# „Restoring Ecological Diversity of Forests with Airborne Imaging Technologies"

# RED FAITH Project

# FOREST ACTION PLAN

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| **Content requirement** | The aim of the compilation of the professional material is that the partners (Mecsekerdő Forestry Co. Ltd. and Hrvatske Sume) needs to summarize the results of the project, the knowledge of their future use and the opportunities for close professional cooperation in the future in the framework of a Forest Action Plan. |
| **Project ID** | HUHR/1601/2.2.1/0004 |
| **Costumer** | Mecsekerdő Forestry Co. Ltd. |
| **Creator** | László Bekő |
| **Date** | 20 September 2019 |
| **Location** | Nagykanizsa |

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# 1 Introduction

The Forest Action Plan produced by the "Restoring Ecological Diversity of Forests with Airborne Imaging Technologies" is a summary of the results of the RED FAITH Project, which aims to summarize the achievements of this project and set new directions for their use by project partners in the form of a feasible action plan.

An important part of the document is the presentation of the nature conservation aspects of remote sensed areas within the framework of this project, and the characterization of the areas affected by the NATURA 2000 network (forests of Northern Zselic, Southern Zselic and Mecsek in Hungary, and forests in Baranya in Croatia). In addition, a description of the beneficial effects resulting from the detection of invasive tree species and their precise location, including the potential of high-resolution aerial remote sensing data in the forest.

Another important factor of planning is the exploration and evaluation of the current situation. This provided an opportunity to describe the natural values and threats to the areas concerned and to characterize the economic and nature conservation problems associated with the presence of invasive plants. In connection with this, the economic damage in the areas of Mecsekerdő Forestry Co. Ltd. is also planned.

A further essential part of the Action Plan is the presentation of aerial research and their technologies carried out within the framework of this project, as well as the presentation of research data, with a strong emphasis on the potential for knowledge sharing.

And one of the most crucial parts of planning is to formulate concrete actions, set future goals, identify the potential of the data and identify the steps needed.

# 2 Executive Summary

Brief summary of the Forest Action Plan components of the „Restoring Ecological Diversity of Forests with Airborne Imaging" Technologies: RED FAITH Project:

**Nature conservation aspects**

***Involvement with the NATURA 2000 network***

The RED FAITH Project captures a total of 3 sites of Community Importance (SCI) and 2 Special Protection Areas (SPAs) through aerial remote sensing.

The Forestry Action Plan lists the habitats, indicator species and conservation objectives and priorities of the affected areas (Northern Zselic forests, Southern Zselic and Mecsek, Management unit Haljevo - Kozaračke forests, Management unit Forests of Darda and Management unit Dvorac – Siget), as well

as the positive effects of invasive species detection by remote sensing technologies on protected species.

**Assessment of the situation**

***Presentation of natural values in the project area***

The surveyed areas affect a total of 3 microregions (Northern Zselic microregion, Southern Zselic microregion, Mecsek Mountains) in Hungary, and 3 microregion (Management unit Haljevo - Kozaračke forests, Management unit Forests of Darda and Management unit Dvorac – Siget) in Baranya in Croatia. For each microregion, the terrain, climate and vegetation characteristics of the areas are presented.

***Danger factors***

For the NATURA 2000 sites concerned, the invasive tree species most endangering them are described:

- Tree of heaven (*Ailanthus altissima [Mill.] Swingle*)
- White acacia (*Robinia pseudoacacia L.*)
- False indigo bush (*Amorpha fruticosa L.*)

***Economic and conservation problems caused by invasive plants:***

The most endangering invasive tree species:

- Tree of heaven (*Ailanthus altissima [Mill.] Swingle*)
- White acacia (*Robinia pseudoacacia L.*)
- False indigo bush (*Amorpha fruticosa L.*)

the economic and conservation dilemmas they originate or derive from them, are shown.

***Economic damage in the area of Mecsek Forestry Co. Ltd.***

In this subchapter, the areas of economic damage occurring between 2013 and 2019 affecting the area of Mecsekerdő Forestry Co. Ltd. are represented.

**Project objectivities and implementation**

In this part of the planning, the "Restoring Ecological Diversity of Forests with Airborne Imaging Technologies" will briefly present the technologies used in the RED FAITH Project, such as aerial laser scanning, aerial hyperspectral technology and digital metering camera technology. Then, the characteristics of the captured data and the products produced will be discussed, as will the remote sensed and thematic data have produced and the potential of knowledge sharing.

**Action Plan**

The guiding and horizontal objective of the Forest Action Plan can be achieved through operational objectives. The Plan defines a total of 5 operational objectives, for which a total of 10 core activities are recommended. Each of these is explained in detail in the document.

# 3 Natural conservation aspects of the project

## 3.1 The relevance of the sites researched within the RED FAITH Project to the NATURA 2000 network

The remote sensing data of REDFAITH project covered the following domestic NATURA 2000 sites [Sites of Community Importance (SCI) and Special Protection Areas (SPA)] (Figures 1. and 2.), which are under the authority of the Danube-Drava National Park directorate. Sites of Community Importance in the researched area:

- HUDD20016 - Forests of Northern Zselic - Special Area of Conservation (SAC)
    - Proportion of RED FAITH area in the forest of North Zselic: 3.38%
- HUDD20004 - Southern Zselic - Special Area of Conservation (SAC)
    - Proportion of RED FAITH area in South Zselic: 33.59%
- HUDD20030 - Mecsek - Special Area of Conservation (SAC)
    - Proportion of RED FAITH area in Mecsek: 35.19%
- HR2001308 - The lower course of the river Drava - Special Area of Conservation (SAC)
    - Proportion of RED FAITH area in The lower course of the river Drava: ,%
- HR2000394 – Kopački rit - Special Area of Conservation (SAC)
    - Proportion of RED FAITH area in Kopački rit (SAC): ,%

Special bird protection areas in the researched area:

- HUDD10013 - Zselic Special Protection Area for Birds
    - Proportion of RED FAITH area in Zselic: 36.97%
- HUDD10007 - Mecsek Special Protection Area
    - Proportion of RED FAITH area in Mecsek: 34.26%
- HR1000016 – Podunavlje i donje Podravlje Special Protection Area for Birds
    - Proportion of RED FAITH area in Podunavlje i donje Podravlje: ,%

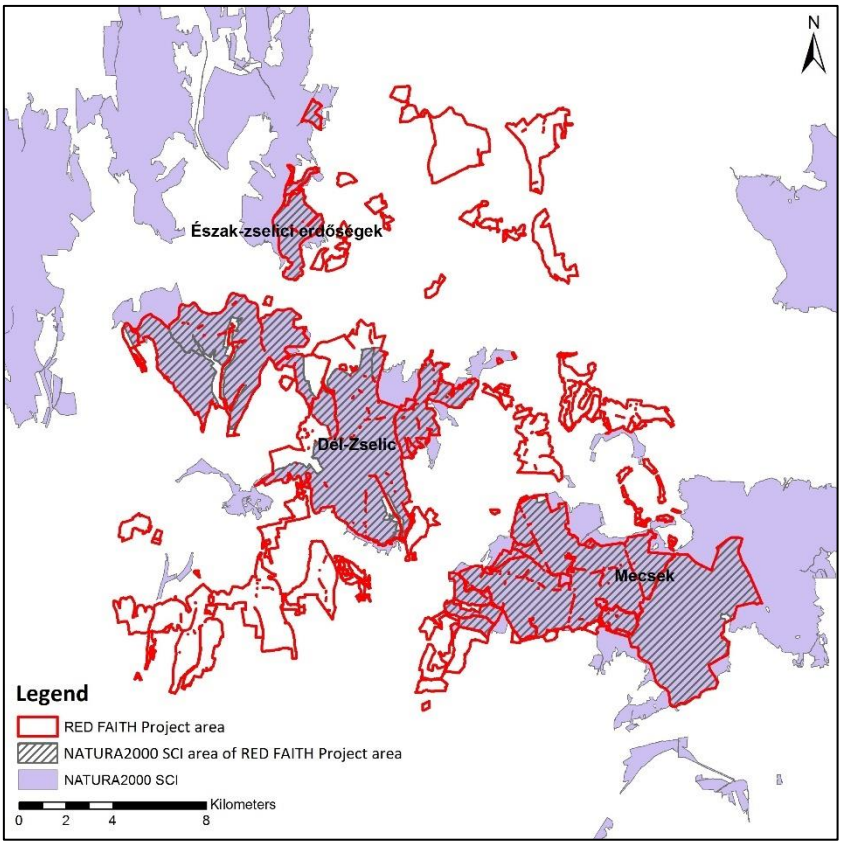



**Figure 1.** Location of sites surveyed within the RED FAITH project and NATURA 2000 SCI sites

Source: Based on Mecsekerdő Forestry Co. Ltd. self-edited, 2019

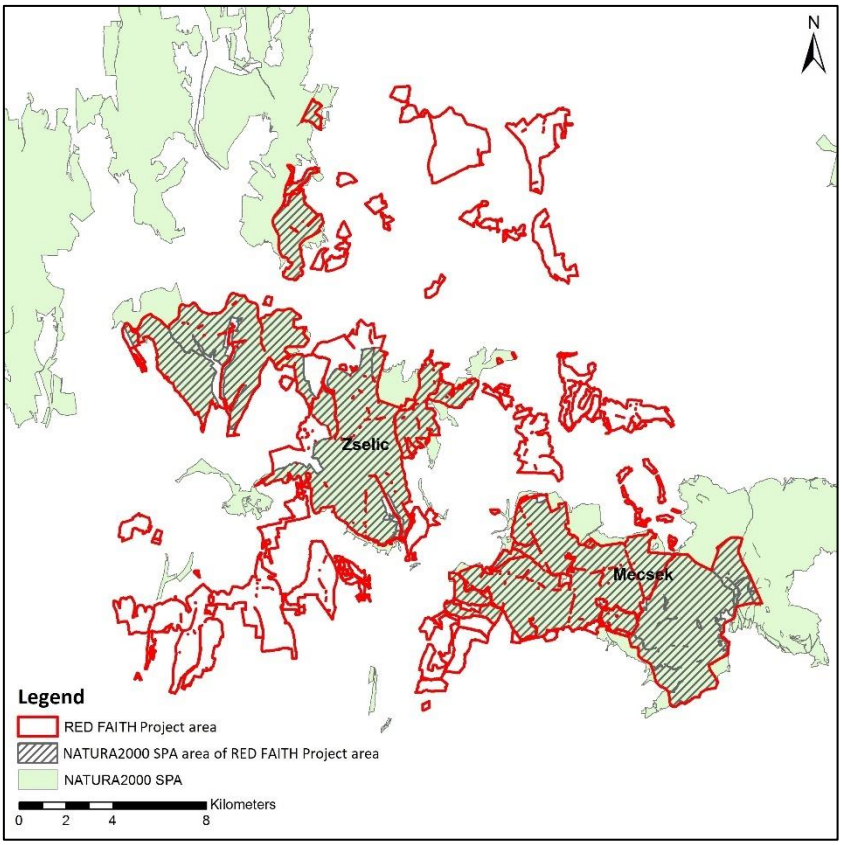



**Figure 2.** Location of sites surveyed within the RED FAITH project and NATURA 2000 SCI sites

Source: Based on Mecsekerdő Forestry Co. Ltd. Self-edited, 2019

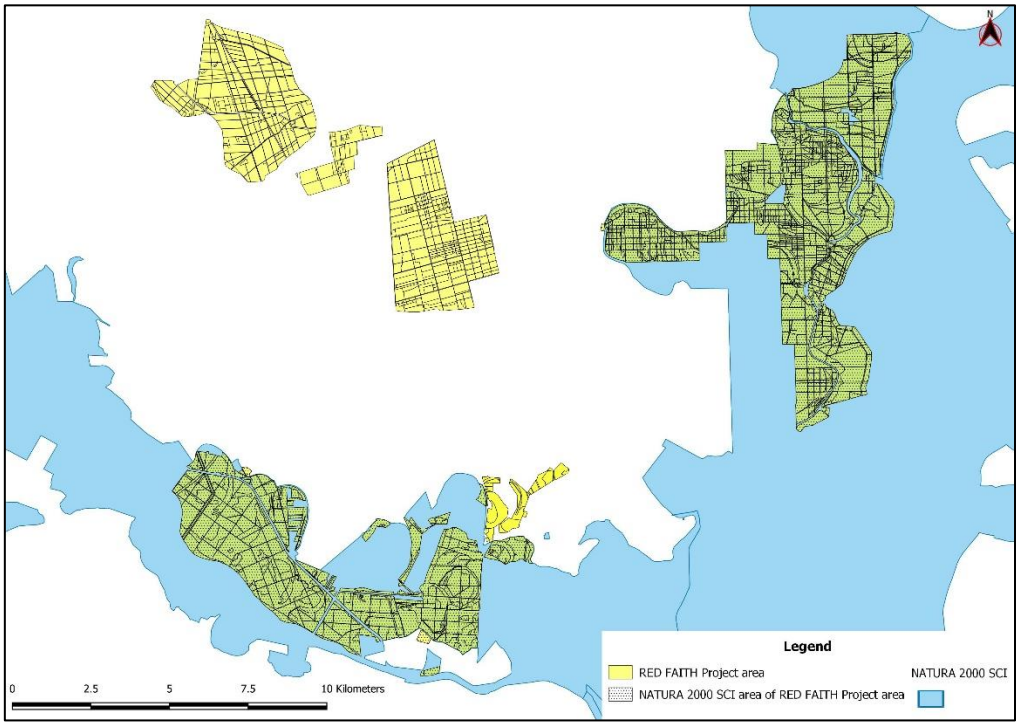



**Figure 3.** Location of sites surveyed within the RED FAITH project and NATURA 2000 SCI sites in CR

Source: Based on Hrvatske šume Ltd. Self-edited, 2019

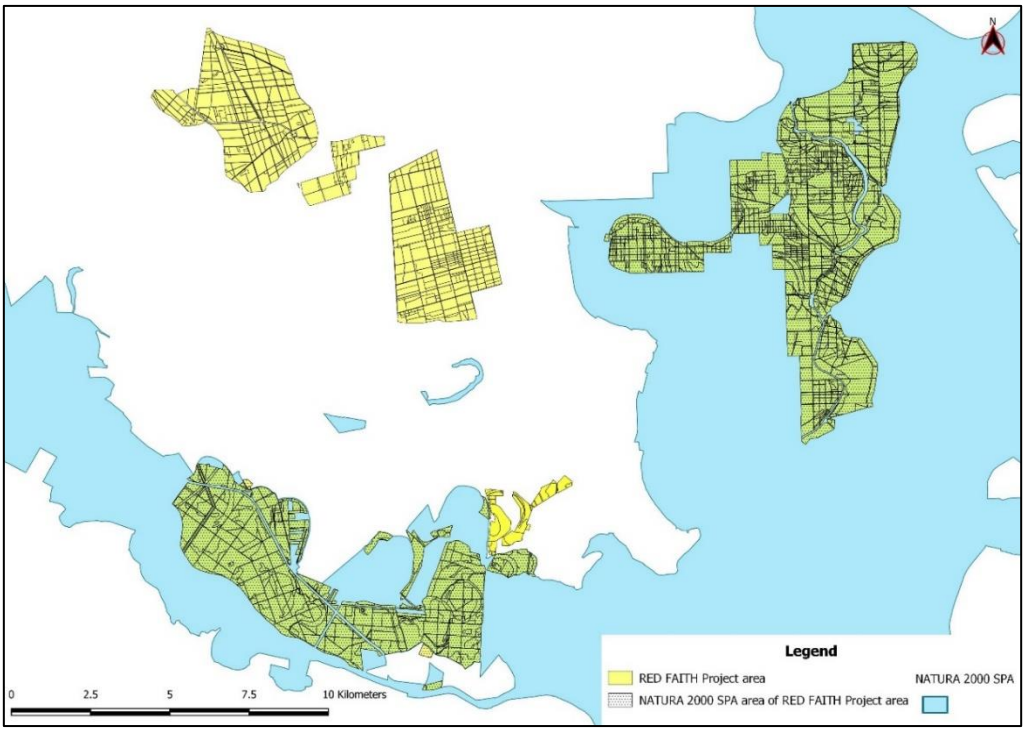



**Figure 4.** Location of sites surveyed within the RED FAITH project and NATURA 2000 SPA sites in CR

Source: Based on Hrvatske šume Ltd. Self-edited, 2019

In the following, the habitats, protected species, nature conservation priorities and objectives of the NATURA 2000 sites concerned will be presented.

### *3.1.1 Presentation of Northern Zselic Forests (Észak-zselici erdőségek) NATURA 2000 site (HUDD20016)*

***Indicator habitat types of the area***

**Table 1.** Habitat types and assessment of habitats in the NATURA 2000 (HUDD20016) forests of Northern Zselic

| Habitat type code | Habitat type name | Representativity | National importance |
|---|---|---|---|
| 91K0 | Illyrian *Fagus sylvatica* forests (*Aremonio-Fagion*) | A | A |
| 91L0 | Illyrian oak-hornbeam forests (*Erythronio-carpinion*) | A | A |
| 6430 | Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels | B | B |
| 91E0 | Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*) | B | B |
| 6510 | Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*) | C | C |
| 91F0 | Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*) | B | B |
| 9180 | *Tilio-Acerion* forests of slopes, screes and ravines | B | B |
| 91M0 | Pannonian-Balkanic turkey oak –sessile oak forests | C | C |

*The legend of the table is in the Annex 1

Source: Based on TIR Self-edited, 2019

***Indicator species of site***

**Table 2.** Indicator species in the NATURA 2000 site (HUDD20016) of the forests of Northern Zselic (species as defined in Article 4 of Directive 2009/147 / EC and listed in Annex II to Directive 92/43 / EEC and evaluation of these species)

| Name of species | Type | Frequency category | Presence |
|---|---|---|---|
| *Lucanus cervus* | p | P | C |
| *Leptidea morsei* | p | V | D |
| *Bombina bombina* | p | P | D |
| *Morimus funereus* | p | P | C |
| *Maculinea teleius* | p | P | C |
| *Hypodryas maturna* | p | P | D |
| *Bombina variegata* | p | P | D |
| *Eriogaster catax* | p | C | C |
| *Barbastella barbastellus* | p | P | C |
| *Emys orbicularis* | p | P | D |
| *Rosalia alpina* | p | C | B |
| *Maculinea nausithous* | p | P | D |
| *Lutra lutra* | p | R | C |
| *Cerambyx cerdo* | p | P | C |
| *Myotis myotis* | p | P | D |
| *Lycaena dispar* | p | R | D |
| *Myotis myotis* | p | P | D |
| *Lycaena dispar* | p | R | D |
| *Maculinea nausithous* | p | P | D |
| *Emys orbicularis* | p | P | D |
| *Maculinea teleius* | p | P | C |
| *Lucanus cervus* | p | P | C |
| *Barbastella barbastellus* | p | P | C |
| *Bombina variegata* | p | P | D |
| *Leptidea morsei* | p | V | D |
| *Cerambyx cerdo* | p | P | C |
| *Lutra lutra* | p | R | C |
| *Rosalia alpina* | p | C | B |
| *Morimus funereus* | p | P | C |
| *Eriogaster catax* | p | C | C |
| *Bombina bombina* | p | P | D |
| *Hypodryas maturna* | p | P | D |

* The legend of the table is in the Annex 1

Source: Based on TIR Self-edited, 2019

***Conservation priorities***

A priority objective for nature conservations are the following:

- Illyrian Fagus sylvatica forests (*Aremonio-Fagion*),
- maintaining the favourable conservation status of Illyrian oak-hornbeam forests (*Erythronio-carpinion*).

Also, a priority objectivities are the following:

- Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*) (91F0),
- Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*) (91E0) and their restoration with the favourable conservation status.

The area also includes extremely rare and valuable, species-rich Illyrian species with high species diversity. Rare high marginal vegetation also has a high degree of naturalness (OKIR, 2019).

***Conservation objectives***

General objectives:

Conservation, maintenance and restoration of the species and habitat types on which the Natura 2000 sites are designated, as well as the maintenance of the state of conservation and management of the Natura 2000 site (OKIR, 2019).

Main objectives:

- Usage of semi-natural forest management methods.
- Preservation of aged native tree species units, ensuring the permanent presence of dead standing and lying trees.
- Introduction of continuous forest cover mode.
- Special protection of forest habitat types with characteristic Illyrian features of the undergrowth.
- Enhance the naturalness of the habitat gallery forests adjacent to watercourses and transform nearby monodominant cultures into potential forest habitat types.

Additional goals and objectivities:

- Reduce the number of wild populations.
- Prevent shrub growth in forest clearings, hydrophilic high weeds and marshes
- Reducing the occupation of invasive species (e.g.: false indigo, goldenrod, tree of heaven, white acacia)
- Preserving and restoring the naturalness of watercourses, avoiding over-deepening of the watercourse, and protecting the areas accompanied by natural vegetation.
- Prevent erosion processes in steep cutting areas by, for example, leaving tree or shrub stripes.
- Conducting detailed surveys of the area, paying particular attention to the area's markers and other species of community’s interests and habitats.

(OKIR, 2019)

***Danger factors in the area***

Major and moderate threats to the site:

- Forestry and forest management
- Hunting
- Invasive, non-native species

(OKIR, 2019)

The site does not have a NATURA 2000 maintenance plan and is neither in the process of being negotiated nor in the process of being approved (DDNPI, 2019).

### *3.1.2 Presentation of Southern Zselic (Dél-Zselic) NATURA 2000 site (HUDD20004)*

***Indicator habitat types of site***

**Table 3.** Habitat types and assessment of habitats in the NATURA 2000 (HUDD20004) Southern Zselic.

| Habitat type code | Habitat type name | Representativity | National importance |
|---|---|---|---|
| 91M0 | Pannonian-Balkanic turkey oak –sessile oak forests | C | C |
| 91E0 | Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*) | C | C |
| 91K0 | Illyrian *Fagus sylvatica* forests (*Aremonio-Fagion*) | A | B |
| 6430 | Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels | D | |
| 91L0 | Illyrian oak-hornbeam forests (*Erythronio-carpinion*) | A | B |
| 91F0 | Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*) | C | C |
| 6510 | Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*) | D | |
| 6440 | Alluvial meadows of river valleys of the *Cnidion dubii* | D | |

* The legend of the table is in the Annex 1

Source: Based on TIR Self-edited, 2019

***Indicator species of site***

**Table 4.** Indicator species in the NATURA 2000 site (HUDD20004) of Southern Zselic (species as defined in Article 4 of Directive 2009/147 / EC and listed in Annex II to Directive 92/43 / EEC and evaluation of these species)

| Name of species | Type | Frequency category | Presence |
|---|---|---|---|
| *Cerambyx cerdo* | p | P | C |
| *Bombina variegata* | p | P | C |
| *Rhinolophus hipposideros* | p | P | C |
| *Lucanus cervus* | p | P | C |
| *Emys orbicularis* | p | P | C |
| *Lutra lutra* | p | - | C |
| *Rosalia alpina* | p | P | B |
| *Lutra lutra* | p | - | C |
| *Emys orbicularis* | p | P | C |
| *Rhinolophus hipposideros* | p | P | C |
| *Rosalia alpina* | p | P | B |
| *Cerambyx cerdo* | p | P | C |
| *Bombina variegata* | p | P | C |
| *Lucanus cervus* | p | P | C |

* The legend of the table is in the Annex 1

Source: Based on TIR Self-edited, 2019

***Conservation priorities***

A priority objective for nature conservations are the following:

- Illyrian *Fagus sylvatica* forests (*Aremonio-Fagion*),
- maintaining the favourable conservation status of Illyrian oak-hornbeam forests (*Erythronio-carpinion*) (91L0).

Also, a priority objectivities are the following:

- Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*) (91F0),
- Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*) (91E0) and their restoration with the favourable conservation status.

High-quality Illyrian forests and other similar forest habitat types, as well as grasslands in the area, are important for nature conservation purposes in large forests (OKIR, 2019).

***Nature conservation objectivities***

General objectivities:

Conservation, maintenance and restoration of the species and habitat types on which the Natura 2000 designation is based, and the maintenance of the state of conservation and management underpinning the delimitation of Natura 2000 sites (OKIR, 2019).

Main objectivities:

- Use of semi-natural forest management methods. Preservation of aged trees of native species units, ensuring the permanent presence of dead tree standing and lying.
- Introduction of continuous forest cover mode.
- Special protection of forest habitat types with characteristic Illyrian features of the undergrowth.
- Enhance the naturalness of the habitat gallery forests adjacent to watercourses and transform nearby monodominant cultures into potential forest habitat types.

