Investigation of trees in the Ljubljana Basin, Slovenia

Student resarch report

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Abstract

Slovenia, at the centre of Europe, has the privilege of having almost 60% forest cover on its undulated / diverse surface. Close to home, we measured the height of the trees at 4 different sites in the Ljubljana basin. We used the classical clinometer method and the GLOBE observer app. Both methods are reliable but require a skilled team or individual to exclude subjective error. By surveying the forest and trees at our measurement sites, reviewing the scientific literature and talking to district foresters on the ground, we can confirm that the Ljubljana basin currently has sufficient green areas covered by forest and therefore their quality ecosystem services. However, we must strive to ensure that the vitality of these areas is carefully protected through professional forestry management, as every tree is important for maintaining the balance of the ecosystem, both natural and urban.

1 INTRODUCTION

1.1 PURPOSE:

Our research project is a response to the multi-year "Trees Around the GLOBE" Student Research Campaign. We want to contribute to a greater observation and understanding of the role of forests as well as individual trees. Our school is located in the very centre of the capital of Slovenia, a small country in terms of area and demographics, but with a large forest cover. As everywhere in the world, people are migrating from the countryside to the city. Fortunately, our cities are not so large and we have a relatively good environmental situation. This value is precious but fragile, and we must work to preserve what we have.

We decided to look at the trees where we live. We measured the height of trees at different locations in the Ljubljana basin using a standard clinometer [Figure 1] and the GLOBE app. We wanted to check what trees were near our home, their height and approximate age. The trees are placed in different plant - stands. Forests are temperate deciduous and belong to the Central European region (Figure 7). We measured trees in the forest at the foot of Rašice, on the slopes of Velike Lipljene, in the meadows of the Ljubljana Marshes and in Tivoli Park. We had never observed trees in detail before, so the task presented us with a special challenge. We are aware that comparing the absolute values of our measurements is not comparable on a scientific scale, but it has raised many questions about the importance of trees and forests in our immediate environment.

FIGURE 1 – MEASURING TREE HEIGHT

FIGURE 2 – MEASURING TREE HEIGHT

FIGURE 3 - MEASURING TREE HEIGHT

1.2 ENVIRONMENTAL FUNCTIONS OF FORESTS

A forest is a very complex ecosystem that provides habitat for many species of plants, animals and fungi. A dynamic balance is established between them, ensuring the forest's sustainability. The forest ecosystem has various functions, such as preventing soil erosion, retaining rainwater to prevent flooding downstream and increasing air humidity during periods of drought, trees are large consumers of carbon dioxide and producers of oxygen, a source of timber, provide clean drinking water, and are used for recreation as well as for tourism development. There are 71 native tree species in Slovenian forests (61 deciduous and 10 coniferous), the most common being beech, fir, spruce, oak, pine, maple and ash. Other species are rarer, but their role is nevertheless significant.

Most trees and shrubs in cities or communities are planted to provide beauty or shade. While these are excellent benefits, woody plants serve many other purposes. The benefits of trees can be grouped into social, communal, environmental, and economic categories. Trees alter the environment in which we live by moderating climate, improving air quality, reducing stormwater runoff, and harbouring wildlife. Local climates are moderated from extreme sun, wind, and rain. Radiant energy from the sun is absorbed or deflected by leaves on deciduous trees in the summer and is only filtered by branches of deciduous trees in winter. The larger the tree, the greater the cooling effect. By using trees in the cities, we can moderate the heat-island effect caused by pavement and buildings in commercial areas [1].

Today, city forests are often treated as part of a larger urban and peri-urban green structure. The term ‘urban forest’ has come into wider use. In many cities, woodland plays a very important role, not in the least from a social and cultural perspective, within the overall urban forest and urban landscape [2].

Recently, there has been a surge in so-called "green transition" activities around the world, and especially in the EU. It is right that in the process of education we also learn about modern environmental and social approaches to these new initiatives, which are likely to be important for us in the future.

Nature in Slovenia is among the most diverse in European Union. Generations of Slovenians have managed to preserve our nature to such an extent that more than half of our territory are areas of special interest (56% - Natura 2000, protected areas, natural beauty, etc.) Natura 2000 sites cover about 37% of the country's territory [3].

1.3 HYPOTHESES:

Hypothesis 1: The Ljubljana Basin has sufficient green space for quality ecosystem services.

Hypothesis 2: The average height of trees is approximately the same at all measurement points.

