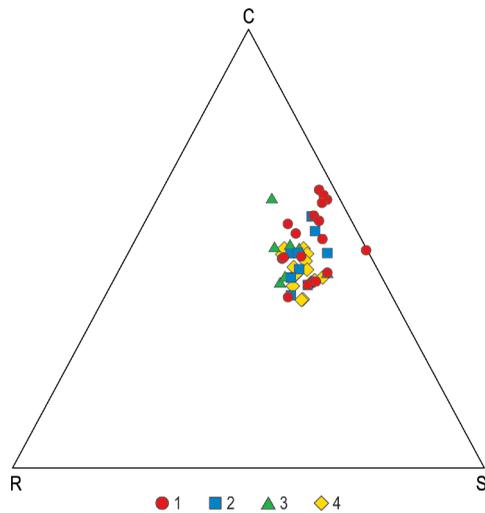
Figure 9. *CSR diagram with ecological functional types. Position of the section in the CSR triangle is presented in the upper right side. Legend: see Fig. 5.*
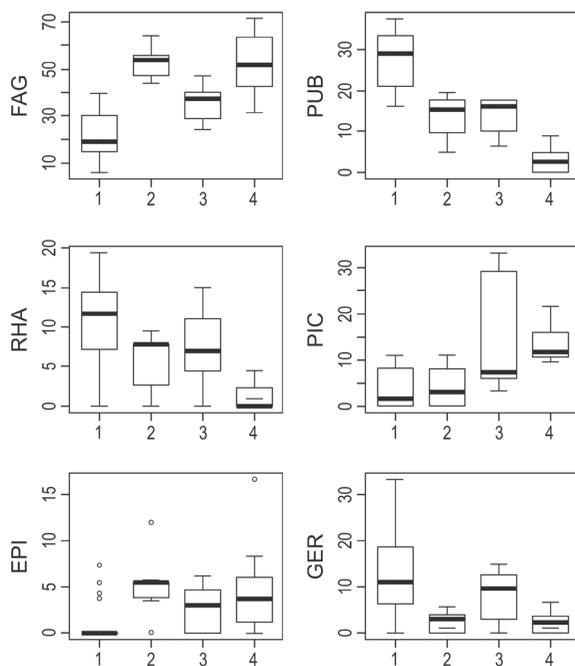

Figure 10. *Box-plots of social behavioral types. Legend: FAG - species of mesophilous forests, PUB - species of thermophilous deciduous forests, RHA - shrub and mantle species, PIC – species of acidophilous forests, EPI species of forest clearings, GER – species of forest edges and dry grasslands. Numbers on y axis present percentage of each social behavioral type, samples are grouped as in Fig. 5.*

DISCUSSION

Analysis of present occurrence showed that a dense population of TH can be found only in the western part of Slovenia, which is under the influence of the Mediterranean Sea. The situation is similar in neighboring Croa-

tia *(48–49)*. In this area, TH has settled all appropriate niches, whereas in central and eastern, more continental parts of the country, it can be found only along transport networks and rivers, which are the main drivers for the spread of TH *(8, 50)*. In this part, TH invasion has remained in the lag phase for 150 years since its arrival in Slovenia *(9, 14)*. It is important to survey TH in the future in those areas, in part because expected global warming will cause Mediterranean-like changes of the climate *(51)* and faster expansion of invasive species can be expected *(52)*.

TH appears in the areas close to the Adriatic Sea. It also appears on the karstic plateau, with more pronounced summer hydric stress (precipitation seasonality), but does not appear above an altitude of 655 meters. The lower temperature seasonality excludes the hilly region of Brkini, lying at lower altitudes in the hinterland. TH is also distributed along the alpine rivers, which allow the flow of warm air. The appearance in the Bovec region is the result of planting in the past but the mild and humid local climate apparently suits it. Slope is of a local character and is decisive for the appearance of TH on a smaller scale in the transitional area.

The classification and ordination diagram with passively projected indicator values shows that the main division is on the axis light – moisture, whereby dry and light (sub)Mediterranean forests classified within the cluster 1, susceptible for invasion by TH, are on the one side and humid and closed, less vulnerable forests of cluster 4 on the other. This division can be explained by climatic separation. TH spreads along the gradient from Mediterranean areas towards the continent. Just as in the Mediterranean area the distribution of TH is mainly affected by site fertility, in the continental parts of Europe climate is decisive *(6)*. However, in the transitional zone the appearance is influenced by other factors of a more local character (e.g. soil) *(53)*.

Light is certainly one of the crucial factor that enable the invasion of TH. TH is one of the species that participate in afforestation of abandoned grasslands. At the same time it can be expected also in young forest (e.g. in pole stage), but our research was focused on established forests *(11)*. At the same time it should also be taken in consideration that the closure of canopy is different between oak, beech and spruce tree *(54)*, but it corresponds to the forest type. There exists an interrelation between climate, forest type and light availability at herb layer.