(OKIR, 2019)

Additional goals and objectivities:

- Reduce the number of wild populations.
- Prevent shrub growth in forest clearings, hydrophilic high weeds and marshes.
- Reducing the occupation of invasive species (e.g.: false indigo, goldenrod, tree of heaven, white acacia).
- Preserving and restoring the naturalness of watercourses, avoiding over-deepening of the watercourse, and protecting the areas accompanied by natural vegetation.
- Prevent erosion processes in steep mowing areas by, for example, leaving tree or shrub stripes.
- Conducting detailed surveys of the area, paying particular attention to the area's markers and other species of community's interests and habitats.

(OKIR, 2019)

***Danger factors in the area***

Major and moderate threats to the site:

- Hydrographic changes
- Invasive, non-native species
- Forestry and forest management

(OKIR, 2019)

The site does not have a NATURA 2000 maintenance plan and is neither in the process of being negotiated nor in the process of being approved (DDNPI, 2019).

### 3.1.3 Presentation of Mecsek NATURA 2000 site (HUDD20030)

***Indicator habitat types of site***

**Table 5.** Habitat types and assessment of habitats in the NATURA 2000 (HUDD20030) of Mecsek

| Habitat type code | Habitat type name | Representativity | National importance |
|---|---|---|---|
| 91K0 | Illyrian *Fagus sylvatica* forests (*Aremonio-Fagion*) | B | B |
| 91H0 | Pannonian woods with *Quercus pubescens* | A | A |
| 91E0 | Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*) | C | C |
| 9110 | Luzulo-Fagetum beech forests | A | A |
| 6110 | Rupicolous calcareous or basophilic grasslands of the Alysso-Sedion albi | B | B |
| 8220 | Siliceous rocky slopes with chasmophytic vegetation | C | C |
| 7220 | Petrifying springs with tufa formation (*Cratoneurion*) | B | B |
| 6510 | Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*) | C | C |
| 6190 | *Rupicolous pannonic* grasslands (*Stipo-Festucetalia pallentis*) | C | C |
| 91M0 | Pannonian-Balkanic turkey oak –sessile oak forests | B | B |
| 9180 | *Tilio-Acerion* forests of slopes, screes and ravines | A | A |
| 6240 | Sub-Pannonic steppic grasslands | C | C |
| 40A0 | Subcontinental peri-Pannonic scrub | C | C |
| 6430 | Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels | C | C |
| 8310 | Caves not open to the public | A | A |
| 91L0 | Illyrian oak-hornbeam forests (*Erythronio-carpinion*) | B | B |
| 8210 | Calcareous rocky slopes with chasmophytic vegetation | B | B |

* The legend of the table is in the Annex 1

Source: Based on TIR Self-edited, 2019

***Indicator species of site***

**Table 6.** Indicator species in the NATURA 2000 site (HUDD20030) of Mecsek (species as defined in Article 4 of Directive 2009/147 / EC and listed in Annex II to Directive 92/43 / EEC and evaluation of these species)

| Name of species | Type | Frequency category | Presence |
|---|---|---|---|
| *Myotis bechsteinii* | p | - | C |
| *Himantoglossum caprinum* | p | - | B |
| *Eriogaster catax* | p | C | C |
| *Isophya costata* | p | - | A |
| *Vertigo moulinsiana* | p | P | D |
| *Cerambyx cerdo* | p | P | C |
| *Myotis myotis* | p | - | C |
| *Miniopterus schreibersii* | p | - | B |

| | | | |
|---|---|---|---|
| *Lycaena dispar* | p | R | D |
| *Lucanus cervus* | p | C | C |
| *Serratula lycopifolia* | p | - | C |
| *Rhinolophus hipposideros* | p | P | C |
| *Bombina variegata* | p | P | C |
| *Rhinolophus ferrumequinum* | p | - | C |
| *Erannis ankeraria* | p | P | D |
| *Morimus funereus* | p | P | C |
| *Paladilhia hungarica* | p | R | A |
| *Bombina bombina* | p | P | C |
| *Myotis emarginatus* | p | P | C |
| *Myotis dasycneme* | p | - | C |
| *Myotis blythii* | p | - | C |
| *Pilemia tigrina* | p | P | B |
| *Vertigo angustior* | p | P | C |
| *Barbastella barbastellus* | p | - | C |
| *Pulsatilla grandis* | p | - | C |
| *Hypodryas maturna* | p | P | D |
| *Cordulegaster heros* | p | R | A |
| *Paeonia officinalis ssp. banatica* | p | - | A |
| *Rosalia alpina* | p | P | C |
| *Pilemia tigrina* | p | P | B |
| *Cerambyx cerdo* | p | P | C |
| *Rosalia alpina* | p | P | C |
| *Myotis blythii* | p | - | C |
| *Bombina variegata* | p | P | C |
| *Paeonia officinalis ssp. banatica* | p | - | A |
| *Eriogaster catax* | p | C | C |
| *Myotis bechsteinii* | p | - | C |
| *Cordulegaster heros* | p | R | A |
| *Hypodryas maturna* | p | P | D |
| *Lucanus cervus* | p | C | C |
| *Isophya costata* | p | - | A |
| *Morimus funereus* | p | P | C |
| *Lycaena dispar* | p | R | D |
| *Miniopterus schreibersii* | p | - | B |
| *Myotis dasycneme* | p | - | C |
| *Himantoglossum caprinum* | p | - | B |
| *Vertigo moulinsiana* | p | P | D |
| *Bombina bombina* | p | P | C |
| *Erannis ankeraria* | p | P | D |
| *Myotis myotis* | p | - | C |
| *Paladilhia hungarica* | p | R | A |
| *Serratula lycopifolia* | p | - | C |
| *Vertigo angustior* | p | P | C |
| *Pulsatilla grandis* | p | - | C |
| *Barbastella barbastellus* | p | - | C |

| | | | |
|---|---|---|---|
| *Myotis emarginatus* | p | P | C |
| *Rhinolophus ferrumequinum* | p | - | C |
| *Rhinolophus hipposideros* | p | P | C |

* The legend of the table is in the Annex 1

Source: Based on TIR Self-edited, 2019

***Conservation priorities***

A priority objective for nature conservations are the following:

- sub-Pannonic steppic grasslands (6240)
- Calcareous rocky slopes with *chasmophytic* vegetation (8210)
- Siliceous rocky slopes with *chasmophytic* vegetation (8220)
- Caves not open to the public (8310)
- Luzulo-Fagetum beech forests (9110)
- Rupicolous calcareous or basophilic grasslands of the *Alysso-Sedion albi* (6110)
- Rupicolous pannonic grasslands (*Stipo-Festucetalia pallentis*) (6190)
- Pannonian woods with *Quercus pubescens* (91H0)
- Illyrian *Fagus sylvatica* forests (*Aremonio-Fagion*) (91K0)
- Illyrian oak-hornbeam forests (*Erythronio-carpinion*) (91L0)

furthermore,

- *Paeonia officinalis ssp. banatica*
- *Pulsatilla grandis*
- *Cordulegaster heros*
- *Isophya costata*
- *Miniopterus schreibersi*
- *Myotis bechsteini*

maintain the favourable conservation status (OKIR, 2019).

Also, a priority objectivities are the following:

- Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*) (6510)
- Petrifying springs with tufa formation (*Cratoneurion*) (7220)
- *Tilio-Acerion* forests of slopes, screes and ravines (9180)

furthermore,

- *Pilemia tigrina*

and their restoration with the favourable conservation status. (OKIR, 2019).

The area is home to vast natural and semi-natural habitats of high biodiversity. The area is home to some of the country's most important remaining Illyrian habitat. One of the main characteristics of the area is the unique population of *Paeonia officinalis* (OKIR, 2019)

***Nature conservation objectivities***

General objectivities:

Conservation, maintenance and restoration of the species and habitat types on which the Natura 2000 designation is based, and the maintenance of the state of conservation and management underpinning the delimitation of Natura 2000 sites (OKIR, 2019).

Main objectivities:

- Conservation of the Mecsek's diverse geological and surface geological values, especially stream valleys, ruined upthrusts, open karst areas and caves.
- Minimize forest interventions in the area of karst forests dominated by *Quercus pubescens* (91H0).
- Preservation of *Alnus spp.* and other softwood communities accompanying watercourses, mitigation of anthropogenic impacts on gallery forests.
- Conservation of multi-species forests with native vegetation in the forest habitats that are natural and close to the natural habitat type, corresponding to the habitats of the native communities, and maintaining continuous management methods for forest cover.
- Providing long-term living conditions for forest communities, especially for dead wood, and ensuring the continued presence of standing or lying dead wood from native tree species.
- Protecting the habitats of bat species, partly by protecting caves and partly by protecting the old, shrubbery woods.
- Preservation, maintenance of grasslands, provision of habitats for protected or rare plant and animal species.
- Preservation and protection of the habitats of *Paeonia officinalis L. subsp. banatica*, with special regard to the preservation of the old opening oak forests.
- Protecting the Pulsatilla grandis habitat by suppressing shrubbery and reducing tread damage.
- Reduce shrub growth on the slope steppes (6240) to protect the population of *Pilemia tigrina* and preserve its nutrient plant (*Anchusa barrelieri*).
- Ensure adequate water supply and flow of natural habitats to aqueous and aquatic habitats (stream associations) and minimize forest interventions in gorges.

(OKIR, 2019)

Additional goals and objectivities:

- Mitigation of anthropogenic impacts on geological and geomorphological natural values.
- Preservation of significant hydrological values (watercourses, springs) of the Mecsek. Preservation of the sensitive aquatic fauna, as well as the geomorphologic values and forms created by the influence of water.
- Avoiding further reservation of springs.
- Mitigation of anthropogenic impacts on the natural status of aqueous and aquatic habitats, in particular the reduction of the adverse impacts of agriculture.
- Maintaining the favourable conservation status of tagging habitat types by protecting the species of Community interest (*Serratula lycopifolia*) and protected plant species (e.g.: *Orchis morio, Doronicum sopianae, Stachys alpina, Hepatica nobilis*).
- Reduction of alien and landscape alien species and staff, restructuring of forest areas.
- Reduction and prevention of unfavourable succession processes endangering the survival of lawns and meadows by cleaning mowing and grazing.
- Support and creation of conditions for grazing livestock as a utilization and management activity.
- Improving the naturalness of hayfields, with particular emphasis on reducing invasive plant species (e.g.: white acacia, tree of heaven, milkweed, goldenrod).

(OKIR, 2019)

***Danger factors in the area***

Major and moderate threats to the site:

- Other anthropogenic intervention
- Forestry and forest management
- Motorized vehicles
- Invasive, non-native species
- Drying
- Paragliding, hot air ballooning
- Non-intensive grazing
- Modification of cultivation practices

(OKIR, 2019)

The site does not have a NATURA 2000 maintenance plan and is neither in the process of being negotiated nor in the process of being approved (DDNPI, 2019).

### 3.1.4 Presentation of the lower course of the river Drava NATURA 2000 site (HR2001308)

***Indicator habitat types of site***

**Table 7.** Habitat types and assessment of habitats in the NATURA 2000 (HR2001308)

| Habitat type code | Habitat type name | Representativity | Conservation |
|---|---|---|---|
| 91E0 | Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*) | A | B |

* The legend of the table is in the Annex 1

Source: Based on Natura 2000 Standard Data Form Self-edited, 2019

***Indicator species of site***

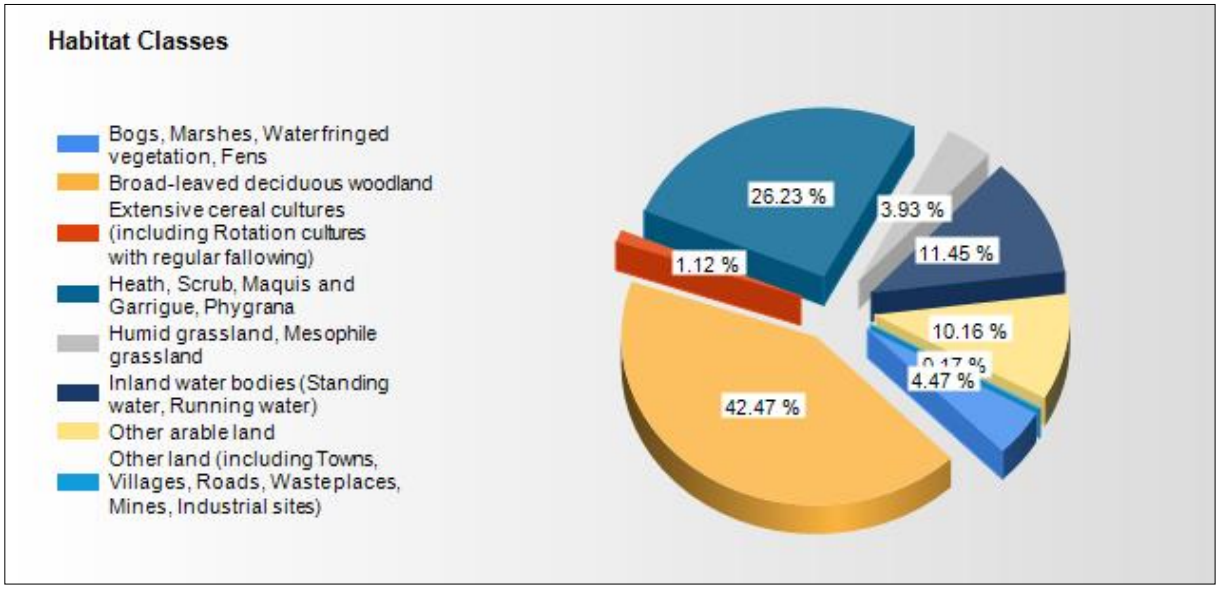
**Table 8.** Indicator species in the NATURA 2000 site (HR2001308) (species as defined in Article 4 of Directive 2009/147 / EC and listed in Annex II to Directive 92/43 / EEC and evaluation of these species)

| Name of species | Type | Abundance category | Conservation |
|---|---|---|---|
| *Bombina bombina* | p | c | B |
| *Triturus dobrogicus* | p | c | B |
| *Aspius aspius* | p | c | A |
| *Cobitis elongatoides* | p | c | A |
| *Eudontomyzon mariae* | p | v | A |
| *Gymnocephalus baloni* | p | c | A |
| *Gymnocephalus schraetzer* | p | r | A |
| *Pelecus cultratus* | p | v | A |
| *Rhodeus amarus* | p | c | A |
| *Romanogobio vladykovi* | p | c | A |
| *Rutilus virgo* | p | c | C |
| *Sabanejewia balcanica* | p | r | A |
| *Zingel streber* | p | r | A |
| *Zingel zingel* | p | v | B |
| *Coenagrion ornatum* | p | r | B |
| *Graphoderus bilineatus* | p | r | B |
| *Leucorrhinia pectoralis* | p | c | A |
| *Lycaena dispar* | p | p | C |
| *Ophiogomphus cecilia* | p | c | A |
| *Lutra lutra* | p | | A |
| *Emys orbicularis* | p | c | A |

* The legend of the table is in the Annex 1

Source: Based on Natura 2000 Standard Data Form Self-edited, 2019

***General site characteristics***




| HABITAT CLASS DESCRIPTION | HABITAT CLASS COVER (%) |
|---|---|
| Inland water bodies (Standing water, Running water) | 11.45 |
| Bogs, Marshes, Water fringed vegetation, Fens | 4.47 |
| Heath, Scrub, Maquis and Garrigue, Phygrana | 26.23 |
| Humid grassland, Mesophile grassland | 3.93 |
| Extensive cereal cultures (including Rotation cultures with regular fallowing) | 1.12 |
| Other arable land | 10.16 |
| Broad-leaved deciduous woodland | 42.47 |
| Other land (including Towns, Villages, Roads, Waste places, Mines, Industrial sites) | 0.17 |
| Total Habitat Cover | 100 |

***Other Site Characteristics***

Part of Regional park Mura - Drava. Lower flow of Drava river (to the estuary). Important river habitats include sandbanks, sand-bars and islands and vertical, eroded, bare riverbanks.

Lithostratigraphic units represented in this area are holocene alluvial deposits (gravels, sands, silts and clays). Drava river is typical lowland meandering river with large floodplains. Wetland area of the river with the old meanders, sandy sandbanks, oxbow lakes and steep banks. Presence of erosion and accumulation processes. Dominated soils are fluvisol and partially hidromeliorated marsh-grey.

***Site quality and importance***

- important site for amphibian species Triturus dobrogicus and Bombina bombina
- important site for Emys orbicularis
- the area is considered to support a significant presence of Lutra lutra
- important site for butterfly species Lycaena dispar
- the site is of importance for the conservation of Coenagrion ornatum in the Continental

Biogeographical Region

- the site is important for the conservation of Graphoderus bilineatus in Croatia.
- because of the large population, the site is of great importance for the conservation of Leucorrhinia pectoralis in the Continental Biogeographical Region
- the site has very large population of Ophiogomphus cecilia, thus being of great importance for the conservation of this species in Croatia
- important site for 91E0, As Salici-Populetum nigrae
- important site for fish species Aspius aspius, Cobitis elongatoides, Eudontomyzon mariae, Gymnocephalus baloni, Gymnocephalus schraetser, Pelecus cultratus, Rhodeus amarus, Romanogobio vladykovi, Rutilus virgo, Sabanejewia balcanica, Zingel streber and Zingel zingel

***Threates, pressures and activities with impact on the site***

| DESCRIPTION | TYPE | RANK |
|---|---|---|
| use of biocides, hormones and chemicals | N | M |
| Fertilisation | N | M |
| Forest and Plantation management & use | N | M |
| missing or wrongly directed conservation measures | N | M |
| Pollution to surface waters (limnic & terrestrial) | N | H |
| dredging/ removal of limnic sediments | N | M |
| Canalisation & water deviation | N | H |
| Modification of hydrographic functioning, general | N | H |

**Type:** N = Negative, P = Positive
**Rank:** H = high, M = medium, L = low
Source: http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=HR2001308

### 3.1.5 Presentation of Kopački rit NATURA 2000 site (HR2000394)

***Indicator habitat types of site***

**Table 9.** Habitat types and assessment of habitats in the NATURA 2000 (HR2001308)

| Habitat type code | Habitat type name | Representativity | Conservation |
|---|---|---|---|
| 3130 | Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea | A | A |
| 3150 | Natural eutrophic lakes with Magnopotamion or Hydrocharition - type vegetation | A | A |
| 6440 | Alluvial meadows of river valleys of the Cnidion dubii | B | C |
| 91E0 | Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*) | A | A |
| 91F0 | Riparian mixed forests of Quercus robur, Ulmus laevis and Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia, along the great rivers (Ulmenion minoris) | A | B |

* The legend of the table is in the Annex 1

Source: Based on Natura 2000 Standard Data Form Self-edited, 2019

***Indicator species of site***

**Table 10.** Indicator species in the NATURA 2000 site (HR2001308) (species as defined in Article 4 of Directive 2009/147 / EC and listed in Annex II to Directive 92/43 / EEC and evaluation of these species)

| Name of species | Type | Abundance category | Conservation |
|---|---|---|---|
| *Bombina bombina* | p | c | A |
| *Triturus dobrogicus* | p | c | A |
| *Aspius aspius* | p | c | A |
| *Eudontomyzon mariae* | p | r | A |
| *Gymnocephalus baloni* | p | r | B |
| *Gymnocephalus schraetzer* | p | r | A |
| *Misgurnus fossilis* | p | v | A |
| *Pelecus cultratus* | p | v | A |
| *Rhodeus amarus* | p | c | A |
| *Romanogobio vladykovi* | p | r | B |
| *Rutilus virgo* | | | |
| *Zingel zingel* | p | r | A |
| *Cerambyx cerdo* | p | c | B |
| *Coenagrion ornatum* | p | p | B |
| *Cucujus cinnaberinus* | p | p | A |
| *Euplagia quadripunctaria* | p | c | B |
| *Graphoderus bilineatus* | p | r | A |
| *Leucorrhinia pectoralis* | p | p | B |
| *Lucanus cervus* | p | c | B |
| *Lycaena dispar* | p | v | C |
| *Ophiogomphus cecilia* | p | r | B |

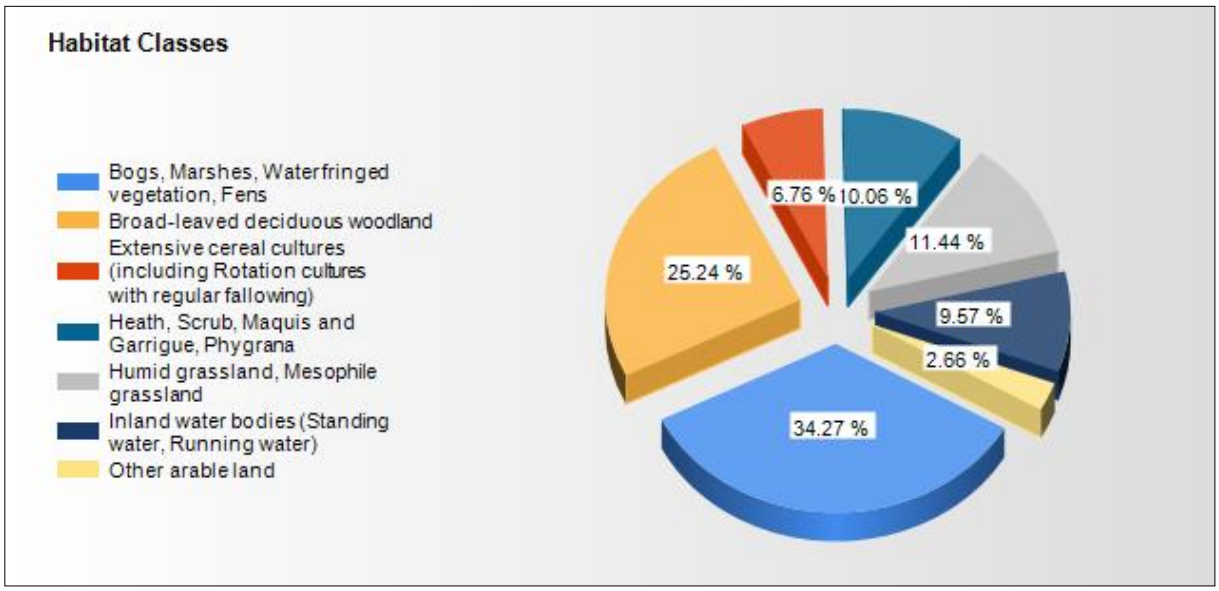
| | | | |
|---|---|---|---|
| *Rhysodes sulcatus* | p | p | A |
| *Lutra lutra* | p | | A |
| *Marsilea quadrifolia* | p | p | C |
| *Emys orbicularis* | p | c | A |

* The legend of the table is in the Annex 1

Source: Based on Natura 2000 Standard Data Form Self-edited, 2019

Other important species of flora and fauna are: Acipenser ruthenus, Alopecurus aequalis, Apatura metis, Carassius carassius, Carex nigra, Carex vesicaria, Cyperus fuscus, Epitheca bimaculata, Hemianax ephippiger, Hippuris vulgaris, Lestes virens, Orchis purpurea, Pseudolysimachion longifolium, Stratiotes aloides, Sympetrum flaveolum, Typha laxmannii

***General site characteristics***




| HABITAT CLASS DESCRIPTION | HABITAT CLASS COVER (%) |
|---|---|
| Inland water bodies (Standing water, Running water) | 9.57 |
| Bogs, Marshes, Water fringed vegetation, Fens | 34.27 |
| Heath, Scrub, Maquis and Garrigue, Phygrana | 10.06 |
| Humid grassland, Mesophile grassland | 11.44 |
| Extensive cereal cultures (including Rotation cultures with regular fallowing) | 6.76 |
| Other arable land | 2.66 |
| Broad-leaved deciduous woodland | 25.24 |
| Total Habitat Cover | 100 |

***Other Site Characteristics***

Kopački rit is situated in the northeastern part of the Republic of Croatia. Geographically speaking, Kopački rit is the flat part of Baranja, belonging to Osječko-baranja County, mainly lowland situated between the Drava and Danube rivers and the state border with the Republic of Hungary. It stretches from the northern part of the Drava where the mouth of the Drava flows into the Danube and upstream on the left and right banks of the Danube towards the former Kazuk port. The state border towards the Republic of Serbia designated the Nature Park's eastern border.

Kopački rit is a floodplain that developed due to the activities of two large rivers, the Danube and the Drava. Significant flood areas exist in the northern, southern and western surrounding parts of the Nature park that stretch from Batina up north, to Bijelo Brdo down south and Donji Miholjac towards west. The altitudes of Baranja do not exceed 250 m, and the Nature Park is at the lowest altitude starting from only 78 m above sea level (the bottom of Kopačko Lake) to 86 m above sea level.