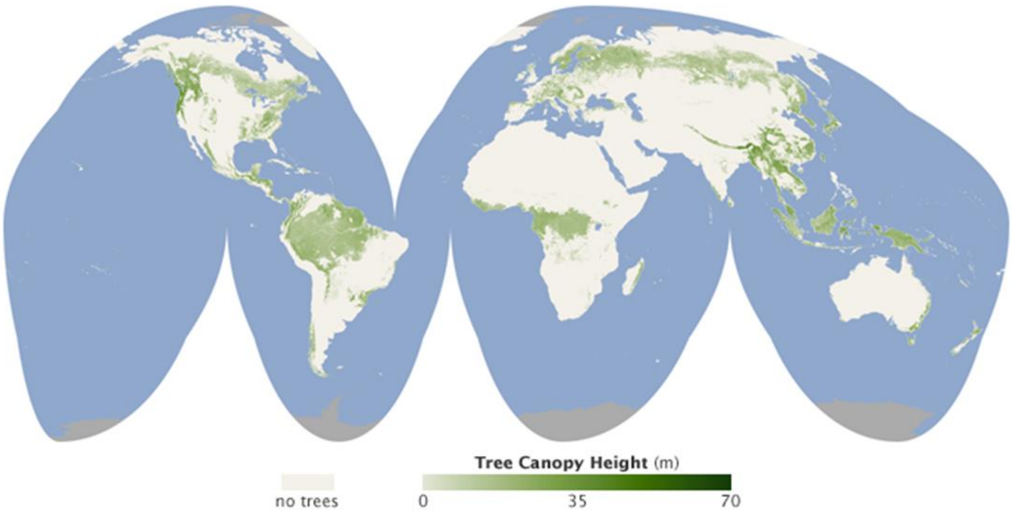
Hypothesis 3: The method of determining tree height with GLOBE Observer is comparable to clinometer measurements.

2 METHODOLOGY

2.1 TREE HEIGHT MEASUREMENT

Before starting to collect measurements, we considered four different methods to measure the height of the trees: clinometer, altimeter, satellite and the Globe observer app. The height of the world's forests range from over 40 meters to under 20 metres (Figure 4).

Satellite data has revolutionized how we view our planet and how we collect data about it. Modern satellite technology allows us to measure and map the earth's geographical features in incredible detail, and tree measurement is not left out. Satellite data can be used to derive forest canopy height and structure, among other things. Forest canopies are an essential parameter for the estimation of forest ecosystems' carbon stocks, and satellite data provides a cost-effective remote sensing approach for estimating forest canopy height. The information from satellites is then used to estimate biomass at large scales, and the data can also be used to identify changes in forest canopies over time.



The height of the world's forests range from over 40 meters in the U.S. Pacific Northwest, to just under 20 meters for the boreal forests that ring the Arctic. In this map, darker green relates to taller forests. [NASA Earth Observatory map by Jesse Allen & Robert Simmon, using data from Michael Lefsky, Colorado State University].

SEEING FORESTS FOR THE TREES AND THE CARBON: MAPPING THE WORLD'S FORESTS IN THREE DIMENSIONS (NASA.GOV)

FIGURE 4 - MAPPING THE WORLD'S FOREST

The Globe Observer Application is a citizen science program that enables citizens to collect environmental data using their smartphones. The application is used to collect data on essential environmental factors such as the atmosphere, clouds, water, and land. It uses a simple interface that allows users to take pictures and measurements of the environment around them and upload the data to an online database. The application can be used to measure the height of individual trees using the phone's GPS and camera. It provides an opportunity to involve citizens in environmental data collection, making it a cost-effective and efficient way of collecting crucial data. The app makes it very simple to measure trees, you enter your height into the app, and it calculates the length of your stride. Stand about 7-10 metres from the tree you want to measure, take a picture of the top and bottom of the tree, walk to it and enter how many steps it took in the app. The app then calculates the approximate height of the tree.

Altimeters are devices that can measure the height of an object based on differences in air pressure. In forestry, altimeters are used to measure tree height. They are lightweight and easy to use and offer a non-invasive way of measuring the height of trees. The instrument works by measuring the time it takes for a light beam to bounce back from the tree's top to the altimeter.

It provides an accurate measurement of tree height and is often used in conjunction with other measurement tools.