TH is expected to invade more intensively hornbeam, black and scots pine forests, as well as turkey and sessile oak forests and pubescent oak and hop-hornbeam forests. It can also easily appear in submontane and thermophilous beech forests and in ravines. Invasion is less likely in acidophilous sessile oak, chestnut and scots pine forests and in montane beech, Norway spruce and silver fir forests. *(55–60)*. The riverine forest dominated by *Alnus*

glutinosa that was eliminated from the analysis can also be added to the group of susceptible communities. This stand was sampled within the area susceptible to TH invasion. Riverine forests from other regions have already been recognized as vulnerable *(61)*.

The ecological bioindicator values *(43)* show two extremes, cluster 1 is characterized by high light and temperature and low humidity and nutrients, and vice versa for cluster 4. Clusters 2 and 3 are in an intermediate position. TH is drought resistant *(62)* and does not tolerate shading *(11)*. It seems that nutrients do not have an important role *(6)*. The only exception in the case of indicator values is the pH of the soil, moderately alkaline soil can be found within clusters 1 and 2, which are more susceptible to TH invasion, and neutral pH indicator values in clusters 3 and 4, which are less vulnerable to invasion. It can be concluded that TH is a good competitor on shallow soils on carbonate bedrock *(63)*.

The analysis of chorotypes confirmed the (sub)Mediterranean origin of the species *(3)*. In forests from susceptible clusters 1 and 2, a higher proportion of Mediterranean and Eurasian elements can be found, whereas clusters 3 and 4 show a higher proportion of boreal species and species from SE European Mountains.

Morphological life strategies reflect to a major extent the climatic conditions *(64)* and therefore more phanerophytes can be found in polidominant (sub)Mediterranean forests and more hemicryptophytes in the more mesic forests of cluster 4. More geophytes can be found in mesic sites on carbonate bedrock *(65–66)*.

As all here observed tree species has C strategy in database *(44)*, this would mask eventual differences, we calculated the CSR signature only on the basis of the herb layer *(67)*. The position of the CSR signature is close to the CS axis, which means that these communities are final stages of development. More competitors can be found in cluster 1 and more stress tolerant and ruderal species in the other three clusters. The higher proportion of the latter strategies is caused by shading in closed stands and human impact in more productive forests *(68–69)*. We could not find reasons for vulnerability from the ecological signature. It has already been established that TH can invade initial successional stages and forest gaps and clearings, in which the ruderal signature is much more pronounced *(69)*.

Social behavioral type shows the predominance of species from thermophilous forests, shrubby species and species from forest edges and dry grasslands in cluster 1 and partially also in clusters 2 and 3, whereas cluster 4 is dominated by species of mesophilous and acidophilous forests. A difference between clusters 2 and 3 is recognizable and coincides with the bioindicator value for soil pH (soil reaction). In communities from clusters 1 and 2, which are susceptible to invasion of TH, a low proportion

of species from acidophilous forests can be found. These species do not appear on shallow soils on carbonate bedrock and create a difference with communities of cluster 3 (and 4) appearing on deep, decalcified soils *(70–71)*.

Our research, which forecasts the future distribution of TH in the studied region, will offer the basis for the preparation of measures to prevent its spread. Such procedures are common in other parts of the world *(72)*, although it is also necessary to take into consideration the opinion of Brus et al. *(73)*, who thinks that we must reconsider our perception of TH and to accept it as part of our natural environment.

CONCLUSION

Dense populations of TH can be found only in the western part of Slovenia, whereas in central and eastern Slovenia TH appears only sporadically, mostly along rivers.

We found that the main factor that initiates the invasion of TH on a larger scale are macro-climatic conditions, and site conditions on a smaller scale. In the research area, the main factor for the appearance of TH is the influence of the Mediterranean climate on a larger scale and deep, decalcified soils on a smaller one.

TH can be expected in sub-Mediterranean lowland hornbeam forest, secondary black and scots pine forests, turkey oak forests, sessile oak forests and pubescent oak and hop-hornbeam forests as well as in submontane and thermophilous beech forests and in ravine forests. Forests that are less susceptible to TH invasion are montane beech forests, chestnut forests, sessile oak forests, scots pine forests and forests dominated by beech, Norway spruce and silver fir.

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APPENDIX 1. ANALYTICAL TABLE OF RELEVÉS

APPENDIX 1. ANALYTICAL TABLE OF RELEVÉS

Tab. 1. *Analytical table of relevés. Species with fidelity value higher than 0,5 are presented, as well as some most common species.*