Kopački rit has a typical relief structure because of the river's water activity and the floodwaters that flood the area. Rivers create banks and islands called "ade" and armbands called Dunavoc or Stara Drava in their live streams. On the other hand, the water in the floodplain deposits sediments in one place but deepens the ground in another, so the whole area obtains a specific undulate appearance. That is how ponds (depressions) and beams (higher grounds) were created and stretch hundreds of meters next to one another. Ponds and beams are narrow and long and have a specific curved appearance from the sky. The altitude difference between ponds and beams is 8 m. max. The ponds meet by the ends through a natural channel or so-called "fok" and enter Dunavac or the Danube. The beams fill and empty the ponds. Foks were artificially deepened and the trenched canals took over the foks function.

Nature Park belongs to the lowland area which is built of quaternary sediments that are classified as the most important hydro-geological unit formed during the pleistocene and holocene. Holocene sediments are fluvial sands and sandy loams and fluvial-marsh clay, loam and clay that are prevalent in the floodplain, and alluvial sandy loams and sands that are prevalent in the area outside the inundation. It is developed floodplains which is characterized with meanders. Dominant soils are eugley and fluvisol.

***Site quality and importance***

- the area is considered to support a significant presence of Triturus dobrogicus
- the area is considered to support a significant presence of Bombina bombina and is one of the most important area for conservation of this species in Croatia

- important site for Emys orbicularis
- the area is considered to support a significant presence of Lutra lutra
- important site for Euplagia quadripunctaria
- important site for Lucanus cervus and Cerambyx cerdo
- one of two sites in Croatia for Rhysodes sulcatus
- the site is of importance for the conservation of Coenagrion ornatum in the Continental

Biogeographical Region

- with eight known occurence localities, the site is of great importance for conservation of species

Graphoderus bilineatus in Croatia

- the site is of importance for the conservation of Leucorrhinia pectoralis in the Continental

Biogeographical Region

- the site is important for the conservation of Ophiogomphus cecilia in the Continental

Biogeographical Region

- important site for fish species Aspius aspius, Romanogobio vladykovi, Gymnocephalus baloni, Gymnocephalus schraetser, Misgurnus fossilis, Pelecus cultratus, Rhodeus amarus, Eudontomyzon mariae, Zingel zingel; also this area represents the biggest spawning area of freshwater fishes in general of Danube and Drava watershed in this part of Europe
- important site for habitat type 3130 with Marsilea quadrifolia; estimated area of this HT includes water bodies where it occures along the water edges and over the lake bottom when water withdrows.
- important site for 91E0, for many associassions, one of the most important site for conservation of this habitat in Croatia
- important site for 91F0, As Fraxino angustifoliae-Ulmetum laevis

***Threates, pressures and activities with impact on the site***

| DESCRIPTION | TYPE | RANK |
|---|---|---|
| Fertilisation | N | M |
| removal of dead and dying trees | N | L |
| Hunting | N | L |
| Pollution to surface waters (limnic & terrestrial) | N | L |
| invasive non-native species | N | M |
| human induced changes in hydraulic conditions | N | M |

**Type:** N = Negative, P = Positive
**Rank:** H = high, M = medium, L = low
Source: http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=HR2000394

## 3.2 Positive effects of detection of invasive species on protected species

The spread of invasive plant species and their habitat conversion effects are a major environmental problem worldwide. A significant proportion of these species are woody. During their lifetime, they are able to significantly transform the habitats they inhabit. In many cases, they are shade tolerant to native species, grow faster, require less water, alter the chemical characteristics of soil with their undergrowth, inhibit the development of other plants with their allelopathics, and overshadow native species regeneration (Mack et al., 2000; Botta-Dukát et al., 2004).

If invasive tree species are detected in time, they will be treated more effectively and will therefore not, or to a much lesser extent, suppress the effects of invasive species in the area. Ecological living conditions can be improved by eliminating disturbing effects. These in themselves appear to be positive for protected species.

# 4 Assessment of the situation

## 4.1 Presentation of natural values in the project area

### *4.1.1 Main natural features of the Northern Zselic region*

Dövényi Z. (ed.) (2010): Based on the cadastre of the micro-regions of Hungary:

The microregion is located in Baranya and Somogy counties. It covers an area of 679 km$^2$ (15.3% of the mesoregion and 5.8% of the large macroregion).

***Relief***

Starting from Kapos Valley with steep slopes rising to 250-300 elevation, the hills are adjacent to Inner-Somogy on the west, and to Baranya-Hegyhát and valleys on the east. Its southern zigzag boundary is

the watershed between Kapos and Drava (Black Water, Pécs Water), which separates it from South Zselic. It also has its highest point (Hollófészek: 358 m above sea level). Apart from the latter, it is framed by structural boundaries. It is divided into valleys and intermediate backs aligned with north-south break lines. Most of the heavily and moderately divided hills have a relative relief of 50-100 and 100-150 meters/km$^2$, with the valley margins exceeding this (average relative relief 84m/km$^2$).

***Climate***

Moderately warm - Moderately humid climate. The number of hours of sunshine per year is between 2000 and 2020. During the summer, approx. 810, during the winter it will be 200 hours of sunshine. The annual average temperature is around 10.0 °C, with it slightly above it in the northwest and slightly below it in the south and east. The average temperature during the growing season is around 16.5 °C, 16.3 °C in the south and 16.7 °C in the north. Medium temperatures above 10 °C are expected for 190-195 days between April 5-10. and October 17-20. Frost-free period starts around April 13 (eastern parts) and April 15-18. It runs till October 22- 24 (western parts), so the frost-free period in the east is approx. 195, in the west approx. 190 days. The highest annual maximum summer temperatures are around 33.5 °C and slightly below 33.0 °C in the southeast. The average of the annual minimum temperature varies between -14.0 °C and -15.0 °C in the southeast, and -15.5 °C and -16.5 °C elsewhere. The annual precipitation is 680-730mm (less in the middle landscapes), of which 390-420mm comes during the vegetation period. The maximum 24-hour rainfall is 160mm (Sásd). The average number of snow-covered days is 35-38 and the average maximum snow thickness is 25-28cm. The aridity index in the area is between 0.96 and 1.00. The most common wind direction is north and south with average wind speeds of 2.5-3m/s, but above the Korpádi ridge breeze is 3m/s. The climate is suitable for arable and less heat demanding horticultural crops.

***Vegetation***

This is the most montane type of hilly region of South-Transdanubia, a large part of which is covered by native forests. Its dominant climatic zonal vegetation is the beech, less rainy parts and in frosty valleys the silver thorns and hornbeam-sessile oaks are dominant. In the periphery of the hills there were once turkey-oak-woods, and even downy oaks, but with the expanse of settlements and enclosed gardens, they have largely disappeared, only to the northeast alder groves, alder swamp forests and oak-ash groves along streams of constant water from the hills have been highly fragmented, and most of the swamps and marshes formed in their place have been destroyed, replaced by arable, wild, artificial pond systems or canals, surrounding with featureless vegetation. The meadows of the Kapos Valley are largely degraded, but there are spots of moderate nature (*Orchis palustris, Dactylorhiza incarnata*). The meadows of the hills are mostly forested after the end of grazing and mowing, but their rare patches contain some rare plant species (*Ophrys sphegodes, Orchis tridentata, Orchis morio,*

*Gentiana cruciata*). The regeneration potential of the landscape is strong, and spontaneous shrub-forestation is rapid. The characteristics of the forest flora are mainly attributable to sub-Mediterranean plant species. Western Balkan and Eastern Alpine species include the *Vicia oroboides, Erythronium dens-canis, Scilla drunensis, Cyclamen purpurascens.* Balkan species are the R*uscus aculeatus, R. hypoglossum, Tamus communis, Aremonia agrimonoides*. Common habitats: K2, K5, OC, RC, P2b, L2a; moderately frequent habitats: P7, E2, RB, J5, K1a, OB, H5a, A1, H4, B1a; Rare habitats: OA, RA, B5, E1, P2a, BA, D34, M8, D5, A23, B2, J2, B3, P45, K7a, LY1, C1, B4, D5, E2.

Number of species: 1000-1100; protected species: 80-100; invasive species: *Acer negundo*, *Ailanthus altissima*, *Amorpha fruticose*, *Asclepias syriaca*; alien *Aster* spp.: *Phytolacca Americana*, *Reynoutria* spp., *Robinia pseudoacacia*, *Solidago* spp.

### *4.1.2 The main natural features of the Southern Zselic region*

Dövényi Z. (ed.) (2010): Based on the cadastre of the micro-regions of Hungary:

The micro-region is located in Baranya and Somogy counties. Its area is 495km2 (11.1% mesoregion and 4.2% of the large landscape).

***Relief***

The average elevation of the area is 200-250m. There are valleys deepen to 10-50m and ridges 50-100 that provides a relative relief of 100-150m/km$^2$, but especially in the western part of the area 10-25m/km2 relative relief occurs in large areas.

***Climate***

The climate is moderately warm to moderately humid. A The number of hours of sunshine is between 2000 and 2020, 810 in summer and in the winter will be 200 hours of sunshine. The annual average temperature is 10.0 °C, just above it in the south and west, and one to two tenths below in the north. The average temperature during the growing season is around 16.5 °C, but it reaches 17.0 °C in the southeast. Daily average temperatures are expected April 3 to 8 to rise above 10.0 °C and it runs to October 17-20, approx. 195-198 days. The frost-free period is 190-195 days, the spring deadline is April 13-15, and the autumn is October 22-25. The highs of the hottest summer days have many years' average of 33.5 ° C, but just below 33.0 ° C in the east. The absolute annual minimum temperatures are around -14.0 ° C in the east, -15.0 ° C in the centre and -16.0 ° C in the west. The annual precipitation is 680-720mm, of which 390-410mm in the east, 410-430mm in the west. During 24 hours, 105 mm was the highest precipitation (Hetvehely). In the winter, an average of 35-38 snow covered days are expected with an average maximum snow thickness of 23-26cm. The aridity index is between 0.98 and 1.00. North and south winds blow the most; average wind speed 2.5-3m/s. The climate of the area is favourable for more heat-intensive plants in the south-east and for water-intensive plants in the west.

***Vegetation***

Down to the south, much of the hillsides are farmland, with remnants of natural vegetation mainly in valleys and steep sides. Its climatic zone is hornbeam-sessile oak, with silver-beech beech forests in the north, and gallery forests (alder grove, alder swamp forest, hardwood). Cherry-oak forests were in the south-east and exposed in the south, mainly occupied by vines and enclosed gardens, and the remaining populations include *Carex michelii* and *Orchis purpurea*. Around the villages in the valleys there used to be flourishing extensive farming; the vast expanses of abandoned pastures and meadows (*Trisetum flavescens, Ornithogalum pyramidale*) are the dominant elements of today's landscape. In run-off valleys, *Petasites hybridus* and *Caltha palustris, Inula helenium*, *Carex paniculata*, *Carex elata* can be found. In the southern part of the microregion, meadows of gentle wavy surface formed by flat hills and wide valleys running in the plain *Orchis elegans, Dactylorhiza incarnata* form the vegetation of what used to be a forest. Typical species of forest flora are of sub-Mediterranean and Illyrian elements. Characteristic plants of fresh forests are *Helleborus dumetorum, Erythronium dens-canis, Lathyrus venetus*, south-western meadow (*Luzula forsteri*), small-flowered cinquefoil, *Scrophularia scopolii*, *Aremonia agrimonoides*.

Common habitats: K2, K5, OC, E1, RC; Moderately-common habitats: P2b, K1a, RB, P2a, OB, RA, L2a, J5, B1a, B5; Rare habitats: E2, P7, P45, H5a, BA, LY2, D34, A1, L2b, L2x, M8, J1a, D5, H4, I2, B4.
Number of species: 1000-1100; Number of protected species: 60-80; Invasive species: *Acer negundo*, *Ailanthus altissima*, *Asclepias syriaca*, *Phytolacca americana*, *Reynoutria spp.*, *Robinia pseudoacacia*, *Solidago spp.*

### *4.1.3 Main natural features of the Mecsek Mountains micro-region*

Dövényi Z. (ed.) (2010): Based on the cadastre of the microregions of Hungary:
The micro-region is located in Baranya and Tolna counties. Its area is 335km$^2$ (7.5% mesoregion and 2.8% of the large landscape).

***Relief***

The average relative relief of the mountains is 110m/km$^2$. It reaches 250-300m/km$^2$ in peripheral areas and along some valley sections but has extensive plateaux and geomorphological levels where relative relief is just over 50m/km$^2$.

***Climate***

Moderately warm to moderately moist, moderately cool at the peaks with a humid climate. Yearly sunshine is between 2040 and 2060 hours, 810-820 in the summer and 210-230 in the winter. Winter sunshine hours are about 10% higher than in the surrounding plains and hills. However, the sunshine

of the summer months is 2-3% less than in the surrounding areas. Annual average temperatures are around 10.0 ° C in the northeast and southwest, around 9.5 °C in the middle, high altitude areas, and below 9.0 ° C at the peaks. The average temperature during the summer semester is 16.5-16.8 °C at the hills, but below 15.5 ° C at the peaks. The period above the average temperature of 10 °C starts in the southern foreground of the Mecsek and at the bottom of the southern slopes on March 28-30, at the peaks after April 15, elsewhere between April 5-10.. The end of the period in the same distribution is October 20-22, October 14-16, and October 17-20. Durations are 200-205, 180 and 190-195 days, respectively. The frost-free period is 200-205 days in the south and south slopes (5-10 April, 30 October); at the peaks at around 185-190 days (April 15-20, October 23-25), and around 195 days elsewhere (April 10-15, October 23-25). The average summertime temperatures are below 31.0 °C on the peaks and around 33.0 °C elsewhere. The average winter minimum is between -14.0 and -15.0 °C. In the south the annual rainfall is 650-700mm, in the north 720-760mm, at the peaks slightly above 780mm. During the growing season, the northern regions are expected to be around 400mm, elsewhere between 410 and 440mm, with peaks over 450mm. Most of the overnight rain, 124mm, was observed at Pécs-Árpádtető. The average annual number of snow-covered days are 35-40 in the mountains and the southern slopes and more than 50 on the peaks. The average maximum snow thickness in the west increases from 20 to 25 cm to 40 cm at the peaks. The arithmetic index is 1.00 to 1.06 in the south, 0.92 to 0.98 in the north, and less than 0.90 on the peaks. The most common wind direction is northwest, though not particularly frequent. The average wind speed at the peaks is close to 5m/s and in valleys 3-3.5m/s. Territoriality and climate favour the management of forests and certain arable and horticultural crops.

***Vegetation***

Almost 70% of the area is covered by forests, most of which are native species of wood. Many associations occur only here and in the nearby Villány Mountains (e.g.: silver linden debris forests and gorges). The valleys, rich in streams, contain alder groves and small patches of spring lawns. Characteristics of the sub-Mediterranean and Balkan species are: *Helleborus odorus*, *Medicago rigidula*, *Chaerophyllum aureum*, *Asperula taurina*, *Plantago argentea*, *Aremonia agrimonoides*, *Doronicum orientale*, *Festuca dalmatica*, *Inula spiraeifolia*, *Ruscus hypoglossum*, *R. aculeatus*, *Orchis simia*, *Ophrys oestrifera*. *Aconitum anthora*, *Waldsteinia geoides* and *Spiraea media* occuring together above Pécs's areas is similar to the Északi-középhegység. In the western part of the mountains, on the Permian and Triassic sandstones the calciferous and sub-Atlantic attributions appears mostly (*Dryopteris affinis*, *Vaccinium vitis-idaea*, *Calluna vulgaris*, *Spergula pentandra*), in the eastern half sub-continental attributes are *Linum flavum, Ajuga laxmannii, Anchusa barrelieri*. It is poor in rocky grasslands and rock cover associations. The sub-Mediterranean loess grasslands (*Avenula adsurgens*,

*Cirsium boujartii*, *Orchis tridentata*) are still found in the patches on the edge of the Eastern Mecsek. Pastures, marshes and meadows in the area are sporadic (*Trisetum flavescens, Moenchia mantica, Orchis morio, Spiranthes spiralis*), slowly diminishing with traditional cultivation. Several species only occur here in Hungary (*Cuscuta approximata, Stachys alpina, Chamaecytisus heuffelii, Paeonia banatica*). Its weed flora is very rich.

Common habitats: K2, K5, L2a, OC, P2b, L1, RC, E1; Moderately-common habitats: L4a, LY2, K7b, OB, P2a, J5, P45, K7a, LY1, LY4, M1, H4, H5a, D5, L4b; Rare habitats: RB, P7, E2, H3a, RA, L2x, M8, E34, E5, B5, BA, B1a, D34, A1, A3a, A5, G2, H1, H2, I4, I1, I2, J2, M6, M7, B3, B4, C1, G3.

Number of species: more than 1200; Number of protected species: more than 120; Invasive species: *Acer negundo, Amorpha fruticose, Ailanthus altissima, Asclepias syriaca, Aster spp., Phytolacca americana, Reynoutria spp., Robinia pseudoacacia, Solidago spp.*

### *4.1.4 Main natural features of the Haljevo – Kozaračke forests management unit*

The management unit is located in the central part of Baranja, south of Banovo Hill on the Danube loess plateau at the altitude of 88-100 m. The highest parts of the management unit are located in the northern belt of Haljevo forest, with the highest point of 100 m (16 a), and then the land descends gradualy with the exchange of microdepressions (0.5-1 m) towards the highest parts in Kozarac-Koha forest, where altitudes vary between 88-91 m, with the highest point of 91.2 m (between 90 asl and 95 asl). In hydrographic sense, this forest area belongs to the river Danube basin. Total area of the Haljevo-Kozaračka forest management unit is 2914.13 ha.

***Relief, geological background and soil***

Today the Baranja region belongs to the vast Panonian lowlands. After the water runoff from the Panonian Sea (Paratetis) big sea and lake sediments remained, which were covered by thick loess layers at the end of Diluvial. Today these sea sediments can be found at the depth of 6-12 and more metres, while loess sediments can be found throughout Baranja, especially in central area, where they were not strechted by river flows. Relief characteristics and partucular water conditions are determinant factors for creating, development and spreading of specific soil types at Baranja region. It goes especially for vast flood areas where subaqual and hydromorphic soils had developed. In the process of their pedogenesis the major factors were underground and surface waters. Automorphic (climazonal) soil is characteristic for decanting areas of river terraces, loess plains in Bansko Hill, where major pedogenetic factors are relief, climate and lithological composition. These soils cover the whole management unit. The Baranja region is characterized by distinct pedogenetic duality. Human activity is an important factor too, which influence the pedogenesis and determines the optimal chategorization of the area.

***Climate***

Geographically Baranja is located in the moderate belt which is characterized by distinct climate differenciations over the year. On Köppen climate classification the Baranja reagion is located in the moderate warm rains continental climate zone (Cfwb"x"). It is a moderate warm rain climate, without distinct drought periods. Precipitation is evenly distrubuted throughout the year, and winter is the driest period. summers are warm and winters are moderately cold with a sudden temperature raise at the first period of the year. Average monthly temperature in January, the coldest month, is -0,4$^{o}$C, and in July, the warmest month, it is under 20,7$^{o}$C. The region of this management unit has relatively high humidity over the year with annual average of 78,2% which affects favourably the water balance changes in plant tissue cells and the vaporisation process forms soil and plants. Highest average evapotranspiration has been recorded in July and August. Average annual precipitation is 592 mm/m2. Precipitation is relatively equally distributed over the year. The highest precipitation occurs in June, and the second highest in November. The lowest precipitation occurs in February and September. During vegetation period 59% of precipitation occurs, or in average 350 mm/m2. There is a possibility of late spring frosts till the end of April, and exceptionally in May. Early autumn frosts begin in October, exceptionally in the end of September (data measured from 1951. to 1960.) In this area western-nothwestern winds are prevailing, and much less eastern-northeastern, while other directions are rare. Average wind speed is 0.8-1.2 m/s and maximum is 1.6-2.8 m/s.

***Vegetation***

Forests of Baranja, including this management unit phytogeographiclly belong to euorosibirian-northamerican forest region (european subregion) in the plains (planar) vegetation belt, or pannonian vegetation zone. Orographically the area of this vegetation forest zone consists mainly of midriver plains with beams, depressions and swamps with developed hydromorphic soils on alluvial sediments which differenciated according to the level of moistening of underground and flood waters. As a result of pedogenetic processes various forest vegetation and specific meadow plant communities have developed. In the area of this management unit which is not under influence of floodwaters and underground waters, on loess sediments as a main base and influenced by certain climate factors, automorphic (terestric) loess soils can be found among which pedologic researches determined three special soil types. Characteristic forest community is pedunculate oak forest and European hornbeam forest (Carpino betuli-Quercetum roboris, Rauš 1969.) Especially in younger forests a dominant spieces of pedunculate oak is abundantly mixed with hornbeam and some maple. Most common shrubs are pedwood, elder, hazel, pear, European cranberrybush, hawthorn. Regarding terrestrial plants, species of dry and humid soils can be found such as Hedera helix, Fragaria vesca, Vinca minor, Carex silvatica, Cardamine bulbifera, Anemone nemorosa and others. Smaller part of forest area in this

management unit in Širine has pedologic and phytosociological characteristics of swamp forests which can be found on alluvial soils near Drava and Dunav. Those areas near Karašica channel with soils under constant or temporary influence of underground waters, according to pedologic characteristics, belong to habitat of black and white poplar plant community. This plant community develops on much more stable and developed soil than willow communities, and it allows introduction of elm, ash and even pedunculate oak.

### *4.1.5 Main natural features of the Forests of Darda management unit*

Geographicaly the management unit „Darđanske šume" is located in southeastern Baranja in the flooded area of the river Drava. Mostly there are young river terraces and alluvial and recent river sediments. This area is frequently flooded which influenced the development of these forests. The menagement unit spreads from 19 km upstream of the left bank of Drava (from 23. to 31.5 km) with the forest belt 800-3200 m wide. Peripheral enclaves in the northeastern part of the menagement unit are over 6 km away from the bank. Total area of the management unit is 2992.55 ha.

***Relief, geological background and soil***

The relief is lowland with fluvial and fluvial-wetland morphographic relief type. The area is intersected with numerous depressions, swamps and channels with beams owergrown with forests between them. Some depressions are under water throughout the year or one part of the year. Slopes are small, rarely over 2$^{o}$, and altitudes range from 82 to 87 m. In average the lowest areas are eastern parts of the menagement unit and separated enclaves with altitudes of 83 to 84 m. The terraine gradually raises towards the west. Geological background of the management unit was mostly formed in Quaternary, and geomorphologically it was formed in the younger peroid of Quaternary, Holocene. It is mostly alluvial sediments which were formed by sedimentation of materials of different granulatios with recent and former riverbeds. Geomorphologically these are fluvial (alluvial) sandy loams, with additive of sand and clay. The basic characteristic of all alluvial sediments is wide layer heterogenity, vertically and horizontally. Alluvial sediments basicaly always have relatively high underground water which, through capilary action towards surface, affects greatly the vegetation development, and considering the level and the length of the soil content, it greatly affects the pedogenesis process.

***Climate***

Moderate warm rain climate, without extreme droughts, precipitation evenly distrbuted over the year, and the driest period of year is winter. Summers are warm, winters moderately cold with sudden raise of teperature at the beginning of the year. Average monthly temeperature fot he coldest month, January, is -1.2$^{o}$C, and in the warmest month of July it is uder 21.1$^{o}$C. The area of tho management unit ha relativly high humidity throughout the year with annual average of 79% (station Osijek), which

affects favourably the water balance in plant tissue cells and vaporisation process form soils and plants. Annual average precipitation is 651 mm/m2, measured at the station Osijek. Maximum precipitation occurs in June, and the second one occurs in November. Minimum precipitation comes in February and December. During vegetation period falls 57% of precipitation, 369 mm/m2, according to the Osijek station data. In this area prevailing winds are west-nothwestern, and considerably less east-northeastern, while other directions are rare. Average wind speed is 0.8-1.2 m/s, with maximum of 1.6-2.8 m/s, exceptionally even more.

***Vegetation***

Forests of Baranja, including this management unit phytogeographiclly belong to euorosibirian-northamerican forest region (european subregion) in the plains (planar) vegetation belt, or pannonian vegetation zone. Orographically the area of this vegetation forest zone consists mainly of midriver lowlands with beams, depressions and swamps with developed hydromorphic soils on alluvial sediments which differenciated according to the level of moistening of underground and flood waters**.** The management unit Darđanske šume spreads in the Drava left bank belt, whose area is considerably smaller under influence of floodwaters, than it is the case with Danube swamp forests. Somewhat the exception is the northeastern part of Biljski rit where the forest development has been affected by mostly underground waters which through Barbara channel, and then through spilling into old Drava inlets, keep underground water levels high and form forest communities characteristic for swamp forests of neighbouring Kopački rit.