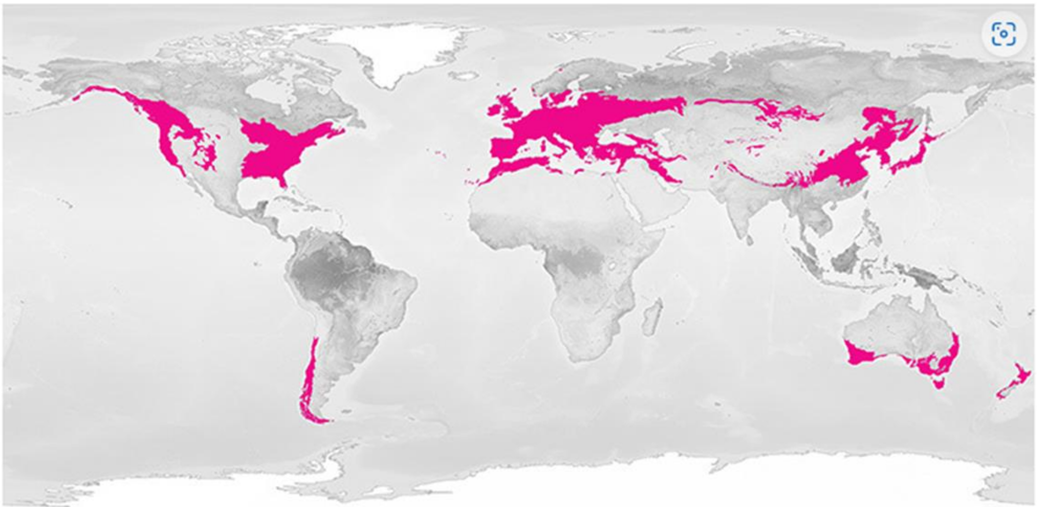
A clinometer is an instrument used to measure the angle of inclination or slope of an object. A clinometer is used to measure the height of a tree indirectly through the height angle and distance to the trunk. The clinometer has been in use for many years, and it is still a popular tool among foresters for measuring tree height. It is a cost-effective tool that is easy to use, but its accuracy depends on the user's skill level.

For our project, we chose to use the clinometer and the Globe observer app as they are the most accessible and easiest to use.

FIGURE 5 - MAP OF EUROPE HIGHLIGHTING SLOVENIA

FIGURE 6 - MAP OF SLOVENIA

We measured trees of our temperate deciduous forests (Abieti-Fagetum dinaricum) - mixed coniferous and deciduous trees.



Eastern United States, Canada, Europe, China, and Japan

[Temperate Deciduous Forest: Mission: Biomes (nasa.gov)]

FIGURE 7 - TEMPERATE DECIDOUS FORESTS (GLOBE / NASA)

2.2 MEASUREMENT SITES

FIGURE 8 - MAP OF THE MEASUREMENT SITES

Site GPS coordinates:

Rašica: 46,1275819° N   14,5037698° E

Tivoli: 46,0529832° N   14,4761568° E

Ljubljana marsh: 46,015993° N   14,4161081°E

Velike Lipljene: 45,902229°N   14,6370953°E

2.2.1 SITE 1: TIVOLI PARK

Our first measurement site was Ljubljana's Tivoli City Park.

Due to urbanisation, there are fewer and fewer green spaces in cities, consequently they are becoming increasingly valuable, as they improve our quality of life.

Our school follows the concepts of Education and training for sustainable development. We built an urban roof garden on the terrace, greened the roof terrace and built a beehive. In our biology lessons, environmental studies and other subjects, we often go to Tivoli, our nearest natural classroom.

Tivoli is Ljubljana's largest park, extending into the city centre. It is located on the western outskirts of the Centre district and stretches as far as Šiška in the north, Vič in the south and Rožnik in the west. It measures approximately 5 km^2. Three avenues divide it into individual units. The park is decorated with many works of art, such as statues and fountains. It was created in 1813, during the Illyrian Provinces, according to a plan by the French engineer J. Blanchard.

Tivoli Park is part of the Tivoli, Rožnik and Šišen hill landscape Park. The decree declaring it a natural landmark date from 1984. Its primary objective is to preserve natural values, biodiversity and landscape diversity.

Since 2016, the park has been managed by the public company Voka Snaga, Tivoli, Rožnik and Šišen hill landscape Park Service.

Tivoli City Park is the most significant green space in the city of Ljubljana. People like to use the parks for various physical activities or mental breaks, and at the same time, it helps to preserve biodiversity in urban areas [4].

FIGURE 9 - MAP OF TIVOLI PARK

FIGURE 10 - MAP OF THE MEASURED TREE LOCATIONS IN TIVOLI PARK

Here you can see the location of all the trees we started observing in Tivoli Park.

In 2020, 2471 trees were recorded in the Tivoli Park tree register. Our selection includes 15 trees.

In January 2023, a tree felling took place at Rožnik hill, which is part of Tivoli Park. The felling sparked some disapproval among residents and environmentalists. The concern was of unnecessary destruction of the natural environment without sufficient justification and prior public notification. The Municipality of Ljubljana assured that the felling was carried out in accordance with regulations and that only dangerous or diseased trees were removed.

As ecologists, we are very scrutinous when investigating tree fellings, even when they are in accordance with regulations.