	Dominant tree species	layer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
	Presence of tree of heaven		1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
FAG	*Carpinus betulus*	1	.	3	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
FAG	*Carpinus betulus*	2	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
FAG	*Carpinus betulus*	4	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
FAG	*Carpinus betulus*	6	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Quercus cerris*	1	.	.	4	.	.	.	2	.	.	.	.	.	.	.	1	1	+	.	1	.	.	.	.	.	1	.	.	1	2	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Quercus cerris*	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	+	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Quercus cerris*	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Quercus cerris*	6	.	.	+	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Fraxinus ornus*	1	.	2	.	1	.	.	.	1	3	3	3	1	2	3	1	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	r	r	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Fraxinus ornus*	2	.	3	.	.	.	.	.	1	2	3	2	2	3	.	2	.	.	.	.	.	.	2	2	.	.	.	.	.	3	3	.	.	.	2	r	.	.	.	r	.	.	.	.	.	.	.	.	.	.
PUB	*Fraxinus ornus*	4	1	1	2	3	+	3	1	+	1	1	1	1	1	1	1	1	+	+	1	.	.	1	1	.	+	.	.	+	2	1	.	+	+	+	r	.	.	.	+	.	r	.	.	.	.	.	.	.	.	.
PUB	*Fraxinus ornus*	6	1	.	1	1	.	.	1	+	1	1	1	+	2	.	1	.	.	+	.	.	1	+	+	+	+	+	+	+	+	.	.	.	.	.	+	.	+	+	.	r	.	+	.	.	.	.	.	.	.	.
	Pinus nigra	1	.	.	.	2	3	.	.	.	.	+	2	.	3	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Pinus nigra	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Pinus sylvestis	1	.	.	.	.	+	.	.	.	.	.	.	.	.	.	3	4	.	.	.	.	.	.	.	.	.	.	.	1	.	3	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Robinia pseudacacia	1	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Robinia pseudacacia	2	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	2	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Robinia pseudacacia	4	.	.	.	.	.	.	+	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Robinia pseudacacia	6	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Quercus petraea	1	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Quercus petraea	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Quercus petraea	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Quercus petraea	6	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Ostrya carpinifolia*	1	.	+	.	.	.	.	3	4	.	.	.	.	.	3	2	.	.	2	.	2	+	4	1	.	1	.	.	+	+	+	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Ostrya carpinifolia*	2	.	1	.	.	.	.	2	3	2	+	1	1	+	.	.	.	.	.	.	.	.	1	2	.	2	.	.	1	1	.	.	.	.	.	+	.	.	.	.	r	r	.	.	.	.	.	r	.	.	.
PUB	*Ostrya carpinifolia*	4	.	+	1	.	+	.	.	+	.	.	+	.	.	.	.	.	.	+	+	.	.	.	1	.	.	.	.	+	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Ostrya carpinifolia*	6	.	.	.	.	.	.	.	+	.	.	.	+	+	+	+	.	.	.	.	+	+	+	1	.	.	.	.	.	+	.	+	.	.	.	.	+	.	.	.	.	.	.	.	+	.	+	.	.	.	.
PUB	*Quercus pubescens*	1	.	.	.	.	.	.	.	.	.	.	2	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Quercus pubescens*	2	.	.	.	.	.	.	.	+	.	1	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PUB	*Quercus pubescens*	4	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

PUB	*Quercus pubescens*	6
QUE	*Castanea sativa*	1
QUE	*Castanea sativa*	2
QUE	*Castanea sativa*	4
QUE	*Castanea sativa*	6
	Fagus sylvatica	1
	Fagus sylvatica	2
	Fagus sylvatica	4
	Fagus sylvatica	6
FAG	*Tilia cordata*	1
FAG	*Tilia cordata*	2
FAG	*Tilia cordata*	4
FAG	*Tilia cordata*	6
FAG	*Ulmus glabra*	1
FAG	*Ulmus glabra*	2
FAG	*Ulmus glabra*	4
FAG	*Ulmus glabra*	6
QUE	*Picea abies*	1
QUE	*Picea abies*	2
QUE	*Picea abies*	4
QUE	*Picea abies*	6
QUE	*Abies alba*	1
QUE	*Abies alba*	2
QUE	*Abies alba*	4
QUE	*Abies alba*	6
	Diagnostic species for cluster 1 and 2	
	Hedera helix	2
	Hedera helix	4
	Hedera helix	6
PUB	*Sesleria autumnalis*	6
PUB	*Ruscus aculeatus*	4
PUB	*Ruscus aculeatus*	6
	Diagnostic species for cluster 3 and 4	
FAG	*Oxalis acetosella*	6
FAG	*Prenanthes purpurea*	6

	Species		
QUE	*Maianthemum bifolium*	6	
FAG	*Athyrium filix-femina*	6	
QUE	*Polyrichum formosum*	9	
	Diagnostic species for cluster 1		
RHA	*Cotinus coggygria*	1	
RHA	*Cotinus coggygria*	4	
RHA	*Cotinus coggygria*	6	
	Vincetoxicum hirundinaria	6	
RHA	*Ligustrum vulgare*	4	
RHA	*Ligustrum vulgare*	4	
RHA	*Ligustrum vulgare*	6	
RHA	*Ligustum vulgare*	6	
RHA	*Crataegus monogyna*	1	
RHA	*Crataegus monogyna*	4	
RHA	*Crataegus monogyna*	6	
	Diagnostic species for cluster 2		
FAG	*Asarum europaeum*	6	
FAG	*Galium laevigatum*	6	
	Diagnostic species for cluster 3		
PUB	*Carex montana*	6	
	Fragaria viridis	6	
RHA	*Rubus fruticosus*	4	
RHA	*Euonymus europaea*	4	
	Festuca heterophylla	6	
PUB	*Cephalanthera longifolia*	6	
	Diagnostic species for cluster 4		
FAG	*Ctenidium molluscum*	9	
FAG	*Cardamine trifolia*	6	
FAG	*Isothecium alopecuroides*	9	
FAG	*Neckera crispa*	9	
FAG	*Schistidium apocarpum*	9	
FAG	*Anemone nemorosa*	6	