In the whole area of the management unit in former inlets of the Drava riverbed remains of swamps, depresions and reeds can be found, in which following plant communities of swamp vegetation have developed:

- Water lilly communities in the wettest swamp habitats
- Rush communities at the edges with swamp vegetation
- Cane communities on swamp gley soil
- Sedge communities on β gley bordering forest vegetation

These plant communities of swamp vegetation are replaced by forest vegetation in higher and drier habitats. In this area, from the wettest to drier habitats, there are three main forest communities:

- White willow forests in the wettest forest habitats
- Elm and plain ash forests in the most developed soils of the Drava alluvial plateau
- Black and white poplar forests in the driest and the least developed variants of alluvial soils in the flooding ponds of the river Drava

Partly forests of this management unit are artificial plantations of allochtonous tree species, mostly Euroamerican poplar, so phytosociologically these forests were determined by the soil type, much less by autochtotonous forest and plant vegetation.

In this area are also pretty common allochtonous invasive species which spread naturalla and now are domesticated. The most common are American ash and boxelder, also there is acacia and others. American ash and boxelder were mostly spread through underground waters.

### *4.1.6 Main natural features of the Dvorac - Siget management unit*

Forests of this management unit are located in Osječko-Baranjska county in the eastern part of Baranja in the wider zone of Danube swamp forests, from which they are separated by the main defence embankment Zmajevac-Kopačevo. The entire area of the management unit is located in the flood protected zone, western from the forementioned embankment. Goegraphically the area of this management unit is located between 45$^{o}$38’ and 45$^{o}$ 44’ north geographic latitude, and 16$^{o}$25’ and 16$^{o}$33’ east from Greenwich. The total area of the management unit „Dvorac-Siget” is 3917.96 ha.

***Relef, geological background and soil***

The management unit is located in the lowland at the altitude of 80-85 m, as a part of the Danube basin. In more strict sense this area is a part of the former mouth of the river Drava into Danube, which is now intersected by numerous ponds and river sleeve remains, partly connected to the channel grid which collects water from neighbouring agricultural areas and distributes the water surplus using pump stations, to the neighbouring flooded forests east from the main defence embarkment. Based on the geological and geomorphological excavation profiles it has been determined that the prevailing geological background here are alluvial sediments formed by sedimentation of different granulation materials by the recent riverbeds. Geomorphologically these are fluvial (alluvial) sandy loams, with additives of sand and clay. The main characteristic of all alluvial sediments is vast layer heterogeneity, both horizontally and vertically. In principal, alluvial sediments always have relatively high underground water which, by capillary action towards the surface, significantly affects the vegetation development. The exception is forest area Siget where loess sediments can be found as the matric potential, partly covered by shallow sand layers. Pedogenetic factors on this gelogical background of the management unit initiated the development of the automorphic and hydromorphous soils, where surface soil belongs as well.

***Climate***

Moderate warm rain climate, without extreme droughts, precipitation evenly distributed throughout the year, with the driest period in winter. Summers are warm, and winters moderately cold with sudden raise of temperature in the first part of the year. According to the measurement data (from

1984. to 2013. in Osijek), annual precipitation for this area is 677.6 mm, and average annual temperature is 11.4°C. The warmest month is July with average temperature of 22.1°C, and the coldest is January wit average temperature of 0.1°C. Average relative humidity goes from 68% in July to 88% in December. Average annual humidity is 76%. Winter months are about 15% more humid than summer months. Average relative humidity in the vegetation period is 71%. It is important to mention the frost, a meteorological phenomenon which can cause a lot of demage, especially in the nursery production. In this area late frosts can occur up to the end of April, and exceptionally during May. Early frosts come in the beginning of October, sometimes even in September. Prevailing winds in this area are northern, northwestern and western, the rest are quite seldom. Average wind speed is 0.8-1.2 m/s, and maximum speed is 1.6-2.8 m/s.

***Vegetation***

After the embankment construction at the end of XIX century, forests of this management unit ended up in the flood protected area. The embankment affected the change of the hydrographic conditions in the development of the pedogenetic processes, hence the phytosociological situation in the area also changed. Instead of characteristic natural swamp forests, of which only small fregments remained near Čarna, the soil humidity has changed and the level of the underground water declined, so drier variants of hydromorfic soils than in the flood zone of subdanube forests, have developed.

A part of the management unit's forests are plantations of autochtonous tree species, so they were phytosociologically determined by the soil type, and much less by the present forest and plant vegetation.

Various allochtonous invasive species can be found in this area too, which spread naturally and have been domesticated. The most common are American ash and boxelder, also American maple, acaccia and others. These species are mostly spread through flood waters.

Six forest plant communities have been determined in the management unit.

- White willow forest
- Black and white poplar forest
- Elm and plain ash forest
- Pedunculate oak forest with gorse and sedge
- Meadow plant communities
- Land reed beds

## 4.2 Danger factors

The following invasive tree species are most at risk from the NATURA 2000 site described in Chapter 3.1.:

- Tree of heaven (*Ailanthus altissima [Mill.] Swingle*)
- White acacia (*Robinia pseudoacacia L.*)
- False indigo bush (*Amorpha fruticosa L.*)

The following chapter is a brief description of these species.

### 4.2.1 Tree of heaven (Ailanthus altissima [Mill.] Swingle)

***Characteristics***

The original range of the Tree of heaven extends along the lower reaches of the Yangtze River in north-eastern and central China and Korea. It occurs at altitudes of 1500 to 1800 m above sea level in its native country. In the XVIII. century it was first moved to Western Europe and North America, where it was originally planted as an ornamental tree in 1856, sources report a natural forest in South Tyrol. Due to its favourable properties, it has spread to every inhabited continent over the last centuries. It is often planted in subtropical and northern temperate regions. Today, large stocks of Tree of heaven are found in East Asia, Europe, North America. It was planted for dredging and as windbreaks in Italy, Anatolia, Yugoslavia and the former Soviet Union. It has been established for cellulose production in Australia, New Zealand, South America and India. The species also appeared spontaneously in Japan, North Africa and Central Europe (Csiszár, 2012).

The first Hungarian records of the heaven tree from 1841-43 testify to the artificial planting attempts of the species at the southern foot of the Szársomlyó Hill in Nagyharsány. From the middle of the 19th century it is considered to be native to the Great Plain, thanks to herd-like, conscious settlements and spontaneous outbursts. Nowadays it occurs almost everywhere in the warmer highlands of the country, in the Great Plain, relatively rare in Western Transdanubia and in the higher regions of our central mountains. Its occurrence centres include Kiskunság with calcareous sand, Tolna Mountains, Keszthely Mountains and Külső-Somogy (Csiszár, 2012).

The *Ailanthus (Ailanthus altissima (Mill.) Swinglebelongs* to the genus *Ailanthus* of the family *Simaroubaceae* (The heaven tree). There are 10 species in the genus with pre- and post-Indian and Far Eastern distribution centres. The basic variant of the species, *Ailanhus altissima var. altissima* is native to China. *Ailanthus altissima var. tanakai* bark is more yellow than the main species, its leaves are shorter. The *Ailanthus altissima* var. *sutchuenensis* can be recognized by its reddish branches. In addition to the glandular heaven tree, the genus also includes the downy tree of heaven *Ailanthus giraldii Dode* and the spiny tree of heaven (*Ailanthus vilmoriniana Dode*) in the temperate region.

It is a medium-sized tree that can reach heights of 25-30 m. It is a short-lived (80-130-150 years), fast-growing tree species. Its seeds are germinating for a long time. It requires heat, germination in Hungary is possible from the end of May. Its deciduous growth occurs in the first half of April and may last until

frost. It blooms in the second half of June and in the first half of July, and two weeks later its fruits turns yellow or reddish.

Its ripe fruits fall from September to the following spring. Its root system is fan-branched below the soil surface. The additional buds on the roots allow the formation of dense colonies and rapid vegetative reproduction (Csiszár, 2012).

- It requires heat and light, does not withstand shading, and its bracts and young specimens often freeze.
- Drought tolerant, does not like heavy rainfall and damp areas.
- Calcareous, slightly salt-tolerant, less nutrient-intensive.
- They prefer to settle in disturbed places and habitats without closed canopy levels. It also appears as a slot resident.

The causes of the nature conservation problems caused by the idol tree are to a large extent due to the effective vegetative propagation ability of the species (Csiszár, 2012).

### *4.2.2 White acacia (Robinia pseudoacacia L.)*

The white acacia is native to the interior of eastern North America. One of the main centres of its distribution is the region of the Appalache Mountains, which is between 150 and 1500 meters above sea level. Main areas and boundaries of its distribution range: Central Pennsylvania, Southern Ohio, Northeast Alabama, North Georgia, South Missouri, Northwest Arkansas, Eastern Oklahoma. In 1601 it moved from Virginia to France, after which it was mainly planted as ornamental and row of trees. In the 1700s it was already common in Germany. In Asia and South-eastern Europe, the species was used for afforestation of eroded slopes and gullies, but it was also used to create tree stands against the wind. Today, its total production area worldwide is approx. It is estimated at 3.25 million ha (Csiszár, 2012).

The White acacia was brought to Hungary between 1710 and 1720, and it was planted as a park tree, a row of trees. The first major planting (290 ha) took place in 1750 in connection with the fortification works near Komárom, after which it became popular and was planted on a variety of soils, sand drift and saline. The first mass planting of the tree species dates from 1865 to 1895. As a result of the 1923 Lowland Farming Act, 37.000 ha of black locust were planted until World War II. White acacia also became one of the dominant species of tree planting in 1949. According to the data of 2010, the acacia area in Hungary is 457 thousand ha, or 23.9% of the forest area. White acacia has been planted on several 160.000 hectares of arable land, where it does not grow satisfactorily from a forestry point of

view, and for economic and conservation reasons, these forests should be converted into native tree species. According to national flora mapping, the species is present throughout the country, but its significance varies from one landscape to another. White acacia is more important than the national average in the sandy areas of the Great Hungarian Plain, in the Nyírség and the Danube-Tisza, as well as in the Cserhát, the Heves-Borsod Hills, the Pannonhalma Hills and the Kemeneshát. Continuous growth of its area is expected in the future (Csiszár, 2012).

White acacia (*Robinia pseudoacacia L.)* is a member of the genus *Robinia* of the *Fabaceae* family (*papilionaceae*), which has a total of about 10 deciduous species. They are typically distributed in warm, seasonally dry parts of North America and Mexico. In addition to the white acacia, the woody locust (*R. luxurians (Dieck.) C. K. Schneid.*) and the Greater locust (*R. viscosa Vent.*) are wood species, the rest of the genus being shrub species. In Hungary, *R. viscosa* is more frequently planted as ornamental plant than *R. hispida.* In our country, 9 selected forest locust species and several horticultural cultivars are planted (Csiszár, 2012).

It can reach a height of 30-35 m in closed stands and in good cultivation. It is a long-lived (200-250 years) fast growing species of wood. The optimal time for germination of black locust is the end of April. Its seeds are hard-shell, can be classified as persistent seed bank and retain their germination capacity for up to 40 years. Under natural conditions only a small percentage of seeds germinate each year. The acacia height increases until the age of 20 is very strong and then decreases. It produces a large number of inflorescences from the age of six, reaching the infant stage between the ages of 10 and 15. The bud starts from mid-March to mid-May (national average: April 22), with full foliage development taking 1 to 1.5 months. Flowering begins in May and lasts an average of 18 days. Black locust of our country starts to blossom in the southwestern region to NW in 10-30 days. The deciduous fall lasts from early October to early November. The fruits ripen on average by mid-October, with seeds spreading in anemochoric and endozoochoric ways. Black locust regenerates well, sprouting from root and root. After damage to the above-ground parts or root system, it develops a large number of root sets, which are more intensively grown than the root sets (Csiszár, 2012).

- Light-demanding but tolerates moderate shading by the age of 6-8 years.
- Moderately drought tolerant, unable to tolerate too wet, cold soil.
- Warm-demanding, frost-sensitive.
- Neutrophil, nitrophile, prefers well-ventilated soils.
- It’s nutrient requirements are relatively low and do not tolerate root competition.

(Csiszár, 2012)

### 4.2.3 The false indigo bush (Amorpha fruticosa L.)

The false indigo bush comes from eastern North America. It is native to the south-eastern United States, north-eastern Mexico. It is now prevalent in almost the entire United States and is present in Canada and Mexico. We have data on settlements in Asia from Iraq, Pakistan, China, Korea and Japan. The species was first introduced to England as an ornamental plant in 1724, and then moved to continental Europe around 1750. The most eastern data of many countries in Europe (except Ireland, Spain, Portugal, Germany, Poland, Scandinavia and the Baltic states) originate from Russia and the eastern coast of Turkey (Csiszár, 2012).

Its mass occurrence today is typical of the valleys of our lowland rivers. The first data about Hungary is from 1907. Its rapid spread - related to economic plantations - began after World War I, especially in the Tisza and Danube valleys. On the national scale, the most suitable habitats are already in the XX. was present in the middle of the 20th century. Its expansion was accelerated by the abandonment of floodplain fields, the decline of livestock and floods, which became more common at the turn of the millennium due to changes in agricultural structure and economic failure. In areas far away from watercourses, habitats continue to expand more slowly, but mainly from irrigation canals and from focal points from artificial plantings. Due to its heat demand its occurrence is limited in the mountains. The genus *Amorpha*, comprising deciduous shrubs and shrubs, belongs to the family of papilionaceae (*Fabaceae*), which has 15 species. In the temperate and subtropical landscapes of North America, only the invasive nature of *Amorpha fruticosa* is known, but some related species occur in botanical gardens (Csiszár, 2012).

On average, it is a loose shrub that grows to 3-4 meters in height and forms a wide shrub with branching branches. It is a relatively short lived, fast growing species. According to annual ring counts, 18-20 year old trunks are common in the Körös region in Hungary, and the oldest specimen is 25 years old. Seeds germinate at relatively high temperatures, and in Hungary the emergence of plants can be observed from May. Its first blooms and ripening are expected in its third, but usually in its fifth year. Leafing begins in May and blooming in June and July. Pollinated by insects. The ripening of the pods begins in September. Harvesting is continuous and may last from autumn to the following summer. The fruits spread well with water. It will drop its leaves by the end of October. The seeds are germinating immediately upon ripening, but are later rested. They germinate for three to five years. It has good vegetative germination. In addition to the generative, its vegetative life cycle is also known. According to this, its stems are 18-20 years old

they rot around their age, break down in the stem, and in their place new shoots sprout from the root system (Csiszár, 2012).

- Light-loving but weaker shade hardly restricts its development (for example, it can be bulky in the plantation of only loose shades of noble summers). But it has less and less place in a closed forest.
- Not really cold tolerant, germination can be greatly reduced by early spring frost and young shoots easily freeze off.
- The false indigo bush can survive on a variety of soil types, including sand, rocky soil and strong alkaline soils. However, germination is limited in dry production areas. It prefers loose, periodically flooded soils, but has a limited tolerance for stagnant water. It can withstand flooding for up to several weeks in our floodplains, but if it is flooded by the tips of the shoots, it will be destroyed by a permanent flood.

(Csiszár, 2012)

False indigo contains terpenoid, phenoloid and alkaloid allelopathic compounds. Allelopathic phenomena may contribute to the species poverty of enclosed false indigo and to the fact that, in less frequent populations, the area around the roots is markedly poor in vegetation.

The enclosed false indigo suppresses lower plants (herbaceous, regrowth of trees and shrubs) with strong shading. Its root competition is also strong. The seedlings of false indigo, however, are suppressed by the enclosed, intact, high-grass lawn. The adult false indigo can be suppressed by the shade of the higher stands of taller trees, and the creeping plants (*Vitis sp., Humulus lupulus, Rubus sp., Echinocystis lobata*), which cover the plants in large numbers, also reduce their vitality.

According to several observations, in the immediate vicinity of the Acer negundo, the false indigo bush is absent or scruffy in the more open areas.

There is a kind of intraspecific competency and the related population dynamics that characterize the false indigo. The population of the aging false indigo bush grows in a favourable growing area and the germination rate is gradually reduced. The lower branches of the remaining individuals gradually die, and then, in the twenty-five to thirty-year-old false indigo bush a "collapse" occurs. Instead of dying specimens (this process is usually preceded and probably hastened by the complete cover of *Echinocystis lobata* - such specimens), the establishment of competing woody species may begin. Over time, the entire stock collapses and the long-dominated habitat of the false indigo bush is gradually transformed into a grassland, (a similar direction of succession was outlined, though without detailing the processes, from the Po Plain, Italy) (Mihály - Botta-Dukát, 2004).

Each part of the false indigo bush contains a highly toxic and repellent substance for insects, the major component of which is the amorphigenin (8'-hydroxy-rotenone) of the rotenoid group. As a result, it has only a small number of more or less specialized consumers. (Mihály - Botta-Dukát, 2004).

The only observed insect consumer in Hungary is the *Acanthoscelides pallidipennis* weevil species, which is present throughout the country and can be observed in large numbers on the false indigo population. As a seed-predator, this beetle infects both developing and already dry fallen fruits. Adult specimens feed on pollen. In its native country it can cause very large crop losses (30-90%), but in our country it does not exceed, in fact, it is usually well below 40% (the data does not include the damage caused by already fallen fruits). The beetle does not have a significant parasitoid in Hungary for the time being. Its importance in limiting the invasion process is unknown, but probably not significant.
For the animals of the pasture the false indigo is non-toxic, they consume its leaves and canes, and can be grazed by cattle, sheep and goats. According to some studies, goats were more likely to reject the plant after initial acceptance. The game is reluctant to consume it. Fungal diseases causing spotted leaf necrosis can be observed in Hungary (Mihály - Botta-Dukát, 2004).

The pollination of false indigo in Hungary is carried out primarily by the honey bee (Apis mellifera) and its seed-predator *Acanthoscelides pallidipennis*. Like legumes in general, false indigo live in symbiosis with nitrogen-binding bacteria (Mihály - Botta-Dukát, 2004).

## 4.3 Economic and nature conservation problems caused by invasive plants

***The nature conservation and economic importance of the Tree of heaven***

The perceived or real economic benefits, the beneficial properties and the nature conservation risks of the species are partly due to the same biotic properties. Its efficient planting was facilitated by its good propagation from seed, easy growing of seedlings, the formation of a strong rootstock and its rapid growth. These are the properties that help invasive propagation and make it very difficult to suppress spontaneous populations. It has a dense root system, drought-tolerant, and has therefore been predicted to play a major role in the lowland sand plantation. The Tree of heaven fulfilled this role spontaneously, regardless of active human planting.
There are conflicting opinions about the usability of its timber. Its economically positive properties include its good nectar production capacity, which makes tree of heaven important in beekeeping aspect.
From the nature conservation aspect, the tree of heaven is one of our most dangerous species. Not only populates the colonized area, but it also actively transforms its structure, species composition, and ecological potential. The primary causes of species composition modification are allelopathic compounds that enter the soil from the roots and from the falling leaves. Nitrogen enrichment in soil during leaf-litter decomposition also contributes to the emergence of disturbance-tolerant, nitrophilic

species over members of the original vegetation. Another important reason for the transformation of tree of heaven-infested habitats is the shading caused by growing specimens, which occurs particularly rapidly in typically hemispherical polycormon colonies. The Tree of heaven is a major threat to valuable, species rich, mid-mountain dry grasslands, shrubbery forests and open sand lawns. The spread of the species threatens, among other things, the habitat of the rare plant species of Szársomlyó, the habitat of *Onosma tornense* near Tornanádaska and the lavender fields of Tihany that has a special history.

According to the experiences of nature conservation interventions, the most effective way of extermination is chemical treatment (Csiszár, 2012).

***The nature conservation and economic significance of White acacia***

The species of White acacia covers the largest area of Hungary among trees, its economic and forestry importance is significant. Acacia cultivation is facilitated by its easy planting, easy growing, rapid growth, relative drought tolerance, not too high nutrient requirement and good vegetative regeneration ability. Excellent firewood and versatile raw material. It has been used extensively in the past for running sand binding, gully limitation, bare mountain and hillside cultivation, and more recently in the re-cultivation of waste dumps and deposits. Its economic importance is increased by the fact that about half of Hungarian honey production is due to this well-honeyed tree species (Csiszár, 2012).

The properties of Acacia, which are favourable for cultivation and renovation, make it extremely dangerous from a nature conservation point of view. Where it is installed or spontaneously settles, it is very difficult to remove, due to its excellent rooting ability and its long-term persistent core bank. Its seeds remain germinating for decades, and their seed-calm is often broken by human intervention (e.g.: burning, trampling, logging, deep ploughing). The characteristic negative ecological process of acacia is the enrichment of the nitrogen content of the soil with the help of Rhizobium bacteria living in the tubercle of acacia roots, as well as the transformation of the grassland species, the weediness, the proliferation of nitrophilic plant species. This tree of species also contributes to the transformation of its habitat with the unilaterally depriving of nutrient stocks of the soil and the allelopathic effect of the fallen foliage. The artificial suppression of acacia is greatly hampered by its excellent area conservation ability. In the area of intervention, it is not enough to overcome scions that spout through years, but also take into account the possibility of tree regeneration from the seed for decades (Csiszár, 2012).

Combining different treatment methods can increase the success of acacia suppression: mechanical removal of scions, grazing after scion remuneration, ringing, chemical treatment, providing artificial shading (Csiszár, 2012).

***Nature conservation and economic importance of Amorpha fruticosa***

It was previously planted in Hungary for forestry and soil protection purposes, but the problems it causes outweigh the hoped benefits, so planting it in Hungary is no longer a practice. Nevertheless, it is still mentioned today and is being promoted by interested parties as a promising species of energy plantations. It is an excellent honey-plant.

With its rapid spontaneous spread and growth, this weed is difficult to control in reforestation and planting in the floodplain. It also restricts arable and grassland management in flooded areas and accelerates clogging of canals and capes.

It is a serious problem that it proliferates much more quickly than the native shrub and tree species on neglected floodplain dams (e.g.: summer dams that have become "unowned") or on the edges of lanes (Csiszár, 2012).

From a nature conservation aspect, it primarily has a catastrophic effect on floodplain treeless vegetation, especially grasslands. If mowing / grazing in these habitats is delayed for a year or two, the *Amorpha fruticosa* will turn them into impassable shrubs with rapid and massive growth. Through its shade and other (e.g.: allelopathic) competition it displaces grass species. Its nitrogen-binding root system and nitrogen-rich leaves significantly increase the nutrient content of the soil, therefore, in areas where the *Amorpha fruticosa* has long been present, even after removal of the trees, grassing is slow and is replaced by nitrogen-loving weed species for a long time. The grassing and the suppression of scions are supported by grazing with cattle.

The impact of *Amorpha fruticosa* on the natural dynamics of floodplain forests (which can only be hypothesized today), or on near-natural forest management that may be close to it, is not known in detail, but it is certainly problematic. In the short term, it rewrites small forest cycle processes with rapid growth, while native and alien tree species of the floodplain forest can overgrow the old *Amorpha fruticosa* trees. Outside of floodplains, it is still of relatively minor importance, but it can be presumed that, as a fast-growing shrub in the forest steppe zone, it can cause serious problems at the border of grassland and forest associations (Csiszár, 2012).

Forestry almost certainly regards it as a weed species. Overall, from an economic point of view, it has no qualities to justify its presence. It can be replaced in virtually all areas of use by native or harmless alien species (Mihály - Botta-Dukát, 2004).

*The nature conservation importance of the species*

The spread of *Amorpha fruticosa* has the most transformative effect on the natural treeless and shrub vegetation in the floodplain. Under the dense, impenetrable shrub, which grows to several meters height, the grassland species cannot survive, or only marginally. For both native nesting birds (such as Harris) and predatory birds that feed in open areas the habitat will become unfit and the homogeneous *Amorpha fruticosa* forests generally have a very poor fauna. For large mammal species (fawn, deer) such forests become almost impassable. For a long time, these closed, monodominant *Amorpha fruticosa* forests represent a succession-absorbing state, a kind of "green desert" in the floodplains (Mihály - Botta-Duka, 2004).

Outside of floodplains, in some non-extreme kind open or only partially closed natural habitats, due to the lack of proper management, we are expecting the slow advancement of the *Amorpha fruticosa* at the expense of the natural species. Otherwise, it generally inhibits natural recovery processes in any secondary or degraded habitat. In areas close to nature, the plant also destroys the landscape from an aesthetic point of view, thereby depriving the show areas of their function. The tourist paths are regularly overgrown in more open places, making them impassable (Mihály - Botta-Duka, 2004).

*Recommended nature conservation strategy:*

On a national scale, the most important thing to do is to prevent the further spread of *Amorpha fruticosa*. Further planting and cultivation, even in areas less threatened by invasion, is not desirable; existing smaller populations should be eliminated and small isolated populations permanently exterminated. Targeted researches, especially in floodplain areas, need to uncover exactly what conditions allow and inhibit spontaneous colonization of the species and what will be the impact of subsequent large-scale water management plans on the further spread of the species (Mihály - Botta-Dukát, 2004).