FIGURE 11 - PHOTO OF THE CONSEQUENCES OF THE TREE FELLING

FIGURE 12 - CONFUSED ANIMALS ON THE FELLED AREA

Deforestation has always had a major impact on the life of forest animals. There are various causes for forest degradation, for example human activity, such as the need for timber and farmland, diseases, pests and natural disasters like forest fires. These effects exacerbate climate change by increasing greenhouse gas emissions. Animal species in the cut area may also face unexpected and unnatural competition with other species, making them vulnerable to predators [5].

FIGURE 13 - PHOTO OF THE CONSEQUENCES OF THE TREE FELLING

Tivoli Park is home to more than 1,000 different species of animals. Such a remarkable diversity of life is maintained by a great variety of habitats in such a small area. For that reason, we were very surprised to see such a massive felling in a park close to the city centre, where the forest provides so much.

The urban environment is stressful not only because of pollution but also due to heat and drought, creating arid conditions. Trees are passively subject to the microclimate but are also actively modifying it, and they perform important urban ecosystem services. With appropriate management, cities can be useful habitats for trees contributing to biological richness and the comfort of life in cities [6].

2.2.2 SITE 2: LJUBLJANA MARSH

The second measurement location is the Ljubljana Marsh (Ljubljansko barje) which is one of the most artificially transformed environments in Slovenia. In the mid -19th century, the construction of the Southern railway (connecting Vienna with Trieste) was carried out here [7]. The marsh was also widely drained to make way for meadows, fields and hedges. The area is littered with a network of drainage channels [8].

Wet meadows in the area provide an important and rich environment for biodiversity. They are the natural environment for many species of wild orchids, grasses, and sedges. Two other notable species are *Fritillaria meleagris* and *Leucojum aestivum*. These meadows also provide an important habitat for rare and internationally endangered species. They are especially important for diurnal butterflies, which are closely tied with certain grass species.

Additionally, other habitats such as floodplain forests, overgrown drainage channels and hedgerows provide food and shelter to birds, bats, amphibians, reptiles, dragonflies and other insects. Biologists have recorded almost 6000 species in the marsh [9] [10].

Unfortunately, biodiversity is threatened by non-native invasive species [11].

Hedgerows are a dense line of trees and shrubbery. They are usually found at the edges of agricultural land and streams. They were either planted artificially or spontaneously. Hedgerows are widespread in the marsh as they have been used for centuries to mark the borders between plots of land. Their role as a habitat for plants and animals is paramount, especially while the grass in the meadows they border is being cut. Some common plant species that can be found in hedgerows are *Rubus fruticosus*, *Rosa canina*, *Prunus spinosa*, *Corylus avellana*, *Sambucus nigra*, *Crataegus laevigata*, *Cornus sanguinea*, species of oak (*Quercus*), species of elm (*Ulmus)*, species of maple (*Acer*), species of ash (*Fraxinus*). The hedges are also important for bigger animals for example the roe deer (*Capreolus capreolus*), the European badger (*Meles meles*), the red fox (*Vulpes vulpes*), the European hare (*Lepus europaeus*), and the stoat (*Mustela erminea*). They also play a vital role in limiting erosion and flooding [12].

Due to their importance to biodiversity, we measured 15 trees in hedgerows (Figure 14)