QUE	*Veronica urticifolia*
	Luzula nivea
FAG	*Paris quadrifolia*
	Asplenium viride
	Phyteuma ovatum
FAG	*Homogyne sylvestris*
	Thuidium tamariscinum
FAG	*Gymnocarpium dryopteris*
FAG	*Daphne mezereum*
FAG	*Daphne mezereum*
PUB	QUERCETEA PUBESCENTIS
	Cornus mas
	Cornus mas
	Helleborus multifidus ssp. *istriacus*
	Melittis melissophyllum
	Tamus communis
	Sorbus torminalis
	Sorbus torminalis
	Sorbus torminalis
	Asparagus acutifolius
RHA	RHAMNO-PRUNETEA
	Clematis vitalba
	Clematis vitalba
	Clematis vitalba
	Corylus avellana
	Corylus avellana
	Corylus avellana
	Rubus ulmifolius
	Rubus ulmifolius
	Rubus ulmifolius
	Rubus idaeus
	Rubus idaeus
	Prunus spinosa
	Prunus spinosa
	Cornus sanguinea

Species		
Cornus sanguinea	6	
Berberis vulgaris	4	
Berberis vulgaris	6	
Prunus mahaleb	1	
Prunus mahaleb	4	
Prunus mahaleb	6	
Rhamnus fallax	4	
Rhamnus fallax	6	
Rubus hirtus	4	
Rubus hirtus	6	
FAG CARPINO-FAGETEA		
Acer pseudoplatanus	1	
Acer pseudoplatanus	2	
Acer pseudoplatanus	3	
Acer pseudoplatanus	4	
Acer pseudoplanatmus	6	
Acer pseudoplatanus	6	
Dryopteris filix-mas	6	
Mycelis muralis	6	
Cyclamen purpurascens	6	
Viola reichenbachiana	6	
Brachypodium sylvaticum	6	
Salvia glutinosa	6	
Primula vulgaris	6	
Anemone trifolia	6	
Sorbus aria	1	
Sorbus aria	2	
Sorbus aria	3	
Sorbus aria	4	
Sorbus aria	6	
Acer campestre	1	
Acer campestre	2	
Acer campestre	4	
Acer campestre	6	
Prunus avium	1	
Prunus avium	3	

Species	
Prunus avium	4
Prunus avium	6
Rosa arvensis	6
Rosa arvensis	4
Rosa arvesis	6
Carex digitata	6
Senecio ovatus	6
Fraxinus excelsior	1
Fraxinus excelsior	2
Fraxinus excesior	3
Fraxinus excelsior	4
Fraxinus excelsior	6
Mercurialis perennis	6
Lathyrus vernus	6
Euphorbia amygdaloides	6
Lamium orvala	6
Actaea spicata	6
Carex sylvatica	6
Polygonatum multiflorum	6
Hieracium murorum	6
Ulmus minor	3
Ulmus minor	4
Ulmus minor	6
Sambucus nigra	4
Sambucus nigra	6
Aposeris foetida	6
Lonicera xylosteum	4
Aremonia agrimonoides	6
Galium odoratum	6
Polystichum aculeatum	6
Galeobdolon flavidum	6
Galium laevigatum	6
Epipactis helleborine	6
Galeobdolon montanum	6
Helleborus niger	6
Omphalodes verna	6
Lilium martagon	6

Species	
Lonicera alpigena	4
Lonicera alpigena	6
Sanicula europaea	6
Cephalanthera damasonium	6
Vinca minor	6
Campanula trachelium	6
Convallaria majalis	6
Laburnum alpinum	1
Laburnum alpinum	3
Laburnum alpinum	4
Laburnum alpinum	6
Polygonatum verticillatum	6
Festuca altissima	6
Lonicera caprifolium	6
Lonicera caprifolium	4
Calamintha sylvatica	6
Hieracium sabaudum	6
Scrophularia nodosa	6
Hacquetia epipactis	6
Aruncus dioicus	6
Euonymus verrucosa	4
Euonymus verrucosa	6
Melica uniflora	6
Cardamine bulbifera	6
Campanula rapunculoides	6
Dryopteris dilatata	6
Lonicera nigra	4
Cardamine enneaphyllos	6
Cephalanthera rubra	6
Euphorbia carniolica	6

QUE QUERCETEA ROBORIS, VACCINIO-PICEETEA

Species	
Solidago virgaurea	6
Luzula luzuloides	6
Neotia nidus-avis	6
Gentiana asclepiadea	6
Sorbus aucuparia	3