In general, non-chemical interventions (mowing, shearing, extraction, grazing) should be considered first against invasive species from a nature conservation perspective, but it should be noted that these procedures are extremely labour-intensive and time-consuming. The choice between mechanical and chemical defence is based on the location of the habitat and other environmental conditions (e.g.: the area's coverage must be taken into account; how large the population is) (Mihály - Botta-Dukát, 2004).

## 4.4 Economic damages in the territory of Mecsekerdő Forestry Co. Ltd.

Forestry does not collect data on the management of invasive tree species and treated areas separately, therefore we investigate the territorial extent of the adverse factors related to weather and disease in the last 7 years (2013 - November 2019) (Table 11).

**Table 11.** Economic damages in the area of Mecsekerdő Forestry Co. Ltd.

| **Sum / Reduced area (ha)** | **Year** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Damaging factor** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **Total** |
| Drought damage | 141.69 | | 54.15 | | 62.88 | 0.24 | 11.56 | 270.52 |
| Inland water | | | 18.60 | 5.07 | | | | 23.67 |
| Other tree species disease | 4.15 | | | | | | | 4.15 |
| Pine decay *(Pinus spp.)* | 2.44 | | | | 0.17 | | 0.47 | 3.08 |
| *Hymenoscyphus fraxineus* | 12.92 | | 10.77 | | | 20.97 | 40.42 | 85.08 |
| Hail damage | 83.66 | | | | | | | 83.66 |
| Wind damage | | 0.72 | | | 1.96 | 4.17 | | 6.85 |
| Rooting | | | 0.15 | 2.26 | | 6.53 | | 8.94 |
| Snow break | | | | 54.12 | 31.64 | 0.73 | | 86.48 |
| Frost | | | | 834.11 | 163.61 | | 34.79 | 1 032.51 |
| Wind break | | | | 7.14 | 3.22 | | | 10.36 |
| Rodents | | | | 0.80 | 7.71 | 5.09 | 3.63 | 17.23 |
| Haltica quercetorum | | | | 1.00 | | | | 1.00 |
| Oak decay (*Quercus cerris*) | | | | 10.32 | | | 0.44 | 10.76 |
| Oak decay (*Quercus petraea*) | | | | 10.44 | | | 0.44 | 10.88 |
| Beech decay (*Fagus sylvatica*) | | | | | | | 0.59 | 0.59 |
| Oak decay (*Quercus robur*) | | | | | | | 0.46 | 0.46 |
| *Corythucha arcuate* | | | | | | | 17 336.60 | 17 336.60 |
| Sum area (ha) | 244.86 | 0.72 | 83.67 | 925.26 | 271.18 | 37.73 | 17 429.40 | 18 992.81 |

Source: Mecsek Forestry Co. Ltd., 2019

It is clear from the table that weather-related damage occurs every year (drought, wind, inland water, frost), which can be a factor of weakness, and trees can be more susceptible to other diseases. In 2013, 2014 and 2015, mainly weather-related damage occurred in small and medium-sized areas, while in 2016, frost damage caused the largest area of damage factor in juveniles. In this year, oak ground fleas appeared in small areas (~ 10 ha), together with devastation of *Quercus cerris* and *Quercus petraea.* In 2017, frost damaged the juveniles caused problem in large areas, in 2018 damage occurred in a

negligible area (37.73 ha), mainly due to disease (*Fraxinus bark ulcer*). In the year 2019 (investigated till November), the largest area was damaged by *Corythucha arcuata*, the total damaged area exceeded 17 thousand hectares. In addition, in small areas (below 1 ha), *Quercus robur, Quercus petraea, Quercus cerris* and *Fagus decay occurred.* The extinction of native tree species in large areas in 2019 also urges for mapping the health base status of forest populations and the monitoring of the appearing destructions by various remote sensing technologies.

# 5 Presentation of project goals and implementation (Hungary)

The main objectives of the project were aerial laser scanning and digital measuring camera survey in the leafless (non-vegetation) period, furthermore airborne hyperspectral survey and digital measuring camera survey in the leafy (vegetation) period, in the 154 km$^2$ area designated by Mecsekerdő Forestry Co. Ltd., as well as the generation of digital thematic data sets from the generated remote sensed data using goal-specific image classification.

The boundaries of the surveyed area are shown in Figure 5. To process the data, the contractor divided the project area into 16 processing areas.

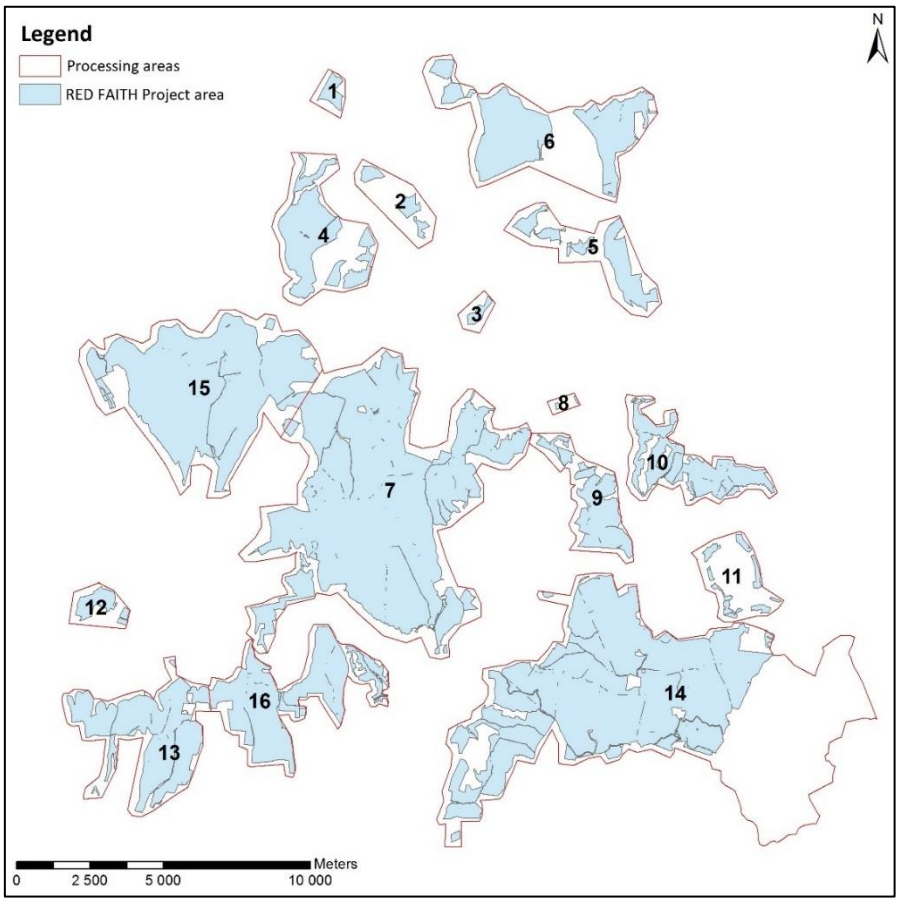



**Figure 5.** The RED FAITH project area and the processing

Source: Mecsekerdő Forestry Co. Ltd., 2018

## 5.1 Applied technologies

Remote sensing data was created using three different technologies. Two of these were passive sensors (hyperspectral, digital medium format camera) and one is an active (airborne laser scanner - ALS) technology. The following sections introduce these three technologies.

In all cases, the surveys were carried out with sensors mounted in fixed wing pilot-led aircraft, which were performed by the flight of predefined flight lines.

### *5.1.1 Airborne laser scanning (ALS)*

LiDAR is an active remote sensing technology that can collect large amounts of telemetry data in a very short time. The acronym LiDAR is derived from "Light Detection and Ranging". The distance can be determined by precise time measuring; by the time difference between the emitted and reflected signals and the speed of light. The advantage of aerial LiDAR is the ability to quickly and accurately gather data from a large area of the earth's surface and its natural and artificial objects, and to measure areas where terrestrial geodetic measurements can only be accomplished with a high level of resources and time. Airborne LiDAR system components include: laser sensor, carrier device (e.g.: low altitude aircraft: 300-4000m), GNSS/INS inertial navigation system, which records the in-flight accurate position and movement of the sensor installed in the aircraft. The principle of measurement is that the sensor emits a laser beam towards the earth's surface and measures the reflection time from which it calculates the distance (laser rangefinder). Thanks to the high-precision navigation system, the location and position of the sensor are known precisely, and the coordinates of the reflection point (x, y, z) can be determined from the measured distance. During laser scanning, a laser beam scans the landscape perpendicular to the direction of flight while the aircraft is flying at a specified speed along the planned flight line (Figure 6.).

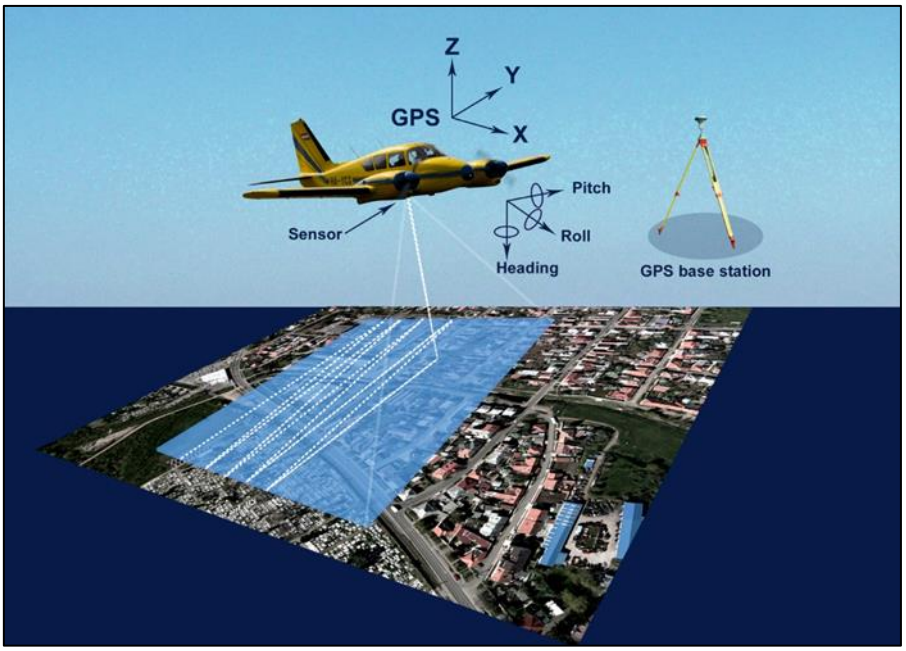



**Figure 6.** Schematic method of airborne laser scanning

More reflections are obtained from an emitted laser pulse as it interacts with objects of different heights during propagation of the pulse, so a portion of its energy is reflected from the nearest object, the remaining part advances and is subsequently reflected. For example, in a forest area, a part of the impulse is reflected from the canopy level, while the remaining part reaches the ground, providing information about the surface (Figure 7.).

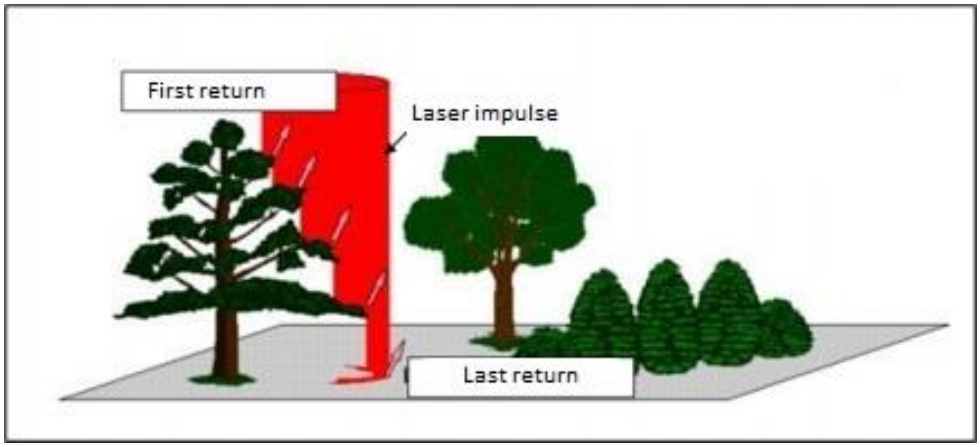



**Figure 7.** Multiple returns of laser impulse

Multiple returns allow the modelling of individual-level geometric features of trees in forest fragments, as well as the mapping of individuals from the second canopy level not visible from above unlike optical sensors. A small part of the laser beam can reach to the ground surface even in leafy forest populations, but a laser survey in the leafless state is more ideal for obtaining sufficient density of soil and lower

level canopy, as well as trunk data. The result of the survey is the raw point cloud, which contains the x, y, z coordinates and identifiers of each reflected and detected point (Figure 8.).

The most typical indicator for the accuracy of airborne laser scanned data is the number of points reflected and detected per square meter, which was at least 18 points/m2 for a leafless survey conducted in the RED FAITH project. This means that, depending on the terrain, there are places where the point density reaches 30-40 points/$m^2$ due to flight paths that are at least 50% overlapping, but there is no area below 18 points/$m^2$. With such density data, the average distance between points is 0.25 m, which allows interpolation of height models up to half a meter or better in raster resolution.

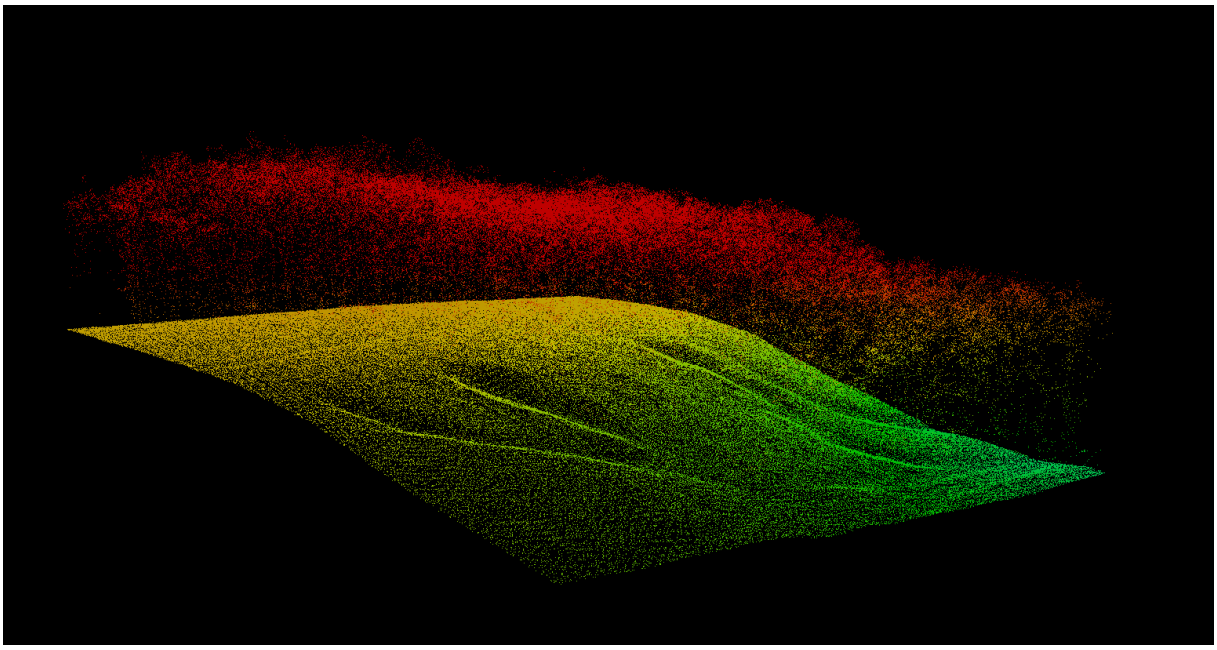


**Figure 8.** Detail of 3D digital point cloud, coloured by elevation

Source: Mecsekerdő Forestry Co. Ltd., 2018

### *5.1.2 Airborne hyperspectral technology*

The hyperspectral airborne imagery (Figure 9.) is high in information content and contains continuous spectra in the visible and near infrared range (400-1000 nm). Hyperspectral imagery is a passive remote sensing technology that detects electromagnetic radiation from the sun and reflected from natural and artificial objects on the surface. It is a data acquisition technique that collects information from the surface, up to hundreds of channels, that form contacting spectral wavelength intervals in such a way that the radiance spectra of each pixel can be derived. Each image can contain 100 or hundreds of narrowband channels, as opposed to 4-8 channels of multispectral data (e.g.: LANDSAT satellite,

TetraCAM multispectral camera). Thus, such an image can be used to determine material or biophysical properties that are not possible from conventional aerial images.

Most of the technologies used for airborne hyperspectral survey consists of a high-precision GNSS/INS system built in with a push-broom type sensor that record navigation data. The most important element of a hyperspectral sensor is the spectrograph, on which electromagnetic wave incoming from the object passes, and diverting the signals in function of wavelength, and this electromagnetic signal goes to the central computer. Hyperspectral surveys are usually performed at lower field resolutions (~ 1 m), depending on the size of the object to be mapped.

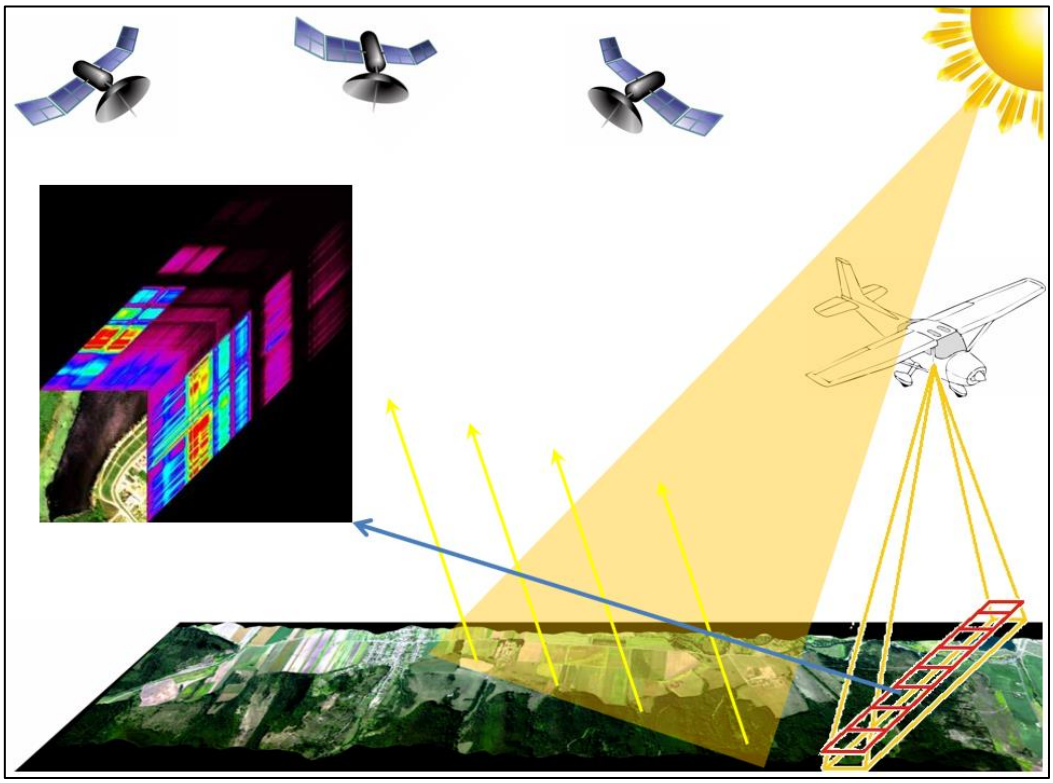


**Figure 9.** Schematic method of airborne hyperspectral technology and the recorded data cube
Source: Mecsekerdő Forestry Co. Ltd., 2018

Since hyperspectral survey is a passive remote sensing technology, it is important to select appropriate weather parameters. Fully cloud-free and fog-free weather is needed in flight, and the correct sun angle is important (>40°), as the correct radiation is needed to obtain good quality spectral information and the shadow effect is also the lowest in this case. The period from May to August is the most suitable for hyperspectral imagery of vegetation for mapping purposes, as the sun angle (Figure 10.) and plant leaves (which determine the radiance value of fixed pixels) are photosynthetically active at this stage.

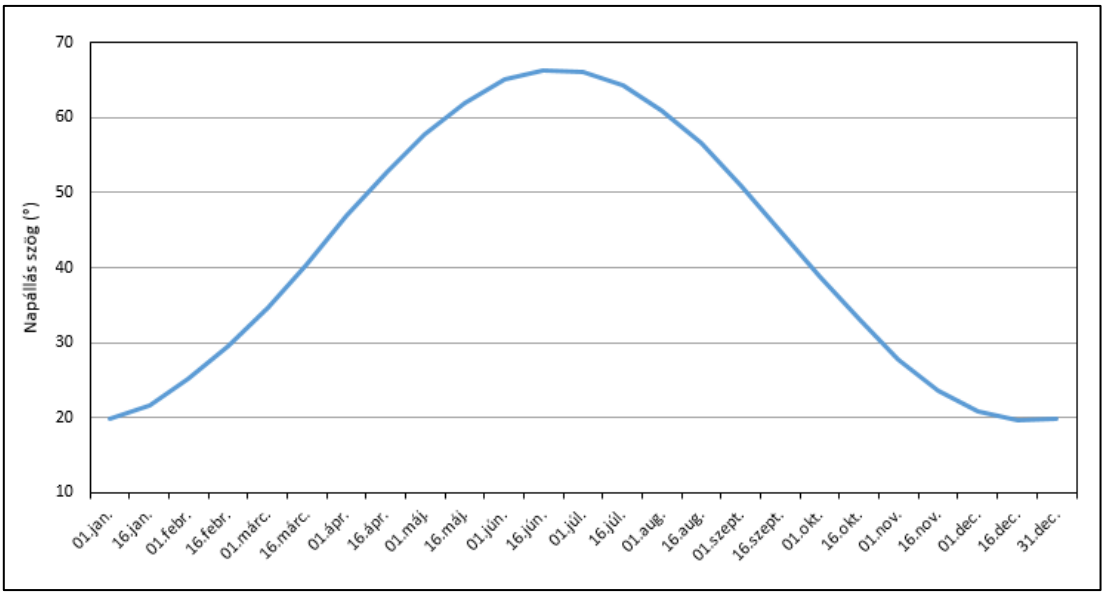



**Figure 10.** The change of the sun angle during the year in Hungary

Source: Mecsekerdő Forestry Co. Ltd., 2018

The use of direct georeferencing results in fast data access and ease of use. In this case, each line of the row-scanned data has accurate GPS and INS data, so geocoded data is immediately available during post-processing.

The data recorded by airborne hyperspectral technology contain a unique narrowband reflectance curve for each surveyed pixel (Figure 11.), which allows further pixel and object-based image analysis.

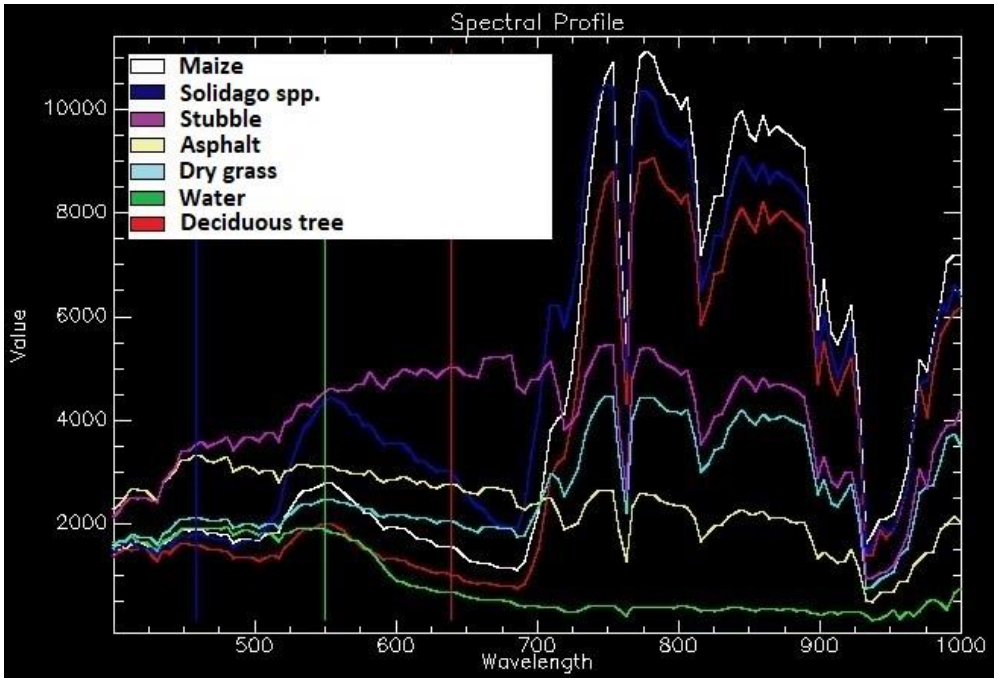



**Figure 11.** Radiance curves of some surface objects in visible and near-infrared range

Source: Self-edited, 2019

### 5.1.3 Digital measuring camera technology

Digital measuring camera technology, similar to hyperspectral imagery, is a passive remote sensing technology which records the surface-reflected range of electromagnetic radiation from the sun. The most important difference is that, in measuring camera surveys, the camera system records 3 or 4 broader spectral channels typically in the R (red), G (green), B (blue), and near infrared (Nir) ranges. These fixed ranges form discrete channels whose visual pixels are represented by the rules of additive colour mixing, where the spectrum is defined in a 3-axis coordinate system. The three axes are blue, green and red or green, red, and infrared (depending on whether 3 or 4 channel images were taken). Most image display software uses automatic contrast enhancement in the base display as well for better display. An image without perspective distortion is called an orthophoto and a digital image is called a digital orthophoto. If there is a fitting to a projection system in parallel with the transformation, we are talking about an orthophoto map or a digital orthophoto map. Low altitude aircraft mounted measuring cameras (ortho cameras) are metric systems that has high area performance and require more specificity and expertise to process than images of the UAV mounted digital cameras, which are often used for the analysis of smaller areas.