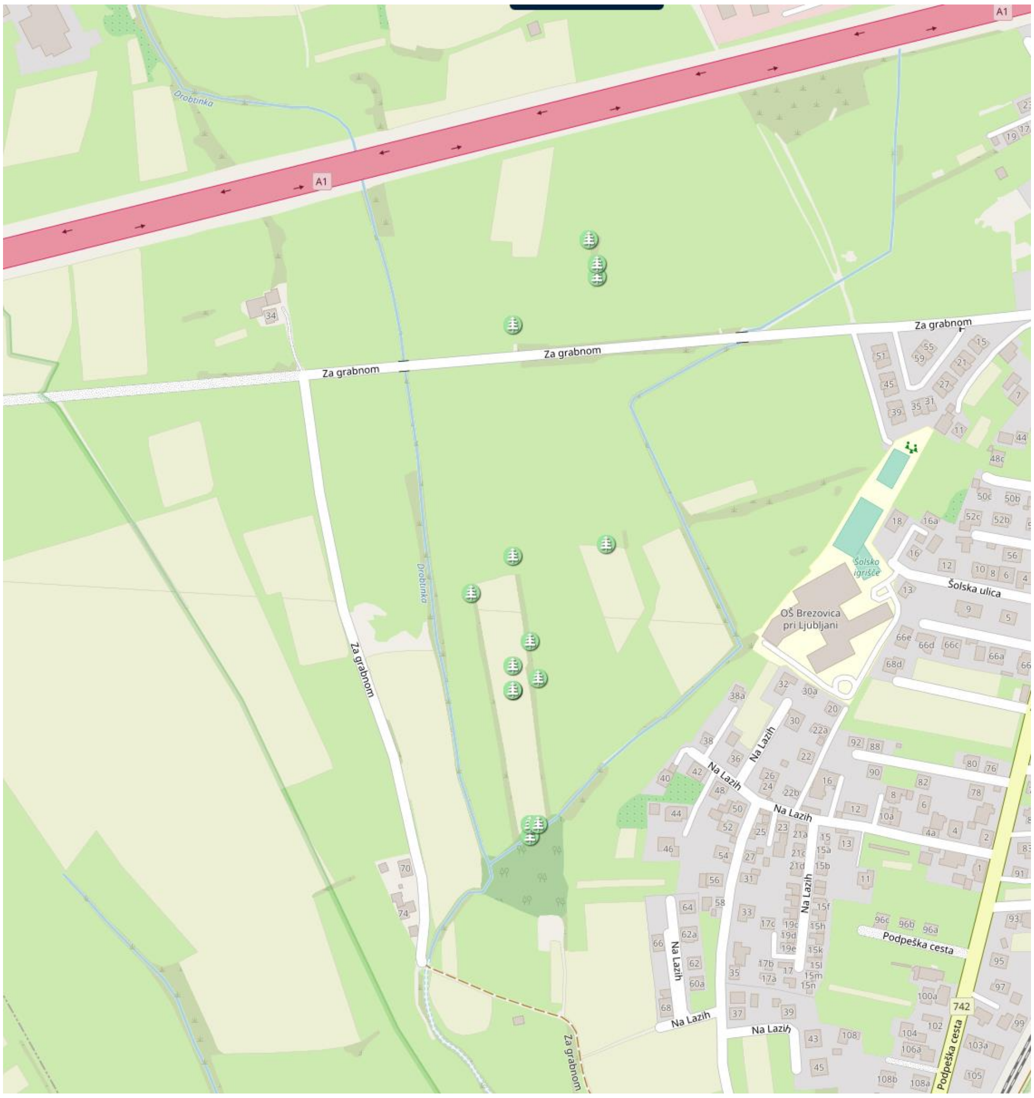


FIGURE 14 - MAP OF THE MEASURED TREE LOCATIONS IN THE LJUBLJANA MARSH

FIGURE 15 - TREE 11

2.2.3 SITE 3: RAŠICA

For the third location we chose a hill in the immediate vicinity of Ljubljana, Rašica, or rather the forest at its foot and just below the summit. This are areas of forest P126, P133 and P218.

FIGURE 16 - MAP OF RAŠICA AREA WITH MARKED FOREST STANDS

All three areas of Rašica where we made our measurements are unmanaged forest and are quite overgrown areas, estimated to be 100 years old. It is a relatively unpolluted area, with three water reservoirs: the Rašica reservoir, the Ribogojnica reservoir and the potential new reservoir no. 2.

It is a mainly deciduous forest. The canopy joint is normal, sometimes gnarled or broken. Densities range from 200 to 500 trees per hectare, depending on the forest's stage of development, and all three are mature stands. The trees are also affected by certain diseases: spruce budworm, ash blight, oak wilt, pine wilt and chestnut canker. However, damage to trees in this area is mainly the result of logging and harvesting (minimal).

The trees in this part of the forest reach heights of about 28 metres, and the tallest is 35.

This forest is also a sanctuary for many species of flora and fauna.

The uses and functions of forests are diverse - timber production, hunting and farming, extraction of other forest goods (chestnuts, blueberries, mushrooms, etc.), recreation, aesthetics, hygiene and health, tourism, biotopes, protection of forest land and stands, hydrology, protection of natural heritage.

The importance of the Rašice forest, close to the capital, is very high, contributing significantly to the climate, providing shelter for animal and plant species and serving as a reminder to people living in the city that they are not as far away from natural ecosystems as they imagine. Rašica is also a very popular recreational location.

FIGURE 17 - MAP OF THE FOREST AROUND RAŠICA, WHICH IS A PART OF THE NATURE 2000 AREA

FIGURE 18 - MAP WITH MARKED WATER SOURCES IN THE RAŠICA AREA

2.2.4 SITE 4: VELIKE LIPLJENE

Our fourth site is Velike Lipljene, a clustered village in the Turjaška region between Grosuplje and Turjak. The cadastral municipality number is 1795 Velike Lipljene, the plot numbers are 665, 735, 711/1, 718/2 and 715/2. The areas where we observed trees are poorly maintained forest. The condition of the forest at this site is good, the forest is not of a very high quality, but it is healthy. It has not been cleared and is biodiverse. Approximately 500 metres south-west of the observation area is the small stream Glinšček.

FIGURE 19 - MAP OF THE VELIKE LIPLJENE MEASUREMENT SITE

The forest on Plots 735, 711/1, 718/2 and 715/2 is the result of overgrowth of agricultural land (mixed forest), while the forest on Plot 655 is partly the result of overgrowth of agricultural land and partly the result of afforestation with spruce.