Species	
Sorbus aucuparia	4
Sorbus aucuparia	6
Dicranum scoparium	9
Calamagrostis arundinacea	6
Vaccinium myrtillus	6
Hypnum cupressiforme	9
Serratula tinctoria	6
Larix decidua	1
Larix decidua	6
Saxifraga cuneifolia	6
Populus tremula	1
Populus tremula	4
Populus tremula	6
Luzula pilosa	6
Atrichum undulatum	9
Other species	
Asplenium trichomanes	6
Brachypodium rupestre	6
Calamagrostis varia	6
Polypodium vulgare	6
Juniperus communis	4
Asplenium ruta-muraria	6
Moehringia trinervia	6
Viola species	6
Dactylis glomerata	6
Fragaria vesca	6
Ajuga reptans	6
Polygonatum odoratum	6
Urtica dioica	6
Carex alba	6
Peltigera canina	9
Bromus erectus	6
Carex flacca	6
Juglans regia	1
Juglans regia	4
Juglans regia	6

Species	layer
Cruciata glabra	6
Geum urbanum	6
Betonica officinalis	6
Geranium robertianum	6
Veratrum album	6
Eupatorium cannabinum	6
Heracleum sphondylium	6
Homalothecium lutescens	9
Adenostyles glabra	6
Clematis alpina	4
Clematis alpina	6
Rosa pendulina	4
Rosa pendulina	6
Fissidens dubius	9

Legend: 1 – upper tree layer, 2 – lower tree layer, 4 – scrub layer, 6 – herb layer, 9 – moss layer.

Localities of relevés:

Number in the table, date (year/month/day), coordinates: north and east, surface of the relevé (m2), altitude (m), aspect (degrees), slope (degrees), cover total (%), cover of (upper) tree layer, cover of lower tree layer (%), cover of shrub layer (%), cover of herb layer (%), cover of moss layer (%), cover of bare rock (%), height of the highest tree (m), authors (AČ Andraž Čarni; ID Igor Dakskobler, LK Lado Kutnar, AM Aleksander Marinšek, UŠ Urban Šilc), remark.

1.Brič,20150901,45.475617,13.749461,200,100,-,0,-,90,-,10,20,0,-,-,UŠ,afforestation of abandoned terraces, deep soils; **2.**Truške,20150901,45.482083,13.814167,200,210,45,10,-,80,-,50,90,0,-,-,UŠ; **3.**Dutovlje,20150710,45.756306,13.780392,200,281,338,2,-,60,40,30,100,1,10,-,AČ,limestone; **4.**Kubed,20150831,45.517417,13.882667,200,130,-,0,-,30,-,80,70,5,-,-,UŠ; **5.**Obrov,20150831,45.527773,14.080464,200,600,-,0,-,60,-,40,80,20,-,-,UŠ; **6.**Manče,20150714,45.810919,13.918689,200,283,45,15,-,70,20,60,40,1,0,-,AČ, limestone (in depressions flysh); **7.**Above Kanal,20150911,46.057961,13.583131,200,475,180,30,90,90,-,15,20,1,40,-,LK,AM,limestone, no TH around; **8.**Oševljek,20150911,45.868775,13.700164,200,270,68,29,70,-,30,80,5,75,-,LK,AM,flysh and carbonate,no TH around; **9.**Vrtoče,20150828,45.879603,13.624394,200,120,360,15,85,50,-,70,85,2,50,8,LK,AM, *Aristolochio luteae-Quercetum pubescentis*,TH is not on the plot but it appears below the power line; **10.**Mirenski grad,20150828,45.878328,13.604053,200,160,23,12,85,50,-,60,90,5,20,10,LK,AM,TH is not on the plot, but near: along the road; **11.**Oševljek near Prvači na,20150828,45.867686,13.694953,200,430,360,20,90,60,-,70,90,2,60,15,LK,AM,*Aristolochio luteae-Quercetum pubescentis*,no TH around; **12.**Temenica,20150828,45.855725,13.673561,200,430,135,10,80,50,-,80,70,5,70,12,LK,AM,*Aristolochio luteae-Quercetum pubescentis*, no TH around; **13.** Mohorini near Renče,20150828,45.876669,13.680917,200,110,90,20,70,70,-,15,30,1,3,18,LK,AM,flysh,eutic cambisol,no TH; **14.**Gažon,20150930,45.524500,13.714417,200,180,225,10,-,80,-,40,90,0,-,-,UŠ; **15.** Sv. Anton,20150831,45.507944,13.856218,200,315,5,-,50,-,30,80,0,-,-,UŠ; **16.**Du rovlje,20150710,45.752506,13.797644,200,276,-,0,-,60,40,50,80,0,20,-,AČ ,flysh; **17.**Gorenje Ležeče,20150716,45.673183,14.069600,200,630,180,8,-,80,20,30,100,1,0,-,AČ ,flysh; **18.**Labore,20150901,45.478528,13.777556,200,320,360,10,-,60,-,10,20,0,-,-,UŠ; **19.**Starod,20150831,45.493167,14.166417,200,650,270,5,-,80,-,20,70,5,-,-,UŠ; **20.**Podgrad, Pla ma,20150831,45.509833,14.130556,200,590,-,0,-,90,-,20,50,40,-,-,UŠ; **21.**Kanalski Vrh,20150827,-,-,200,330 ,315,21,95,95,-,2,25,25,60,-,LK,AM,limestone,no TH around; **22.**Kanalski Vrh,20150911,46.035094,13.584228,200,350,225,36,90,90,-,20,45,0,1,-,LK,AM,carbonate and flysh, no TH around; **23.**Čekovnik,20150821,45.982361,13.954725,200,540,180,35,75,75,-,1,25,40,10,60,20,LK,AM,no TH around; **24.**Gorenja Trebuša,20150827,46.020469,13.855083,200,640,180,14,90,60,-,5,90,1,5,-,LK,AM,no TH around; **25.**Kanalski Vrh,20150911,46.089367,13.633006,200,170,68,31,80,80,-,20,30,1,25,-,LK,AM,Lime tree dominated stand, probably abandoned pasture, no TH around; **26.**Kanalski Vrh,20150827,46.083003,13.655539,200,520,360,12,95,95,-,1,25,0,0,-,AČ,in ditch, flysh; **27.**Dolenci,20150710,45.817692,13.875278,200,245,360,10,-,40,80,30,50,0,0,-,AČ,limestone; **28.**Volče,20150716,45.69818,14.0861,200,704,203,5,-,70,40,40,40,1,0,-,AČ,limestone; **29.**Volče,20150716,45.69096,14.09048,200,625,-,0,-,80,20,40,30,0,0,-,AČ,in ditch, flysh; **30.**Arviže,20150714,45.614664,14.012294,200,740,203,7,-,40,80,40,40,1,0,-,AČ,flysh; **31.**Tublje,20150714,45.598189,13.989297,200,565,-,0,-,50,70,50,50,20,-,AČ,flysh; **32.**Buje,20150901,45.645167,14.085861,200,370,90,3,-,90,-,20,10,0,-,-,UŠ; **33.**Studena gora,20150831,45.525444,14.224638,200,480,45,5,-,80,-,5,10,0,-,-,UŠ,sandstone; **34.**Tarre,20150716,45.598925, 14.075183,200,671,270,12,-,90,10,40,60,0,0,-,AČ; **35.**Cemerija,20150813,46.175114,13.94927,200,900,180,30,-,90,5,5,40,5,5,30,ID,limestone, marl, chart, eutric cambisol, *Ostryo-Fagetum calamagrostiestosum*; **36.**Jelenca,20150702,46.1811,13.88597,200,610,360,35,-,90,5,1,30,20,10,26,ID,limestone, marl, chart, dystric cambisol, *Luzulo-Fagetum* s. lat.; **37.**Hotedršcica,20150717,45.898242,14.106428,200,935,23,8,-