The measuring camera images have generally high field resolution (10-30 cm) providing extremely detailed information about the surface and objects on it. In frame of the REDFAITH project, digital measuring camera surveys were carried out in the leafy and leafless period, and the sensor recorded 4 channels (R, G, B, Nir) during the data recording (Figure 12.).

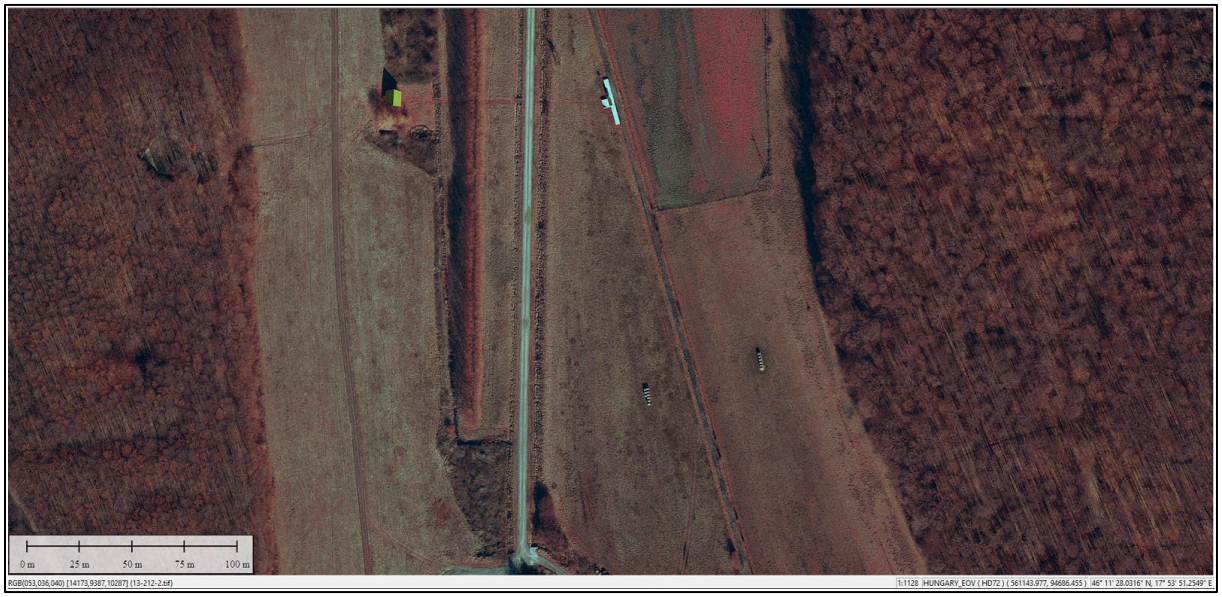



**Figure 12.** Leaf-off ortho photo from RED FAITH project area (near-infrared)

Source: Mecsekerdő Forestry Co. Ltd., 2018

## 5.2 Recorded data and products

The generated remote sensing data using the three technologies were as follows:

Leaf-off survey:

- classified point cloud in LAS format with EOTR2000 tiling
- digital terrain model (DTM) in raster format in 1*1meter cell grid with EOTR2000 tiling
- digital surface model (DSM) in raster format in 1*1meter cell grid with EOTR2000 tiling
- digital orthophoto RGB and NIR with 20*20 cm ground resolution with EOTR2000 tiling

Leaf-on survey:

- 1*1meter field resolution hyperspectral images, containing a minimum 340 spectral channels within a spectral range of 400-1000nm per pixel, with at least 5nm spectral resolution, supplied with geometric and radiometric correction, in raster format (.dat format)
- mosaic image made from the R, G, B channels of hyperspectral image in raster format (GeoTIFF), in EOV projection system and according to EOTR tiling
- digital orthophoto with RGB and NIR 20*20 cm field resolution with EOTR2000 tiling

### *5.2.1 Generated remote sensed data*

During the leafless aerial survey, a high-density (minimum 18 points/m2) laser scanned database was generated from the project area, which is suitable for geometric modelling of forest populations and for high-precision mapping of vegetation-free relief. In addition, digital measuring camera images in the visible (RGB) and near-infrared (CIR) ranges were also taken during the leafless period, which are limited to image analysis due to low sun angle, shadow effects and low light intensity, but suitable for visual interpretation.

During the aerial hyperspectral flight in the summer in the leafy period, hyperspectral bands were made in the wavelength range of 400-1000 nm with 3nm spectral sampling, from which, after being pre-processed, mosaic images were prepared for the processing area unit. These images already included channels of the noise-free wavelength ranges that had been filtered (Figure 13.).

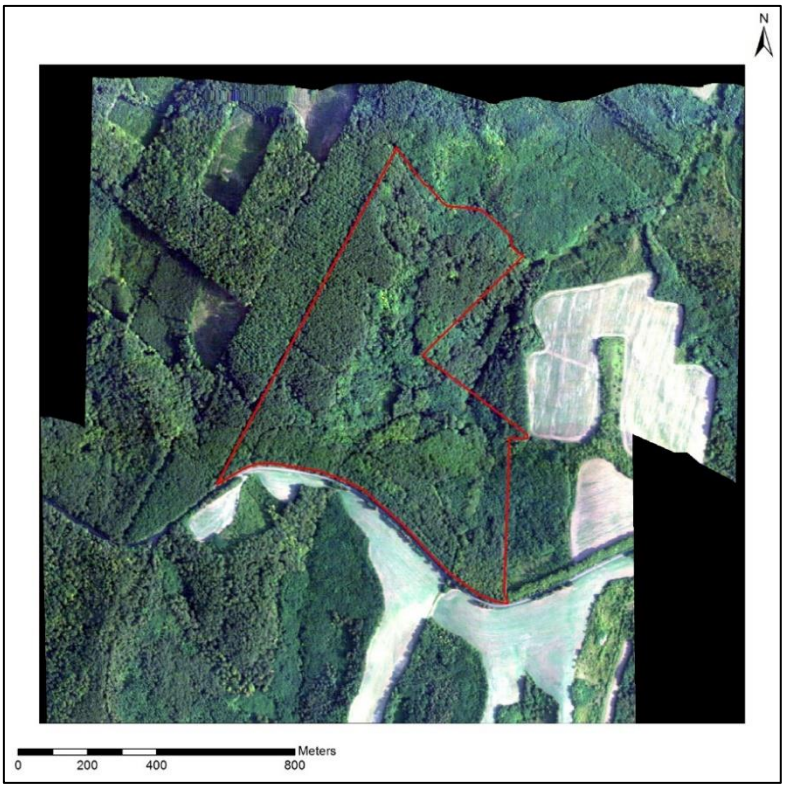



**Figure 13.** Visible hyperspectral image mosaic of Area01

Source: Mecsekerdő Forestry Co. Ltd., 2018

During the summer survey, besides the hyperspectral sensor, the digital measuring camera also made images, which are suitable for mapping forest populations due to the high field resolution, and due to the 4 fixed channels it is suitable for the calculation of high resolution NDVI index as well (Figure 14.).


**Figure 14.** RGB leaf-on orthophoto of RED FAITH project area

Source: Mecsekerdő Forestry Co. Ltd., 2019

### 5.2.2 Produced thematic data

By targeted image classification of remote sensed data, the contractor produced the digital thematic database of the project area, which included land use maps (Figure 15.) and vector graphics of tree species, including invasive species, for each area unit.

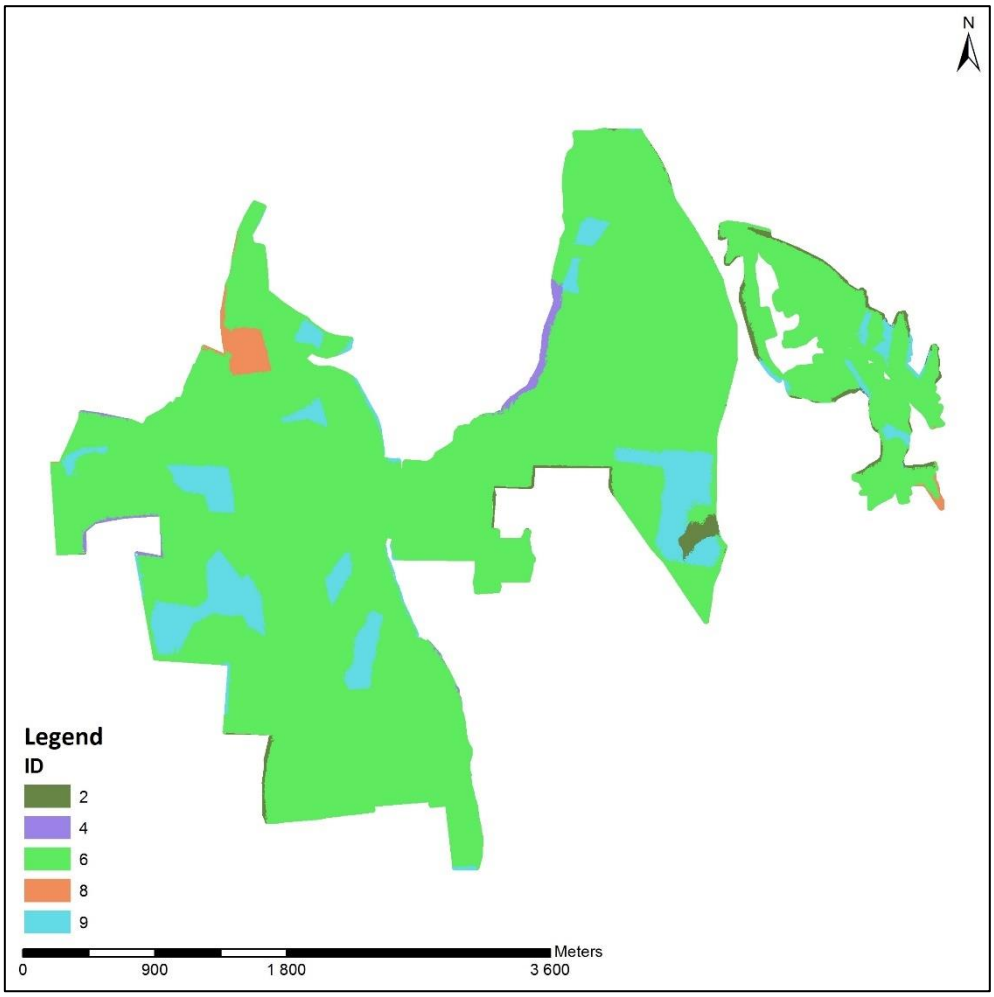



**Figure 15.** Digital land use map of Area16 (Codes: 2: arable; 4: grass; 6: deciduous forest; 8: mixed forest; 9: bushes)

Source: Mecsekerdő Forestry Co. Ltd., 2019

Thematic data are tree species data obtained from the directional image classification of pixel-based hyperspectral images and generated by the integrated processing of canopy segments derived from laser scanning data. The individual-based tree species map was generated by the aggregation into vector canopy polygons of pixel-based classified results (Figure 16.).

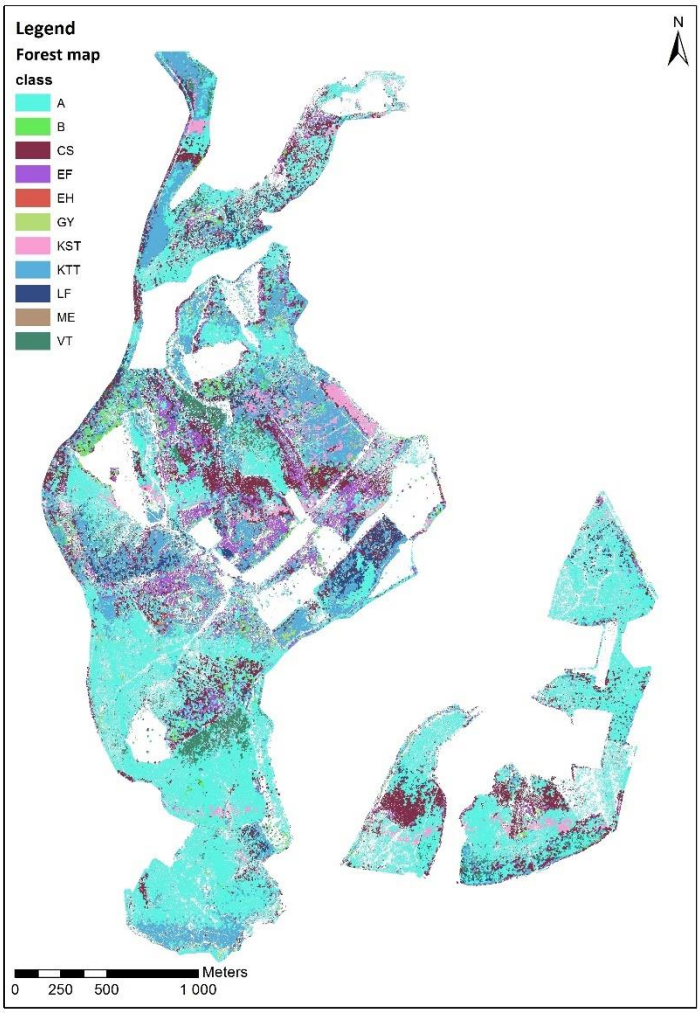



**Figure 16.** Digital forest map of Area04

(Tree species code: A=*Robinia pseudoacacia*, B=*Fagus sylvatica*, CS=*Quercus cerris*, EF=*Pinus sylvestris*, EH=*Tilia tomentosa*, GY=*Carpinus betulus*, KST=*Quercus robur*, KTT=*Quercus petraea*, LF=*Picea abies*, ME=*Alnus glutinosa*, VT=*Quercus rubra*)

Source: Mecsekerdő Forestry Co. Ltd., 2019

### *5.2.3 Knowledge sharing, using remote sensing data in forestry tasks*

In addition to producing aerial remote sensing data and generating and delivering digital databases, the contractor was tasked with familiarizing forestry professionals with the used innovative technologies and data analysis techniques. The purpose of the knowledge sharing was to present the applied airborne survey technologies, the produced basic data and the information that can be generated from them to the forestry professionals working with spatial data and deal with planning.

During the implementation of the project, it was important that professionals working with the generated data will be aware of its potential, application possibilities and to obtain information on deeper analysis methods of remote sensed data.

Within the frame of the implementation, two workshops introduced remote sensing technologies, generated data and thematic digital databases, and during a training session, the participating professionals were introduced to the software and procedures used to analyse the data.

The workshops and scheduling of the training fit to the project implementation stages as well.

Thematic of the 1st workshop:

- Introducing airborne remote sensing technologies: introducing active and passive aerial data acquisition technologies
- Planning and implementing aerial remote sensing campaigns: preparing flight plans for forest areas, executing flights
- Pre-processing of airborne hyperspectral, digital measuring camera and airborne laser scanned data: production of data sets from raw data that suitable for analysis with special regard to images taken from forest areas

Thematic of the 2nd workshop:

- Presentation of aerial remote sensing activities performed within the RED FAITH project
- Use of hyperspectral data for tree species mapping
- The applicability of laser scanned data for forestry purposes

Thematic of the training:

- Download sample data, installation of trial version of software
- Directed image classification of hyperspectral data in a forest area
- Integrated object-based image analysis of hyperspectral and laser scanned data
- Laser scanned point cloud visualization, object-based analysis, production of raster models

# 6 Presentation of project goals and implementation (Croatia)

## 6.1 Purchase and testing specialized equipment

### *6.1.1 eBee aircraft with multispectral camera*

The „SenseFly eBee SQ" (Figure 17.) aircraft with an integrated RGB camera (Parrot Sequoia 16 MP) and multispectral camera (1.2 MP; four spectral channels: GREEN, RED, REDEDGE and NIR) were purchased for the purpose of imaging larger areas and performing longer flights with respect to multirotor aircrafts. It is intended to become Contracting Authority's equipment for routine usage as it enables fast and simple photogrammetric imaging of forest stands.

**Figure 17.** Left - The „SenseFly eBee SQ'' aircraft with an integrated RGB camera and multispectral camera; right – integrated RGB multispectral camera Parrot Sequoia (the images are not on the same scale)

### *6.1.2 DJI Matrice multirotor aircraft with a high-resolution RGB camera and hyperspectral camera*

The DJI Matrice 600 Pro multirotor aircraft (Figure 18.) was designed for complex flight missions which require sensor exchange, bigger carrying capacity and technical flexibility (upgrade). With high-resolution Sony RGB camera, a hyperspectral sensor Ximea MQ022HG-IM-SM5X5-NIR of a spectral range of the 600-975 nm, with 25 spectral bend is provided. Technical and operational characteristics of the hyperspectral sensor were first investigated under laboratory conditions, after which a hyperspectral camera system was developed and assemled on the same aircraft.

**Figure 18.** DJI Matrice 600 ProRange multirotor aircraft

### *6.1.3 ANAFI small multirotor aircraft*

In the scope of the project REDFAITH a practical and easily transferable multirotor aircraft „ANAFI Extended" (Figure 19.) was also purchased. That part of the equipment is purchased as a help for planning a flight missions (through the previous reconnaissance flight missions), but also as the equipment which will in future serve customers for quick insights and recognising the conditions on the field.


**Figure 19.** „ANAFI Extended" multirotor aircraft

### *6.1.4 Software for processing of data collected by airborne imaging – Pix4Dmapper*

For the purpose of project-related processing of data collected by unmanned aircrafts, a Pix4Dmapper programme package has been purchased. It is one of the leading photogrammetric programme packages characterized by a relatively simple and user-friendly interface, and very powerful and highly optimized algorithms.

Those algorithms take advantage of the principles of stereoscopic photogrammetry, which enable the programme to simultaneously define camera internal and external orientation parameters and reconstruct the recorded area geometry based on the images. Typical results of such a procedure are as follows: a) digital orthophoto and b) digital surface model (from a key point cloud).

## 6.2 Evaluation of collected data for monitoring of forest ecosystems

The following sections of this chapter present the most important parts of the research conducted in which the results obtained can be incorporated into the future operations of Hrvatske šume Ltd.

### *6.2.1 Assesment of harvested timber*

Recording was conducted on the felling area of MU Darđanske šume, compartment/subcompartment 26c (Figures 20. and 21.). Before recording, the felled trees were marked with a number (spray) and their cross-section was measured at the midpoint of the log (see Figure 21.), as in-field piece of data for the purpose of result verification. The recording was carried out from three height levels (50, 85 and 100 m AGL), which has (with the 40MP resolution of the RGB camera) resulted in extremely large areal resolution of the images (approx. 0.4, 0.7 and 1 cm).

**Figure 20.** Georeferenced high-resolution (0.4 cm per pixel) RGB image mosaic of the felling area

At such large resolutions, georeferencing and correct scaling has turned out to be a relatively large issue (in absence of control points at known locations), which has subsequently been rectified through the use of images with an unmanned aerial vehicle (which were independently recorded and georeferenced) Understood defining known points in those images. Pix4D software was used to calculate (from overlaps of adjacent images) the heights of all pixels (with the resolutions listed above), which has resulted in a very detailed digital terrain model which precisely represents the areas of the logs, even the surrounding branches (Fig. 22).


**Figure 21.** Details from Figure 20.

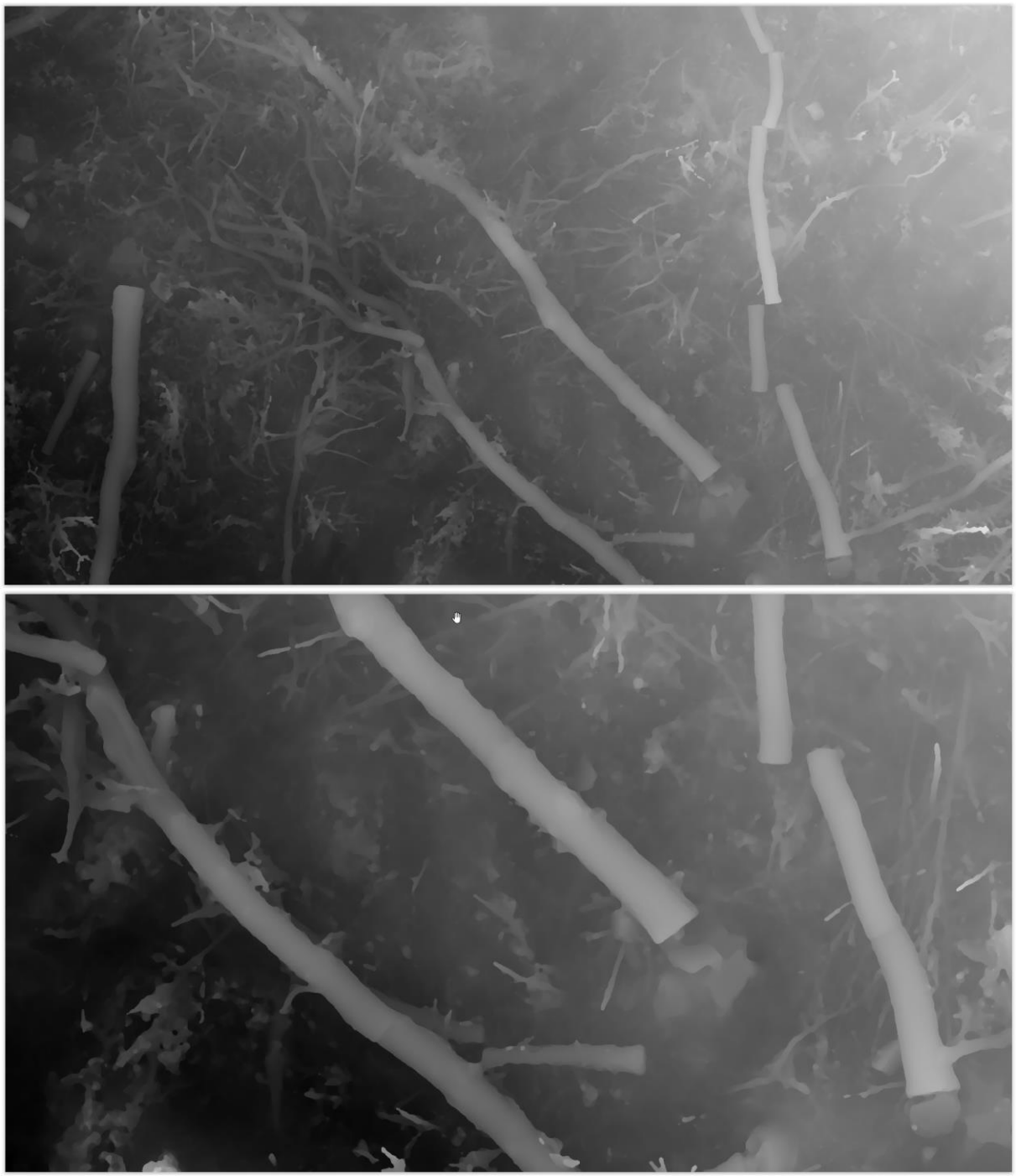


**Figure 22.** A high-resolution digital terrain model (lighter areas – higher), for segments of the recorded area depicted on Image

The detailed digital model was taken as a baseline for a geoinformatic analysis which encompassed the development of original code adapted for that specific purpose (measurement of separate logs based on data gathered through the unmanned aerial vehicles). The code encompasses:

1. Automatic recognition of logs on the ground (after manual definition of the axis of the log; Figure 23.),
2. Automatic segmentation of logs according to arbitrary steps along the axis of the log,

3. Automatic measurement of cross-section of the log at every section along the axis of the log (Figure 24.),
4. Automatic processing of data from all sections of the log and calculation of the volume of the log (along other desired parameters).