Plots 735 and 711/1 have normal forest cover, not compacted. The forest on plot 665 is sparse.

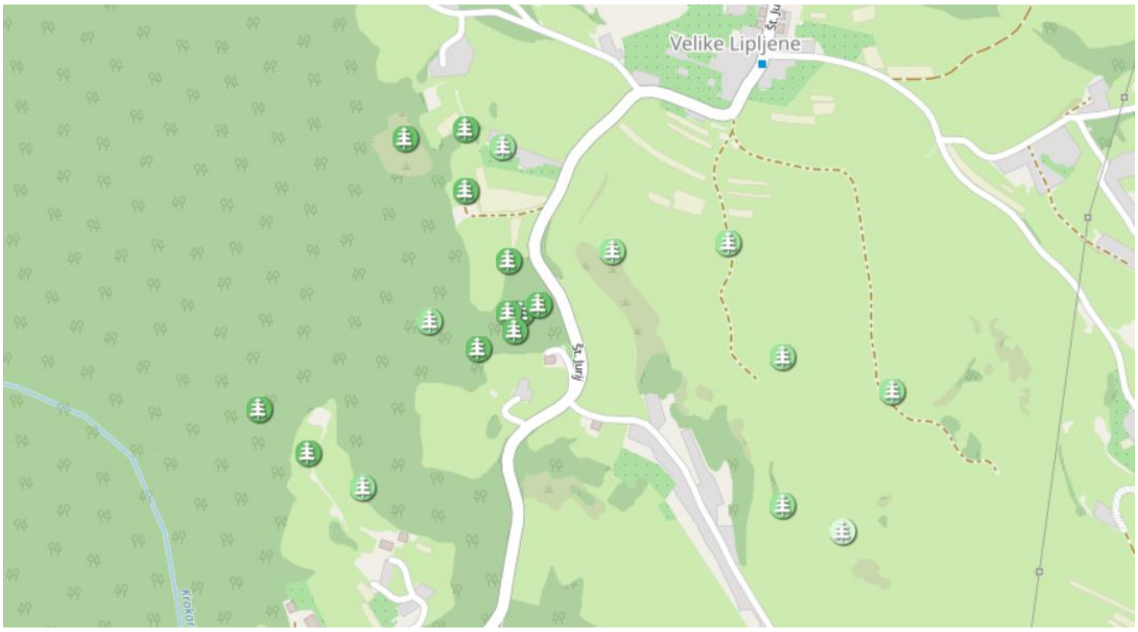


FIGURE 20 - MAP OF THE MEASURED TREE LOCATIONS IN THE VELIKE LIPLJENE AREA

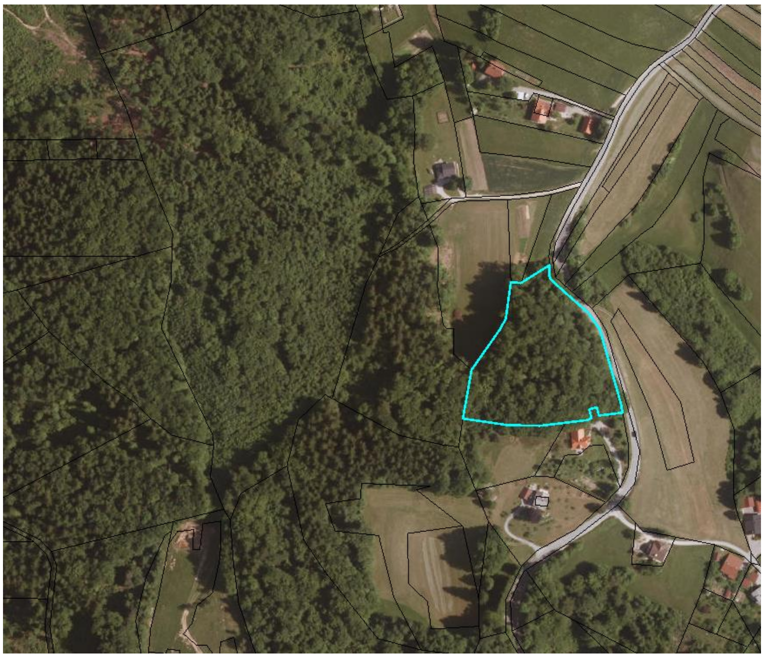


FIGURE 21 - PLOT 735, CADASTRAL MUNICIPALITY 1795 - VELIKE LIPLJENE

Spruces are around 60 years old, beech and oak are the oldest at between 100 and 110 years, and the youngest are around 80 years old. The last reforestation of spruce on part of plot 665 was about 35 years ago. The average height of the trees is between 25 and 30 metres, with the tallest trees being around 35 metres tall.