,80,30,50,60,0,0,-,AČ,limestone; **38.**Govci,20150821,46.004233,13.845058,200,1247,23,20,80,80,-,1,80,2,5,0,LK,AM,no TH around; **39.**Jehle,20150812,46.20028,13.9219,200,980,338,35,-,85,5,1,30,20,70,20,ID,limestone, marl, chart, renzic leptosol, *Saxifrago cuneifolii-Fagetum*; **40.**Koriška gora-Humar,20150812,46.16722,13.9008,200,550,45,40,-,90,5,5,40,10,30,24,ID,limest one, marl, chart, renzic leptosol, *Saxifrago cuneifolii-Fagetum/ Ostryo-Fagetum calamagrostietosum*; **41.**Bant,20150805,46.28102,13.5132,200,534,23,35,-,80,5,1,40,30,30,24,ID,limestone, rendzic leptosol, *Saxifrago cuneifolii-Fagetum*; **42.**Polovnik,20150810,46.30539,13.58699,200,830,360,30,-,90,10,5,30,20,60,25,ID,limestone, rendzic leptosol, *Homogyno sylvestris-Fagetum*; **43.**Zjab ci,20150811,46.3205,13.70994,200,1160,338,35,-,80,10,5,30,10,40,25,ID,limestone, rendzic leptosol, *Homogyno sylvestris-Fagetum*; **44.**Staro Utro,20150804,46.38747,13.72958,200,1520,135,25,-,90,10,5,75,5,20,20,ID,limestone, renzic leptosol, *Anemono trifoliae-Fagetum/ Polysticho lonchitis-Fagetum*; **45.**Polovnik,20150810,46.30977,13.53361,200,870,23,30,-,90,5,5,40,5,30,24,ID,lim estone, chromic cambisol, *Lamio orvalae-Fagetum*; **46.**Golobar,20150811,46.32481,13.61153,200,1020,225,10,-,90,5,5,30,15,20,22,ID,limestone, chromic cambisol, *Lamio orvalae-Fagetum*; **47.**Čekovnik, above Idrija,20150821,45.988833,14.017342,200,560,338,8,90,50,-,60,90,5,2,27,LK,AM,eutric soils, *Omphalodo-Fagetum* transition to *Aceretum* s.lat, there is no TH in the surrounding; **48.**Vojsko,20150821,45.987886,13.901756,200,1075,90,11,60,60,-,20, 40,5,0,22,LK,AM,no TH around; **49.**Podpleče,20150709,46.12316,14.04089,200,775,90,25,-,80,10,5,40,5,10,34,ID,limestone, clay, eutric cambisol, *Galio rotundifolii-Abietetum/ Homogyno sylvestris-Fagetum*; **50.**Lokve,20150821,45.987050,13.817608,200,1104,180,30,90,90,-,0,65,5,5,-,LK,AM,monoculture of *Picea abies*, no TH around.