**Figure 23.** Recorded logs with subsequent manually defined axes (red lines)

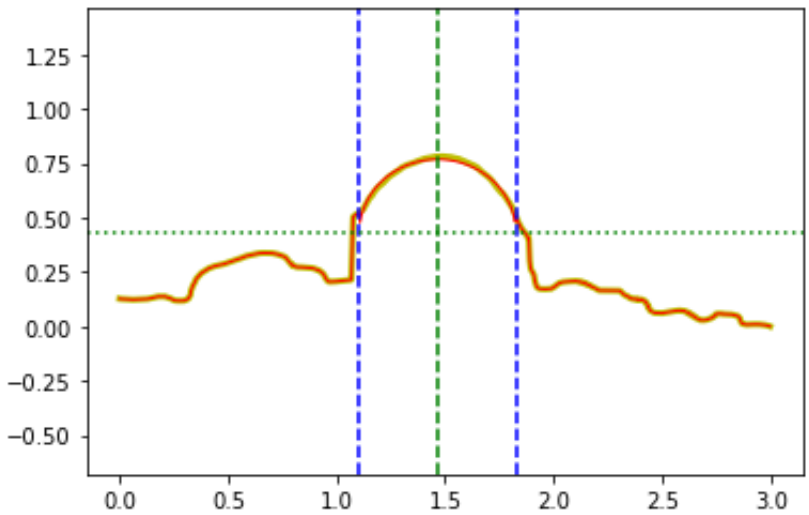



**Figure 24.** Graphical overview of a cross-section of a log as transect in a digital terrain model perpendicular to the axis of the log (in one of the sections along the axis of the log)

Measuring the logs in this manner gives results that are very close to in-field estimates (via the cross-section diameter at breast heights at the middle of the log applied to volume of a cylinder), and it is entirely possible that results obtained in this manner are even more correct than in-field results (especially in cases of logs with irregular shape).

### *6.2.2 Forest health status assessment and monitoring*

Testing this monitoring type is of the most significance within the REDFAITH project given that all other monitoring types possess a methodological alternative in field sampling. Forest tree health status inventorying (and the related concerns such as pests and diseases, the effect of air pollution etc.) has no such alternative (or at its best has one that is highly limited in terms of temporal and spatial resolution). Concurrently, concerns related to forest health status represent the major challenges of modern forestry, especially in terms of climate change and the new pest and disease emergence, all of which combined call for robust, efficient and precise inventorying methods required to cover large surface areas while keeping a high spatial and temporal resolution.

This module was essentially an attempt to inventory a forest tree pest or disease outbreak within the studied area. Unlike other monitoring types, the testing of this type could not have been planned, but rather required anticipating the right time over the course of the project duration. This took place in the summer of 2019, when the pedunculate oak stands in numerous compartments/sub-compartments over multiple MUs saw a large outbreak of the oak lace bug (Corythucha arcuata) that had become a major threat to the protection of forests in Croatia in the recent years. Coincidentally, the affected areas were imaged in August 2019 as part of entire area imaging of MU Haljevo – Kozaračka šuma, MU Darđanska šuma and MU Dvorac Siget. Thusly obtained imaging data was then used for comparative imaging during the oak lace bug outbreak, as well as for the subsequent comparison of the two sets of imaging data. Figure 25. shows RGB images of parts of MU Haljevo – Kozaračka šuma that were under major attack during the second imaging survey. To analyze the data obtained from multispectral imaging of said parts, the following vegetation indexes were calculated for each pixel (30 x 30 cm) of each compartment/sub-compartment:

1. GNDVI (Green Normalized Difference Vegetation Index) per the formula: (NIR − GREEN) / (NIR + GREEN)
2. LCI (Leaf Chlorophyll Index) per the formula: (NIR − REDEDGE) / (NIR + RED)
3. NDRE (Normalized Difference Red Edge) per the formula: (NIR − REDEDGE) / (NIR + REDEDGE)
4. NDVI (Normalized Difference Vegetation Index) per the formula: (NIR − RED) / (NIR + RED)
5. SIPI2 (Structure Intensive Pigment Index 2) per the formula: (NIR − GREEN) / (NIR − RED)

The distribution of vegetation indices prior to and during the peak oak lace bug ravage are available for 4 sections of Management Unit Haljevo Kozaračke šume (78b, 81a, 82a and 83a subcompartments) in which common oak is the predominant species (Figure 26.).

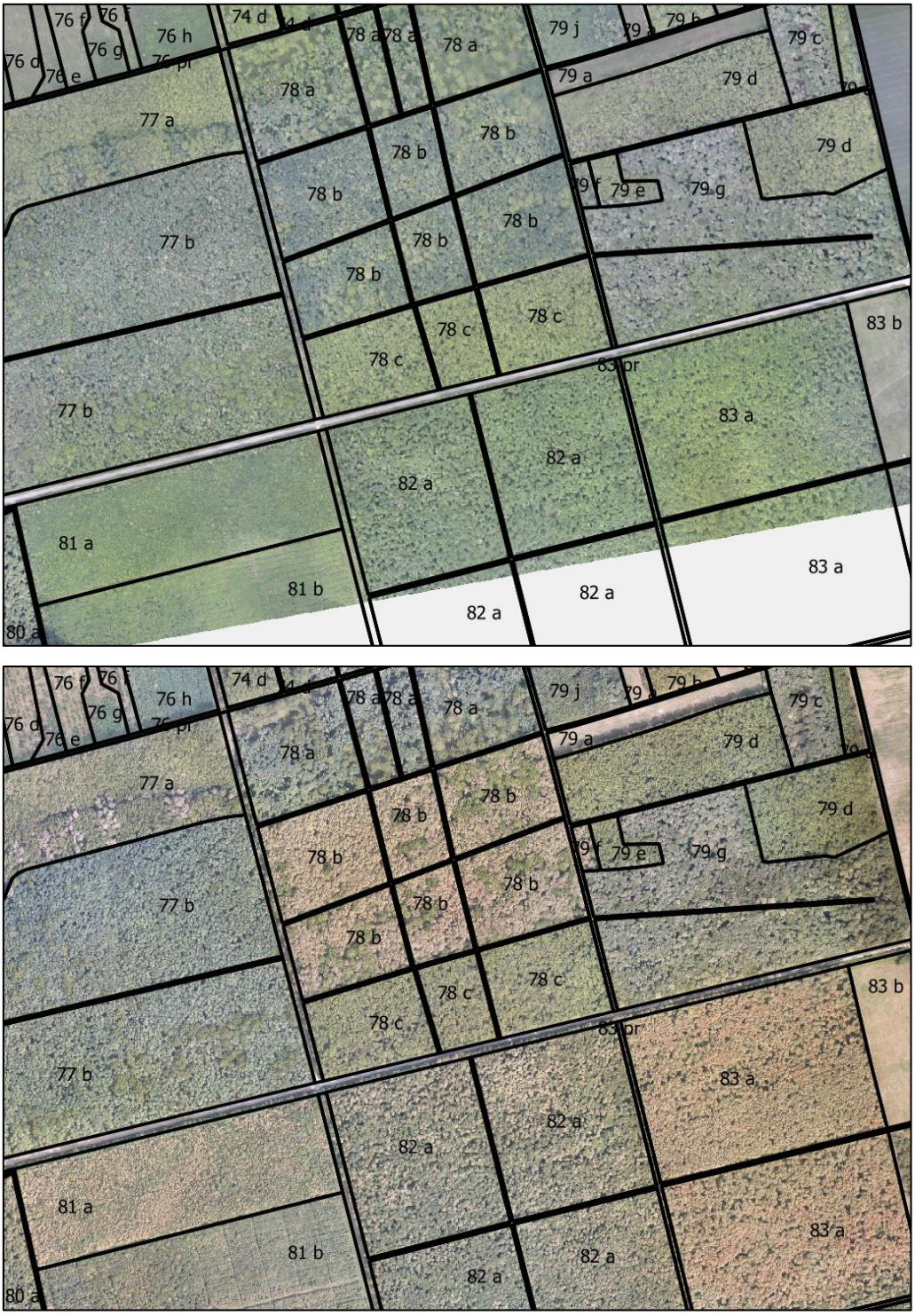



**Figure 25.** RGB camera images of part of Management Unit Haljevo Kozaračke šume. Above – June 2019 (before the oak lace bug attack); below – August 2019, in sections 78b, 81a, 82a and 83a subcompartments, in which the predominant species is common oak

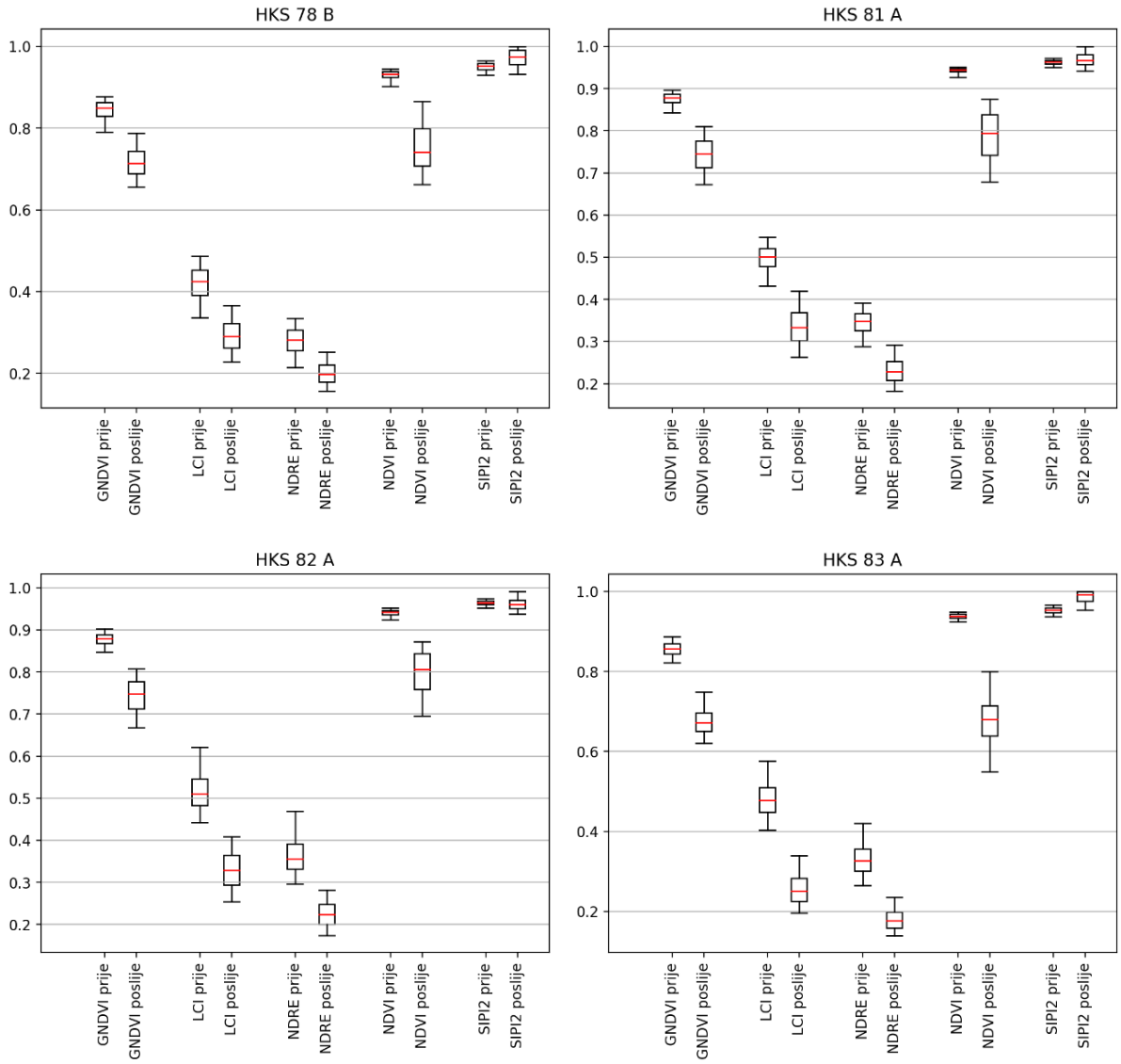



**Figure 26.** The distribution of vegetation indices (Bow-Whisker plots) prior to and during the peak oak lace bug ravage are available for 4 sections of Management Unit Haljevo Kozaračke šume (78b, 81a, 82a and 83a) in which common oak is the predominant species

The results indicate that even before the attack it was possible to indicate where it would be stronger and where it would be weaker. UAV imaging has proven as extraordinarily useful in monitoring forest health status. In a practical example, the equipment procured under the RED FAITH project (and subsequently used for data collection employed in processing within this subchapter) allows Hrvatske šume Ltd. to carry out similar imaging surveys on a weekly basis over large areas (hundreds of hectares). This ensures continued monitoring of the forest health status, early detection of pest outbreak, disease emergence and similar.

### 6.2.3 Mapping of the spatial distribution of target tree species

The primary goal of the procedure was to reveal spectral reflexion variabilities for target tree species (trees, bushes or herbaceous plants). Hence, polygons („region of interest" – ROI) with only one tree species (or only collectively „bushes" or „herbaceous plants") were remotely (from the office) and directly (on-the-spot by an expert) delineated. After that, descriptive statistical processing of spectral reflexion values was carried out for all spectral bands and all pixels belonging to a polygon (homogenous and monodominant with respect to tree species structure).

The first part of the analysis did not result in identification of differences in spectral reflexion between different tree species, which brought to the assumption that the original spectral reflexion values measured by a sensor in all spectral bands were for the most part affected by background illumination (which completely dominated in total reflexion for all 25 spectral bands). Therefore, those original data were subject to modification in a way that 25 hyperspectral bands recorded on-the-spot

a) *were first subject to leading PCA component analysis which led to the conclusion that the background illumination reflexion appears to be the first (dominant) component, after which.*
b) *its values were reduced to zero in all spectral bands and then.*
c) *all the other components (along with the standardized first component) were transformed back into the original area of the 25 hyperspectral bands (reverse PCA).*

The obtained results are shown in Figures 27. (for the data group relating to reforestation success) and 28. (for the data group relating to reforestation success) for every tree species (or collectively defined for herbaceous plants and/or bushes) respectively, and on Figures 29. (reforestation) and 30. (reforestation) comparatively for all species.

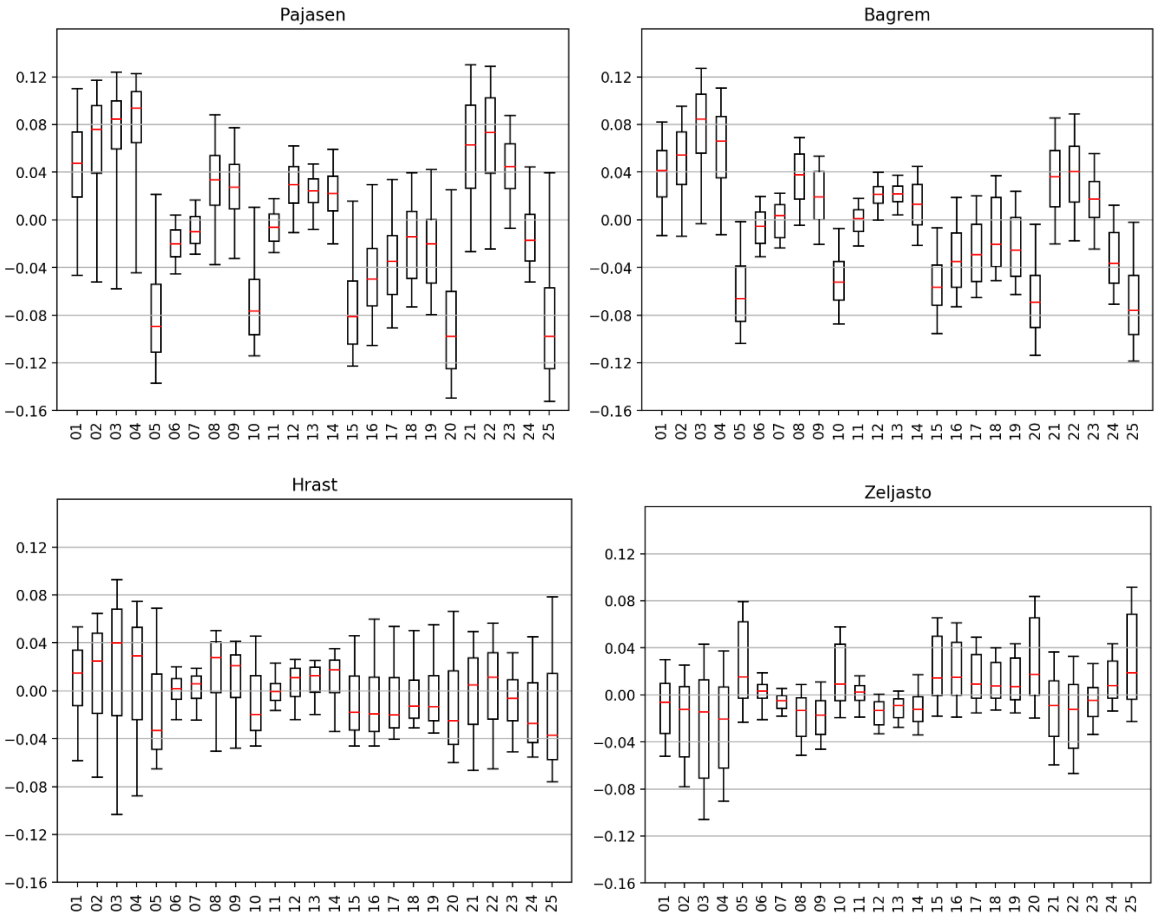



**Figure 27.** Representation of reflectance value in individual bands for three tree species and (collectively defined) bushes in MU Haljevo-Kozaračka šuma section 73a. The red lines represent the median value in a single band (through all pixels in a set and predefined area). The rectangles represent the interquartile range of said values. The ends of lines represent the 5% and 95% percentile of said values.

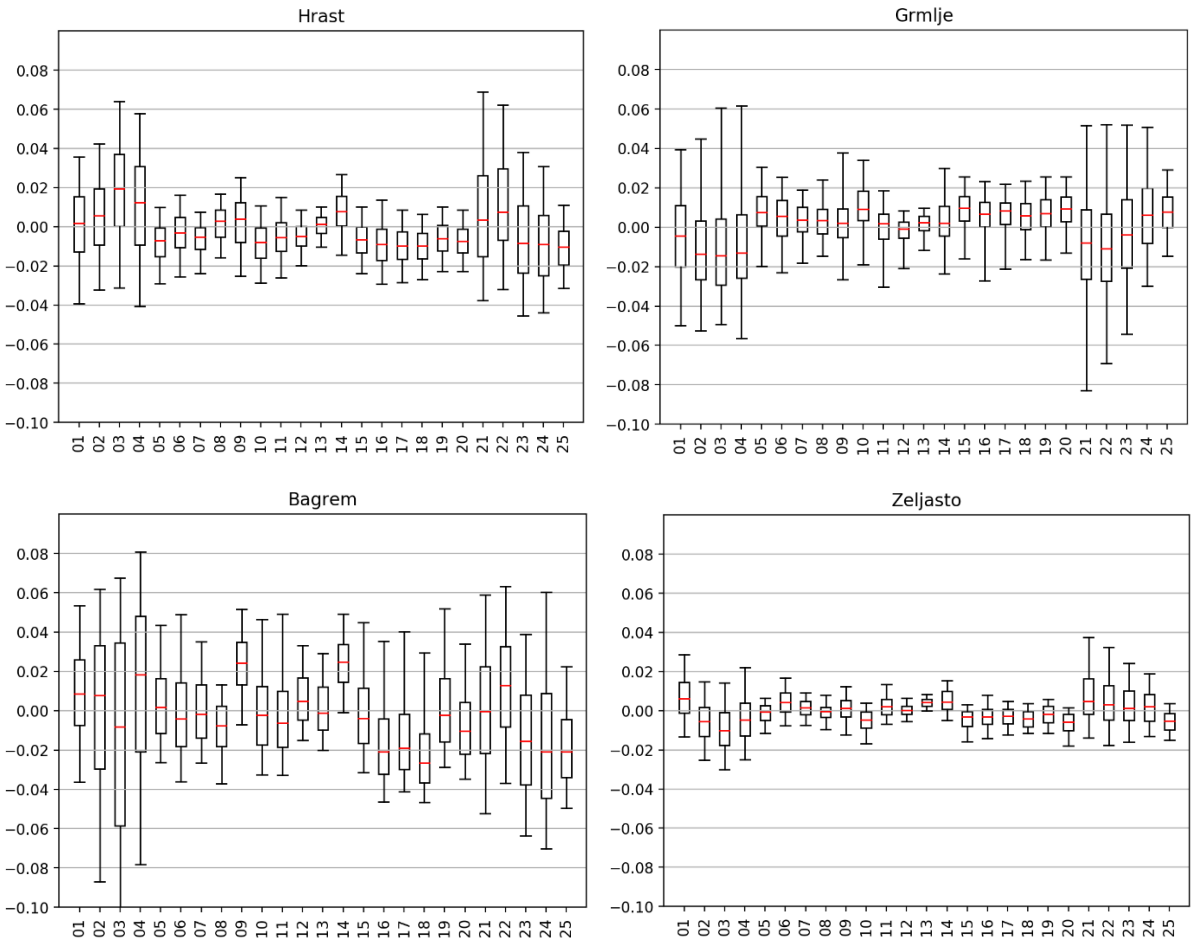



**Figure 28.** Representation of standardized spectral reflectance values (y-axis) obtained by reverse PCS (see text) in particular bands (x-axis) for two tree species (collectively defined), bushes and herbaceous plants in MU Dvorac Siget section 73a. The red lines represent the median value in a single band (through all pixels in a set and predefined area) while the rectangles represent the interquartile range of said values. The ends of lines represent the 5% and 95% percentile of said values.

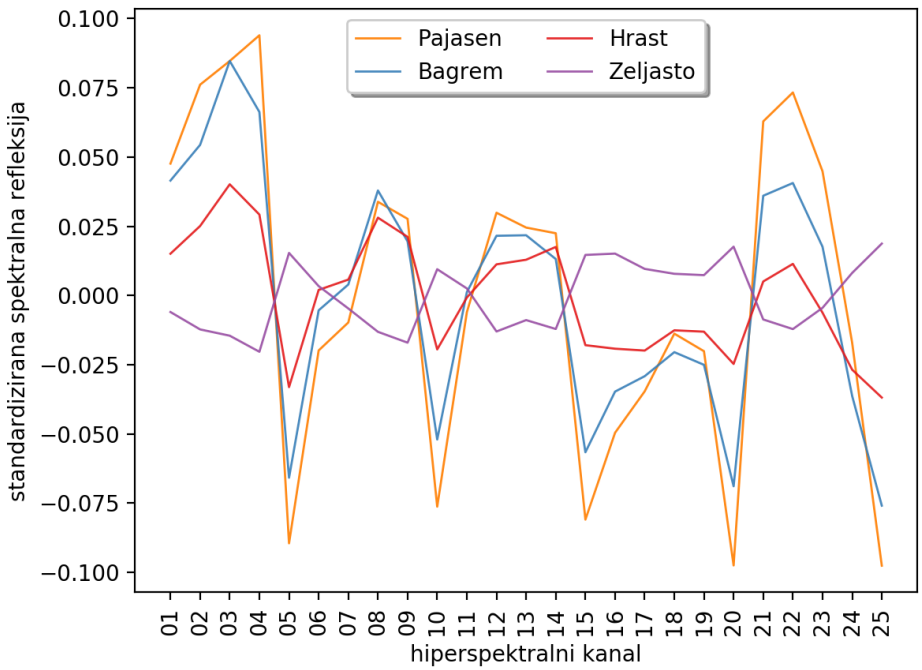



**Figure 29.** Representation of standardized spectral reflectance median (red lines in Figure 27.) values (y-axis) obtained by reverse PCS (see text) in particular bands (x-axis) for three tree species (collectively defined) and herbaceous plants in MU Dvorac Siget section 24b (reforestation success).