Of the biotic factors, spruce weevils cause the most damage, with the most damage being caused by the eight-toothed spruce weevil (*Ips typographus*) and the six-toothed or small spruce weevil (*Pityogenes chalcographus*).

Plot 665 is bordered by the 175 ha Medvedica complex in the Grosuplje GGE (forest management unit), which was formerly state-owned but is now the private property of the Auersperg heirs.

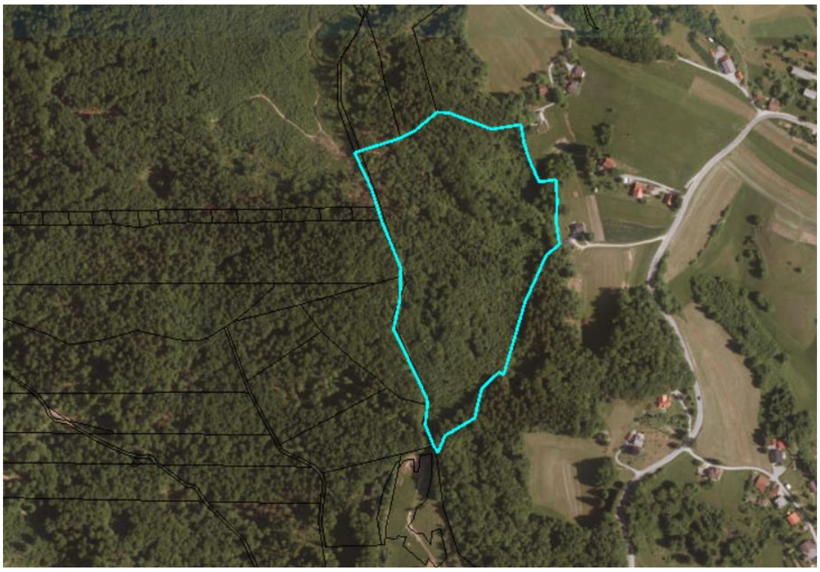


FIGURE 22 - PLOT 665

Forest use: clearing (logging) for forest timber (products), most spruce is sold as logs for further production of wood products, deciduous trees are mostly processed for firewood, logs only exceptionally.

FIGURE 23 - TREE 17

3 RESULTS

Height measurements of individual trees at 4 locations using two metric methods, a clinometer and the GLOBE app.

3.1 TIVOLI PARK

TABLE 1 TREE HEIGHTS MEASURED WITH THE APPLICATION AND A CLINOMETER IN TIVOLI PARK

	clinometer	application	difference
1	8,4	12,6	4,20
2	8,86	13,5	4,64

3	12,2	17	4,80
4	20,29	29,75	9,46
5	17,5	18,75	1,25
6	15,14	17,5	2,36
7	15,33	21,75	6,42
8	20,12	23,25	3,13
9	17,84	21	3,16
10	20,74	25	4,26
11	/	16,23	
12	/	19,97	
13	/	19,72	
14	/	23,52	
15	/	32	
	15,64	**20,77**	5,13