Other species:

Acer monspessulanum [6] 9: +; *Acer platanoides* [6] 22: +, 35: +; *Aegopodium podagraria* [6] 25: +, 50: +; *Agrimonia eupatoria* [6] 4: +; *Agrostis stolonifera* [6] 4: +; *Ajuga pyramidalis* [6] 44: r; *Allium species* [6] 14: +; *Allium ursinum* [6] 49: +; *Angelica sylvestris* [6] 47: +; *Anomodon viticulosus* [9] 45: +; *Anthericum ramosum* [6] 7: +; *Arabis turrita* [6] 39: +; *Asaragus tenuifolius* [6] 16: +; *Asparagus tenuifolius* [6] 8: +, 22: +; *Asperula cyanchica* [6] 9: r; *Asplenium adiantum-nigrum* [6] 8: +; *Barramia halleriana* [9] 42: +; *Betonica officinalis* [6] 34: +; *Betula pendula* [3] 35: r; *Blechnum spicant* [6] 47: +, 49: +; *Brachythecium rutabulum* [9] 41: +; *Brachythecium velutinum* [9] 36: 1, 40: 1; *Briza media* [6] 5: 1, 20: +; *Buglossoides purpurocaerulea* [6] 29: +; *Calamagrostis villosa* [6] 44: 1; *Calamintha grandiflora* [6] 37: 1; *Calamintha menthifolia* [6] 7: +; *Campanula witasekiana* [6] 39: +, 44: +; *Cardamine impatiens* [6] 50: +; *Carex brachystachys* [6] 43: +; *Carex ferruginea* [6] 38: +; *Carex hirta* [6] 19: 2; *Carex humilis* [6] 40: +; *Carex species* [6] 4: 1, 18: 2; *Cirsium erisithales* [6] 23: 1, 47: +; *Cladonia rangiferina* [9] 39: +; *Clinopodium vulgare* [6] 17: +; *Cnidium silaefolium* [6] 3: +; *Colchicum autumnale* [6] 25: +; *Conyza canadensis* [6] 24: +; *Corallorhiza trifida* [6] 46: r; *Coronilla emerus* ssp. *emeroides* [4] 6: +, 14: 2; *Crataegus laevigata* [4] 2: +, 18: +; *Crocus species* [6] 2: r; *Cystopteris fragilis* [6] 43: +, 44: +; *Cytisus hirsutus* [6] 3: +; *Daphne laureola* [6] 23: +, 47: +; *Dentaria waldsteinii* [6] 37: 2; *Deschampsia flexuosa* [6] 7: +; *Dianthus monspessulanus* [6] 9: r; *Dictamnus albus* [6] 11: +, 12: +; *Dryopteris carthusiana* [6] 50: +; *Epilobium montanum* [6] 21: +; *Epipactis muelleri* [6] 35: +; *Equisetum telmateia* [6] 4: +; *Erica carnea* [6] 39: +; *Erigeron annuus* [6] 4: +, 36: +; *Euphorbia angulata* [6] 19: 1; *Euphorbia cyparissias* [6] 10: +; *Euphorbia verrucosa* [6] 17: +; *Festuca gigantea* [6] 37: 2; *Festuca species* [6] 32: +; *Filipendula vulgaris* [6] 4: 1; *Frangula alnus* [4] 31: +, 34: +; *Frangula alnus* [6] 34: +2; *Galeopsis speciosa* [6] 48: +, 50: 1; *Galium mollugo* [6] 35: +; *Galium rotundifolium* [6] 49: 1; *Geranium nodosum* [6] 37: +; *Geranium sanguineum* [6] 9: r; *Gymnocarpium robertianum* [6] 43: r; *Helleborus odorus* [6] 7: 1, 25: 1; *Helleborus species* [6] 2: 1; *Hepatica nobilis* [6] 23: +, 42: 1; *Hieracium dollineri* [6] 23: +; *Hieracium latifolium* [6] 14: +; *Hieracium racemosum* [6] 17: +, 40: +; *Huperzia selago* [6] 39: r; *Hylocomium splendens* [9] 41: +, 42: +; *Hypericum hirsutum* [6] 39: +; *Hypericum montanum* [6] 21: +; *Hypericum perforatum* [6] 18: +; *Impatiens noli-tangere* [6] 50: +; *Inula conyza* [6] 2: +; *Inula salicina* [6] 15: +; *Lathyrus niger* [6] 7: +; *Lathyrus venetus* [6] 21: +, 22: 1; *Lembotropis nigricans* [6] 31: +; *Leucobryum glaucum* [9] 36: 1; *Lilium bulbiferum* [6] 7: +; *Linaria vulgaris* [6] 18: +; *Lobaria pulmonaria* [0] 46: +; *Lunaria rediviva* [6] 48: 1; *Luzula luzulina* [6] 44: +; *Luzula sylvatica* [6] 38: +, 44: 1; *Marchantia polymorpha* [9] 36: +; *Melampyrum pratense* [6] 34: 1; *Melampyrum sylvaticum* [6] 43: r; *Melica uniflora* [6] 5: +, 30: +; *Mercurialis ovata* [6] 40: r; *Metzgeria furcata* [9] 41: +; *Milium effusum* [6] 46: +, 50: +; *Mnium thomsonii* [9] 41: +; *Moehringia trinervia* [6] 45: +; *Molinia arundinacea* [6] 34: 1; *Monotropa hypopitys* [6] 46: +; *Myosotis sylvatica* [6] 50: +; *Ornithogalum pyrenaicum* [6] 25: +; *Petasites albus* [6] 47: 1, 48: +; *Peucedanum oreoselinum* [6] 9: +, 26: +; *Phyteuma scheuchzeri* ssp. *columnae* [6] 23: 1; *Piptatherum virescens* [6] 47: +; *Phyllitis scolopendrium* [6] 21: 1; *Plagiomnium undulatum* [0] 41: +; *Plagiothecium undulatum* [9] 43: +; *Platanthera bifolia* [6] 48: +; *Poa angustifolia* [6] 6: +, 17: +; *Poa nemoralis* [6] 30: 1, 44: +; *Polystichum setiferum* [6] 37: 1; *Polystichum x illyricum* [6] 48: +; *Porella arboris-vitae* [9] 40: +; *Porella platyphylla* [9] 44: +; *Prenella vulgaris* [6] 7: 1; *Pseudoleskeella catenulata* [9] 44: 1; *Pteridium aquilinum* [6] 34: 4, 49: +; *Pulmonaria australis* [6] 15: +; *Pulmonaria officinalis* [6] 25: +, 47: +; *Pyrus pyraster* [4] 6: +, 15: +; *Rhytidiadelphus triquetrus* [9] 43: +; *Rosa canina* [4] 12: +; *Rosa species* [4] 7: +, 14: +; *Saxifraga rotundifolia* [6] 44: 1; *Selaginella helvetica* [6] 39: 1; *Senecio fuchsii* [6] 37: 1; *Solanum dulcamara* [6] 23: +; *Sorbus domestica* [6] 30: +; *Stachys sylvatica* [6] 47: +; *Staphylea pinnata* [6] 22: +; *Staphylea pinnata* [6] 22: +; *Stellaria media* [6] 30: +; *Stellaria montana* [6] 48: +, 50: 1; *Symphytum tuberosum* [6] 35: +, 49: +; *Tanacetum corymbosum* [6] 22: +; *Taraxacum officinale* [6] 24: +, 48: +; *Taxus baccata* [3] 42: r; *Teucrium chamaedrys* [6] 3: +; *Thalictrum minus* [6] 11: r, 31: +; *Thamnobryum alopecurum* [9] 41: +; *Tortella tortuosa* [9] 40: +, 43: +; *Trifolium rubens* [6] 3: +; *Tussilago farfara* [6] 36: +; *Ulmus canescens* [1] 33: +; *Valeriana tripteris* [6] 42: +, 43: +; *Veronica chamaedrys* [6] 30: +, 34: +; *Veronica officinalis* [6] 39: +; *Viburnum lantana* [4] 10: +, 24: +; *Vicia sylvatica* [6] 39: r; *Viola hirta* [6] 4: +, 31: +; *Viola riviniana* [6] 46: +; *Vitis vinifera* ssp. *sylvestris* [4] 12: +;