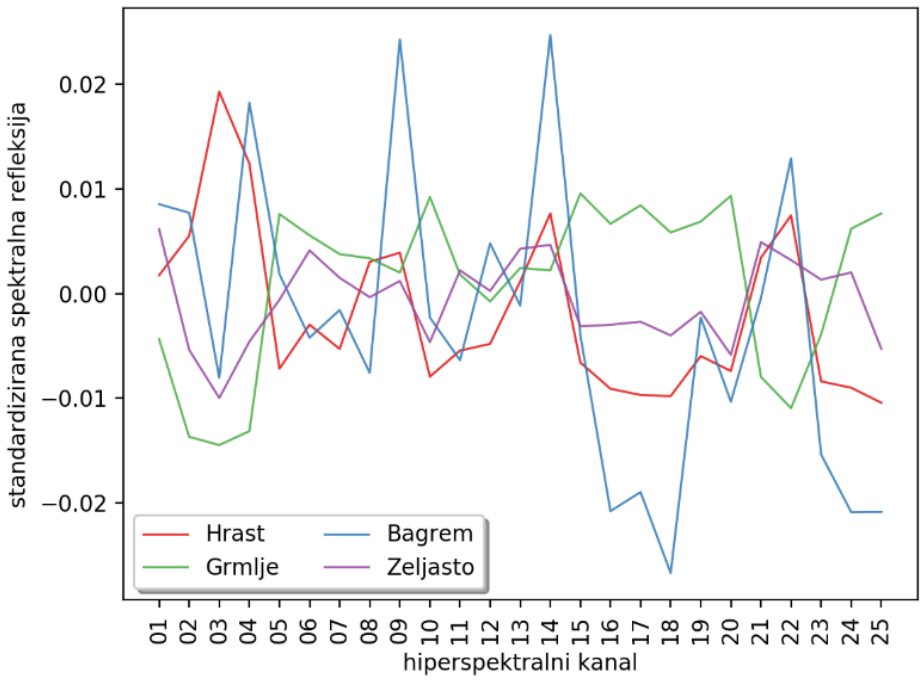



**Figure 30.** Representation of standardized spectral reflectance median (red lines in Figure 28.) values (y-axis) obtained by reverse PCS (see text) in particular bands (x-axis) for two tree species (collectively defined), bushes and herbaceous plants in MU Dvorac Siget department 18a (reforestation success).

Visual inspection of the data presented in Figures 29. and 30. indicates considerable differences in spectral reflectance between different tree species (trees; and collectively defined herbaceous plants and bushes). Overall, this subchapter highlights that the technologies applied within the RED FAITH project are definitely applicable in mapping the spatial distribution of different tree species. The subsequent step would require more intensive research (that would include: a) more extensive field sampling of tree positions considering their species, age and habitat rating, and b) recurring imaging during the growing season) with a view to develop classification models (algorithms) for individual tree species that would be applicable in mapping larger areas (e.g. for detection of present invasive species, for precise mixture ratio calculation etc.).

## 6.3 Hrvatske šume Ltd. staff training

Within the RED FAITH project, training was provided to the Contracting Authority in the following stages (and dynamic):

1. Training select Contracting Authority's (CA) employees for piloting fixed wing-type UAVs (flight planning, conducting flight operations, multispectral and RGB camera imaging, data storing): October, 2018
2. Training select CA employees for piloting multicopter-type UAVs (flight planning, conducting flight operations, RGB camera imaging, data storing): January, 2019
3. Training select CA employees for using specialized software for UAV imaging data processing (image geo-referencing and orthorectification, digital terrain model and digital orthophoto generation, measuring distance, height and volume in images, image classification): December, 2018 (basic functionalities; linking with HŠ fund data); June, 2019 (mosaic generation, geo-referencing); September 2019 (exchanging data with other software; as part of the QGIS software training)
4. Training select CA employees for piloting multicopter-type UAVs for hyperspectral imaging: September, 2019
5. Training select CA employees on principles of complex types of data processing (using the collected aerial multi- and hyperspectral data) that were not among the functionalities of the specialized data processing software procured under the RED FAITH project: September, 2019 (as part of the QGIS software training)
6. Informing CA employees of conducted project activities and obtained results (especially with respect to the applicability and limitations of UAV remote surveying in forestry): end September, 2019

Apart from the above periods, training related to software use as well as data storing, organization and exchange was held as needed continuously throughout the project (through exchange of information and providing advice via telephone and the Internet).

Final training in that thematic section was held as a QGIS software workshop (related to remote surveying in forestry) seeing as how it proved necessary to complete the production process circle from UAV surveying to processing and interpretation of images. The workshop was held from September 2 to September 4, 2019 at the Tikveš-Bilje Forestry Branch premises in Bilje.

Within the RED FAITH project, the following handbooks were prepared:

1. Instructions for Performing Flight Operations with an eBee SenseFly Unmanned Aerial Vehicle and a Multispectral Camera for the Purpose of Terrain Mapping (with a checklist prior to the flight),
2. Instructions for Performing Flight Operations with a DJI Matrice 600 Multicopter and an RGB Hyperspectral Camera for the Purpose of Terrain Mapping (with a checklist prior to the flight),
3. Instructions for Performing Flight Operations with a Parrot ANAFI Multicopter for the Purpose of Terrain Mapping (with a checklist prior to the flight),
4. Instructions for Processing of Data Collected by Pix4Dmapper Programme Remote Sensing

# 7 Action plan

## 7.1 Goals for the future

Horizontal objective (objective to be taken into account when implementing operational objectives):

*Ensure consistency with nature conservation priorities and objectives*

Operational objectives

1. Reduce the spread of invasive plants.
2. Preservation of the habitats of native tree species.
3. Monitoring the occurrence and extent of native tree species and invasive tree species.
4. Supporting the management of temporary and permanent forests
5. Achieving the extension of aerial surveys to the forest areas of Mecsekerdő Forestry Co. Ltd. and Hrvatske šume Ltd. outside the RED FAITH project and to the Croatian-Hungarian cross-border forest areas
6. Contribution to the preparation of NATURA 2000 management plans

## 7.2 Further potential in remote sensing data generated in frame of the RED FAITH project

The main objective of the project was to detect invasive tree species at the individual level, which was implemented by the contractor by guided image classification of noise-filtered, feature extraction channels of hyperspectral data.

Due to the narrow spectral sampling of the hyperspectral data (2.5 nm), it is suitable for the calculation of narrow band biophysical indices. The reflected and detected spectra are formed by the leaves of the plants in a given pixel and the soil (if visible), so certain wavelength ranges are also suitable for examining the health of vegetation and various stress effects.

Vegetation indices can be divided into two major groups:

1. Distance-based indices: sum or difference indices, described as a linear combination of one or more narrow spectral bands, e.g.: GVI, PVI
2. Slope-based indices: quotient type vegetation indices, e.g.: NDVI, ARVI, etc.

Baret és Guyot. 1991.

The red and near infrared channels of the spectral range are typically used to determine the amount of photosynthetically active plant parts. Such indices show a high correlation with the amount of biomass.

The indices characterizing the biophysical variables of woody plants are summarized in Table 12.

**Table 12.** Specific vegetation indices of tree species

| Index name | Characteristic | Formula, wavelength | Source |
|---|---|---|---|
| Modified normalized difference vegetation index (MNDVI) | Correlated to green biomass and chlorophyll abundance | (ρ769-ρ762)/(ρ796+ρ762) | Fuentes et al., 2001 |
| Pigment index (PI) | Correlated to pigment abundance | ρ757/ρ672 | Underwood et al., 2003 |
| Modified chlorophyll absorption in reflectance index (MCARI) | Correlated to chlorophyll abundance | [(ρ697−ρ672) −0.2∗(ρ697− ρ552)]∗(ρ697/ ρ672) | Daughtry et al., 2000 |
| Anthocyanin index (AI) | Correlated to anthocyanin abundance | ρ672/ρ511 | Gamon – Surfus., 1999 |
| Photochemical reflectance index (PRI) | Correlated to xanthophylls abundance | (ρ552−ρ531)/ (ρ552+ρ531) | Gamon et al., 1992 |
| Red edge position (REP) | Correlated to chlorophyll and stress factors | 700+400[((ρ670+ρ780)/2)-ρ700)/(ρ740+ρ700)] | Vogelmann., 1993 |

| | | | |
|---|---|---|---|
| Red-edge spectral parameters (mean, variance, skewness, kurtosis, and integral of first-order derivative curve) | Quantifies shapes of reflectance spectral curves; insensitive to illumination variation | ρ651 ~ ρ761 | Elvidge – Chen., 1995 |
| Green-peak spectral parameters (mean, variance, skewness, kurtosis, and integral) | Quantifies shapes of reflectance spectral curves at green-peak spectral region; insensitive to illumination variation | ρ454 ~ ρ676 | Portigal et al., 1997 |

Source: Hamada et al., 2007

In addition to the biophysical indices listed in the table, many indices concern to plant biophysical status have already been developed and are well applicable in certain areas and plants. In addition, certain areas of the available wavelength range (400-1000nm) may be suitable for detecting site-specific plant lesions, diseases, and stress effects, but this process requires further research and development.

Due to the extensive information content of the hyperspectral image about the RED FAITH project area during the summer (leaf-on) period in 2018, it is possible to study the biophysical basic status of the population forming and native tree species by means of vegetation indices.

In addition, the high point density (minimum 18 points/m$^2$) laser point cloud is a good basis for calculating LiDAR metrical indicators. These raster layers contain statistical indicators calculated for certain points within the search range (e.g. standard deviation, range, minimum, maximum, variance, entropy, percentiles, etc.), which are suitable for the mapping of each population type, stock closure, second canopy level and undergrowth density. Supplementing the spectral information from the hyperspectral survey with the LiDAR metrical indicators of forest areas, the reliability of tree species identification can be increased further, and areas can be localized where image analysis may be problematic (e.g.: dense undergrowth, young stands, etc.). The differentiation of tree species can be further clarified by involving forest population data in the analysis. The essence of this is that if the tree species are known in a given area and their number does not exceed 3-4 species, then the spatial distribution, location and proportion of tree species within the area can be determined with good hit accuracy.

The point cloud origin from the laser survey of the leafless period also contains information about the geometric indicator of each tree in the population (e.g.: height, canopy diameter, surface, stems position, etc.).

## 7.3 Activities

The RED FAITH Action Plan can be developed if it is harmonized with the future goals. Accordingly, the parts and activities of the Action Plan is described with steps needed to realize future horizontal and operative goals.

| **Operational objectives** | **Main activities** | **Support activities** |
|---|---|---|
| *Ensure consistency with nature conservation priorities and objectives* | | |
| *1. Reduce the spreading of invasive plants* | Development and application of an innovative thinning methodology of invasive species based on remote sensing data | Pilot test of UAV based precision spraying methods<br>Implementation of test results into traditional forest protection planning |
| *2. Preservation of the habitats of native tree species* | Health condition analysis of native tree species based on aerial hyperspectral data<br><br>Monitoring the changes of habitat condition based on aerial remote sensing data | Applicability of hyperspectral biophysical indices to map the actual health condition of forest stands<br><br>UAV based large resolution assessments of critical sites and calculation of biophysical indices for change-explorations<br><br>Three yearly aerial assessment of the RED FAITH project area with hyperspectral technology and LiDAR |

| | | |
|---|---|---|
| *3.* Monitoring the occurrence and extent of native tree species and invasive tree species. | Follow-up of the efficiency of innovative clearing methods with aerial technologies<br><br>Growth dynamics modelling for native and non-native tree species based on LiDAR data | Analysis of clearing efficiency of small areas and infection outbreaks with multispectral UAV images<br><br>Three yearly aerial assessment of the RED FAITH project area with hyperspectral technology and LiDAR |
| 4. Supporting the management of temporary and permanent forests | Monitoring the impact of logging interventions on stock structure diversity, closure and living stock. | Monitoring the changes caused by interventions and forest stand increment based on the evaluation of periodic aerial assessments |
| *5. Achieving the extension of aerial surveys to the forest areas of Mecsekerdő Forestry Co. Ltd. and Hrvatske šume Ltd. outside the RED FAITH project and to the Croatian-Hungarian cross-border forest areas* | Finding funding and financial sources to plan and realize further assessments<br><br>Planning and realization activities | Continuous monitoring of national and cross-border funding and other financial opportunities<br><br>Setting of necessary planning and service providing activities for accessing funds |
| *6. Contribution to the preparation of NATURA 2000 management plans* | Innovative forest management planning based on remote sensing data | Base the 10 year periodic regional forestry planning on remote sensing data |

| | | |
|---|---|---|
| | Accurate mapping of invasive threats, more effective estimation of the natural values of the area, more accurate definition of living trees and lying dead wood<br><br>Stronger collaboration with the competent National Park Directorate to manage the given NATURA 2000 sites | Contact with the responsible persons of the competent National Park Directorate |

## 7.4 Detailed description of the activities

### *7.4.1 Development and application of an innovative thinning methodology of invasive species based on remote sensing data*

**Pilot test of UAV based precision spraying methods**

In many cases, invasive tree species are dispersed in forest stands. The clearing of these individuals needs large human resources and use of traditional methods are limited. Using remote sensing data, the exact position of the invasive tree individuals can be determined, which can be implemented to the controlling system of spraying UAVs available on the market. These copters can access invasive tree individuals easily and can utilize targeted spraying. The aim of this activity to test and evaluate the methodology described above through a pilot study. The method must be tested in young stands either if invasive species are dispersed, or if they cover larger areas in the stand. During the pilot the spraying potential of the UAV, the spread pattern, the spraying accuracy, the size of the covered area considering speed and pesticide concentration must be examined. The results of the pilot study are the documentation the methodology and the test reports, which involves the efficiency of the method.

**Implementation of test results into traditional forest protection planning**

Based on the test reports, the applicability of UAV based precision spraying during traditional thinning procedures must be analysed. Those crucial points must be determined, where the technology can effectively support the reduction of invasive species mitigation.

### 7.4.2 Health condition analysis of native tree species based on aerial hyperspectral data

**Applicability of hyperspectral biophysical indices to map the actual health condition of forest stands**

The aim of the activity is to analyse biophysical indices derived from aerial hyperspectral data assessed in 2018 summer (leaf-on) period. The large-scale spectral information is applicable to analyse the actual health condition of the investigated project area. With field reference measurements in areas with low photosynthetical activity the hyperspectral data can be validated and quantified. The result of the activity is a thematic map of the actual health condition of the project area. The produced thematic database is suitable for the indirect analysis of habitat quality and for the identification of stress factors as well.

### 7.4.3 Monitoring the changes of habitat condition based on aerial remote sensing data

**UAV based large resolution assessments of critical sites and calculation of biophysical indices for change-explorations**

The aim of the activity is to monitor critical sites – identified during the analysis of the actual health condition of the project area – with UAVs equipped with multispectral camera system. The advantage of the technology that we can produce time-series data during the vegetation period with multiple assessments. The red and near infrared bands of the multispectral sensor are suitable to generate biophysical indices and compare with the health condition map derived from the hyperspectral data. Furthermore, using time series data the condition of forest stands can be monitored through the whole vegetation period, the appearance of stress factors and their effects can be identified (drought, heat, absence of precipitation, pests, etc.) The results of the activity are time series vegetation indices and health condition analyses.

**Three yearly aerial assessment of the RED FAITH project area with hyperspectral technology and LiDAR**

During the project, a detailed remote sensing database with large information content was produced which gives a basis for several further generated information, analyses, models and calculations (e.g. digital terrain model, digital surface model, tree species map, biomass map, etc.). For the monitoring of the changes of forest stands and for a more detailed analysis of invasive tree species mitigation and spread multisensory remote sensing (laser scanning and hyperspectral) assessments are recommended in every third year. The result of the activity is a three yearly reproduced and updated remote sensing database of the project area.

### 7.4.4 Follow-up of the efficiency of innovative clearing methods with aerial technologies

**Analysis of clearing efficiency of small areas and infection outbreaks with multispectral UAV images**

The aim of the activity is the follow-up of infection outbreaks – identified with remote sensing data process – and pilot sites of precision UAV based spraying with multispectral UAV images. By the supervised classification of multispectral images, tree species and habitats of test sites can be separated, the mitigation of invasive tree species can be monitored. The results of the activity are the time series, large resolution multispectral data and derived invasive spread maps and maps of indices evaluating the efficiency of thinning and clearing.

### 7.4.5 Growth dynamics modelling for native and non-native tree species based on LiDAR data

**Three yearly aerial assessment of the RED FAITH project area with hyperspectral technology and LiDAR**

The aim of this activity is the repetition of aerial assessments with same parameters in every third year. Based on the geometry data of the forest stand - derived from the repeated LiDAR assessments - and the habitat classes - generated through the data process of hyperspectral data – the growth of forest stands can be modelled either in sub-compartment or individual tree level. Accordingly, the distribution and area of invasive and native species can be estimated as well. The result of the activity is a map of sub-compartment level forest stand increment.

### 7.4.6 Supporting the management of temporary and permanent forests

**Monitoring the changes caused by interventions and forest stand increment based on the evaluation of periodic aerial assessments**

Long term management plans are formed for temporary and permanent forest sub-compartments which determine the vision of the given area, species constitution, structural conditions and the number and measure of interventions and actions. The common characteristic of the aims is the heterogenic composition of the stand, in which field measurements are time consuming and cannot be realized with the needed precision because of the closed vegetation. In these circumstances, aerial remote sensing is very useful, results quantified data to manage forest stands which sets the basis of credible and reasoned forest planning and management.

### 7.4.7 Finding funding and financial sources to plan and realize further assessments

**Continuous monitoring of national and cross-border funding and other financial opportunities**

The aim of the activity is to expand the multisensory remote sensing assessments to the whole area of Mecsekerdő Forestry Co. Ltd. The planning and realization unit costs are relatively small considering the large information content but the total costs because of the large size of the area are high. This indicates the need for various funding sources that support the realization of the aerial assessments. Cross-border funding and cooperation opportunities must be prioritized as well as the cooperation of various experts. Projects must meet with the requirements of environmental protection goals and steps for adapting to the negative effects of the climate change.

### 7.4.8 Planning and realization activities

**Setting of necessary planning and service providing activities for accessing funds**

The aim of this activity to select the appropriate key personnel, organizations and service providers for planning and coordination activities needed to expand the assessments. The tasks of selected organizations are to monitor the actual and available calls, communication among participating parties, project development, planning the technical and realization parameters of assessments.

### 7.4.9 Innovative forest management planning based on remote sensing data

**Base the 10 years periodic regional forestry planning on remote sensing data**

The aim of the activity is to involve databases generated during remote sensing assessments and data processes in the procedure of 10 years periodic regional forestry planning. Aerial data is suitable to support management planning for the following reasons:

- tree individual geometry parameters derived from laser scanning (height, canopy diameter, etc.),
- biomass volume,
- tree species classification,
- health condition,
- spread and actual state of invasive species,
- closure.

Further goal of the activity is to define those forest management processes, where remote sensing information can be adapted and implemented to the daily practices routinely.

### *7.4.10 Stronger collaboration with the competent National Park Directorate to manage the given NATURA 2000 sites*

**Contact with the responsible persons of the competent National Park Directorate**

The aims of this activity are to ensure the stronger collaboration between forestry and nature conservation, participate in common projects to fight against the mitigation of invasive species. Furthermore, prepare and expand management plans of NATURA 2000 sites based on remote sensing data. Accordingly, management plans based on remote sensing data are using site specific, up-to-date information and has larger potential to adopt to the negative effects of climate change. The result of the activity is the management plan of the NATURA 2000 sites of the area, which is developed considering the additive information derived from remote sensing data and local characteristics.

# 8 Summary of the plans of Mecsekerdő Forestry Co. Ltd. and Hrvatske Sume Ltd., determine common points and common future goals

During the project, Croatian and Hungarian Forestry's have implemented innovative remote sensing methods and data processing based on aerial remote sensing techniques to map their designated forest areas, with a particular focus on invasive plant detection. Researches applied on the Hungarian and Croatian side to complement each other effectively.

Mecsekerdő Forestry Co. Ltd. has used multisensors of high-area efficiency based on pilot airplane surveys in the field of RED FAITH to perform aerial laser scanning, digital orthophoto and hyperspectral records in leaf-on and leaf-off periods. The primary purpose of this database was to map canopy-based tree species, including the detection of invasive tree species. In addition, the compiled database provides forestry professionals with a wide range of information to obtain more accurate information about forest stands, health status assessments, and dendometric parameters and planning tasks. Aerial remote sensing and data processing were subcontracted, and 2 workshops were held on the scope of the usage of remote sensing information. The sharing of knowledge took place in the framework of a training course, where forestry specialists received extensive and detailed training on the use of information collected by remote sensing and target-specific analysis of the data. With the knowledge gained during the knowledge sharing, the employees of Mecsekerdő Forestry Co. Ltd. can use the remote sensed database information created during the project in accordance with the nature conservation priorities and objectives set out in the action plan, and for the implementation of the goals set in the main and support activities. In addition, the project has proven that forest mapping based on multiple sensors with active and passive remote sensing technologies provide useful information to support forestry activities (inventory, management, planning, utilization, etc.). Therefore, repeating such surveys every 3 years and extending them to forest areas outside the RED

FAITH project and crossing the Croatian-Hungarian border will greatly contribute to mapping the occurrence and extent of native and invasive tree species, as well as to reducing the latter.

The company Hrvatske šume Ltd. has acquired low-altitude UAVs with various sensors as part of the RED FAITH project and has been tested to monitor forest areas in the project. The aerial scanning included RGB, multispectral and hyperspectral cameras mounted on quadcopter and fixed wing unmanned devices. Forestry also acquired software for photogrammetric processing and evaluation of the recorded data. During the project, several UAV surveys were conducted by Hrvatske šume Ltd in selected forest areas to test the applicability of scanning methods. From the data collected and processed with the high-resolution RGB surveys dendometric indices of the harvested trees (eg. height, diameter at breast hight, first branching, etc.) were examined, and the vegetation indices calculated from the multispectral surveys carried out at several time intervals followed the changes in forest health. In addition, spectral separability of the target species was investigated based on hyperspectral data. During the implementation of the project, forestry specialists participated in trainings related to the professional management of quadcopter and fixed wing UAV devices, as well as training in photogrammetric processing and analysis of data with different sensors. The activities carried out in the project have proven that remote sensing activities contribute positively to forestry activities, and UAV aerial photography can be conducted locally in a short period of time, thus providing rapid information on forest areas with limited area performance.

Main goals of the company Hrvatske šume Ltd, connected with the continued activities performed within the project RED FAITH include:

1. Technical equipping for using LiDAR technology in the forest ecosystems monitoring,
2. Adopting the LIDAR technology in the the forest ecosystems monitoring (recording, data analysis and interpretation),
3. Testing of the application of technologies adopted in RED FAITH project, and LiDAR technology in the field of selection and Mediterranean forests in Croatia,
4. Further development of personnel, material and logistic core in the company which will enable forming of the expert team for forest ecosystem monitoring using UAV based remote sensing.

The remote sensing methods carried out by the two forestry's on different platforms complement and support each other well. Aerial surveys based on UAVs can test the applicability of different spectral data and vegetation indices in different forest applications in smaller areas, and then use this information to parameterize and extend the method to hyperspectral surveys to larger, even cross-border areas with aircrafts and pilots.

The multi-sensor survey of Mecsekerdő Forestry Co. Ltd. in the RED FAITH project also supports the main objectives of Hrvatske šume Ltd., based on its experience in processing and analysing LiDAR data. Laser-scanned surveys in leaf-off condition provide detailed dendometric information of standing trees of forests in large areas. This quantitative information can be validated and traced through UAV surveys of harvested forest. Furthermore, the methodology of surveys conducted by Croatian forestry can be used by Hungarian forestry to monitor smaller areas (forest subcompartment).

Forestry-based remote sensing activities in the RED FAITH project and data-driven, goal-based, innovative data analysis and information extraction provide a good basis for future precision forest management. High-level aerial imagery based on accurate location information also contributes to mapping native species of natural forests and detecting unwanted invasive tree species, as well as thinning with precision technologies. The various vegetation indices support the monitoring of forest health, and also identify potential pests, identify intervention points and plan treatments, thereby contributing to the long-term conservation of Natura 2000 sites.

# Annex

Annex 1

## Legend of NATURA 2000 indicator habitats and indicator species (Table 1-6)

**Legend for indicator habitats:**

Representativity: the rate of representativity shows that a habitat type "how typical" is in the area.

A - dominant B – good C – significant representativity

National importance: the proportion of the area covered by the habitat type in relation to the national extent of the habitat type.

significant A - 100 >= p > 15%; B - 15 >= p > 2%; C - 2 >= p > 0% – D non-significant

Representativity for HR sites (Degree of representativity of the habitat type on the site):

A= excellent, B=good, C=significant, D=non-significant

Conservation for HR sites (Degree of conservation of the structure and functions of the natural habitat type): A = excellent conservation, B = good conservation, C = average or reduced conservation

**Legend for the indicator species:**

Habitat type: p – permanent, r – reproduction, w – wintering, c - migratory

Frequency: C – frequent, R – rare, V – very rare, P - present

Population type: A - 100 >= p > 15%; B - 15 >= p > 2%; C - 2 >= p > 0%; D – non-significant

Abundance categories (Cat.) in HR sites: C = common, R = rare, V = very rare, P = present - information is provided if data are deficient (DD) or in addition to population size information

Conservation (Degree of conservation of the features of the habitat which are important for the species concerned and possibilities for restoration)in HR sites: A = excellent conservation, B = good conservation, C = average or reduced conservation

Source: OKIR, 2019; Natura 2000 Standard Data Form

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