Deleted relevé:

Buje (SI),20150716,45.644983,14.086144,200,380,-,0,-,80,10,50,60,0,0,-,AČ,forest along the river.

Acer campestre [2]: +; *Acer pseudoplatanus* [2]: 2; *Aegopodium podagraria* [6]: +; *Alnus glutinosa* [1]: 4; *Anemone nemorosa* [6]: +; *Berberis vulgaris* [4]: +; *Brachypodium sylvaticum* [6]: 1; *Carex sylvatica* [6]: +; *Carpinus betulus* [2]: +; *Carpinus betulus* [4]: +; *Cirsium erisithales* [6]: +; *Corrnus sanguinea* [4]: 3; *Dactylis glomerata* [6]: +; *Cardamine bulbifera* [6]: +; *Euisetum palustre* [6]: +; *Euonymus europaea* [4]: 2; *Galeopsis pubescens* [6]: +; *Glechoma hederaceaea* [6]: 2; *Lamium orvala* [6]: 1; *Myosoton aquaticum* [6]: +; *Ornithogalum pyrenaicum* [6]: +; *Polygonatum multiflorum* [6]: +; *Peridium aquilinum* [6]: +; *Pulmonaria officinalis* [6]: +; *Pyrus pynaster* [1]: +; *Quercus petraea* [4]: +; *Rubus caesius* [6]: +; *Rubus fruticosus* [4]: 2; *Salvia glutinosa* [6]: 2; *Stellaria montana* agg. [6]: +; *Viburnum lantana* [4]: 2; *Viola reichenbachiana* [6]: +.