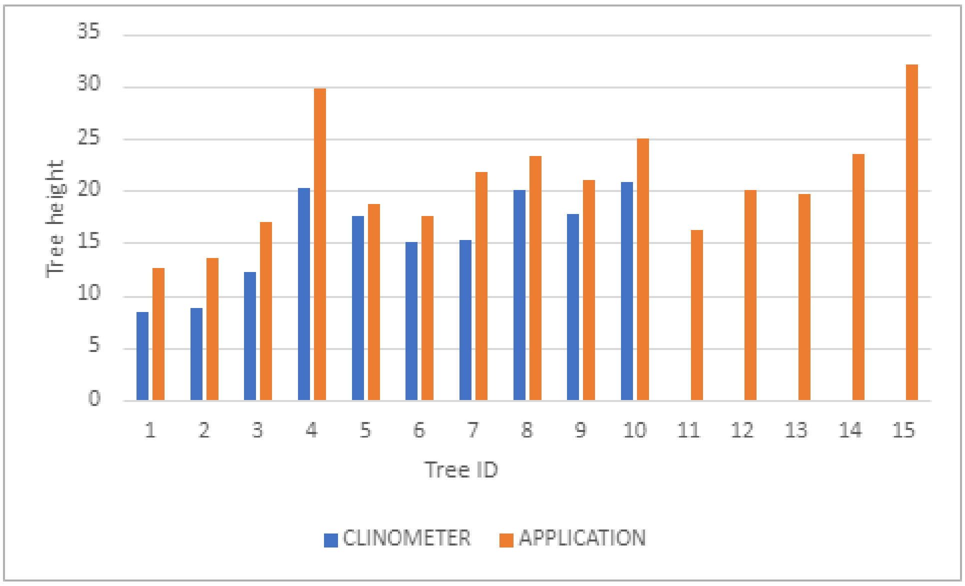


FIGURE 24 - COMPARISON OF BOTH MEASUREMENT METHODS IN TIVOLI PARK

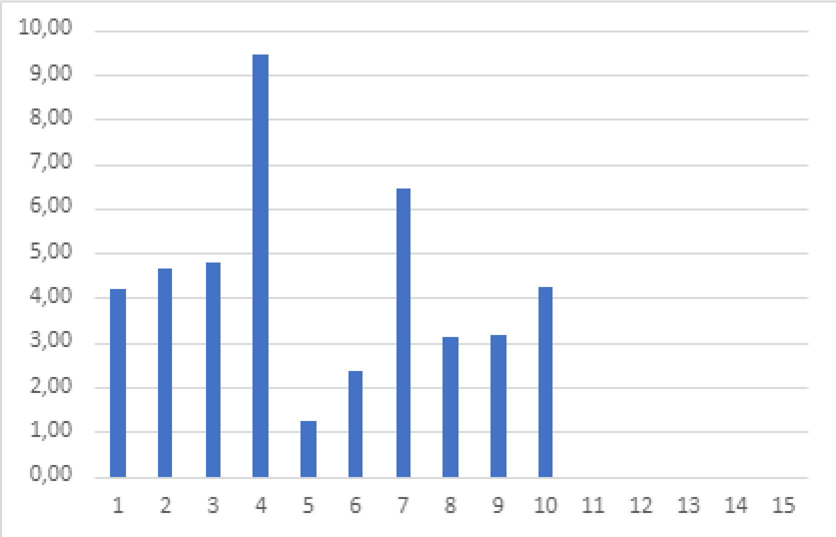


FIGURE 25 - THE DIFFERENCE BETWEEN BOTH MEASUREMENTS METHODS IN TIVOLI PARK

3.2 LJUBLJANA MARSH

TABLE 2 TREE HEIGHTS MEASURED WITH THE APPLICATION AND A CLINOMETER IN THE LJUBLJANA MARSH

	clinometer	application	difference
1	15,29145	15,42	0,13
2	10,44012	13,53	3,09
3	12,16809	11,94	-0,23
4	10,93176	15,25	4,32
5	17,62674	11,92	-5,71
6	10,80885	12,31	1,50
7	11,419785	14,43	3,01
8	10,90284	10,69	-0,21
9	10,819695	12,68	1,86
10	11,53908	13,25	1,71

11	12,3633	18,48	6,12
12	9,6882	11,84	2,15
13	13,64301	11,42	-2,22
14	12,75372	11,53	-1,22
15	12,95616	15,76	2,80
	12,22	**13,36**	1,14

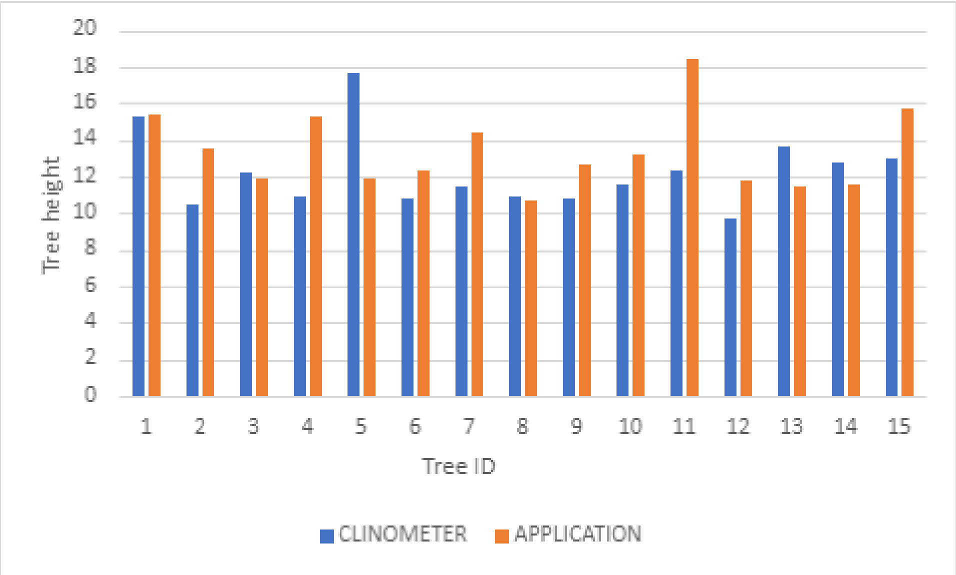


FIGURE 26 - COMPARISON OF BOTH MEASUREMENT METHODS IN THE LJUBLJANA MARSH

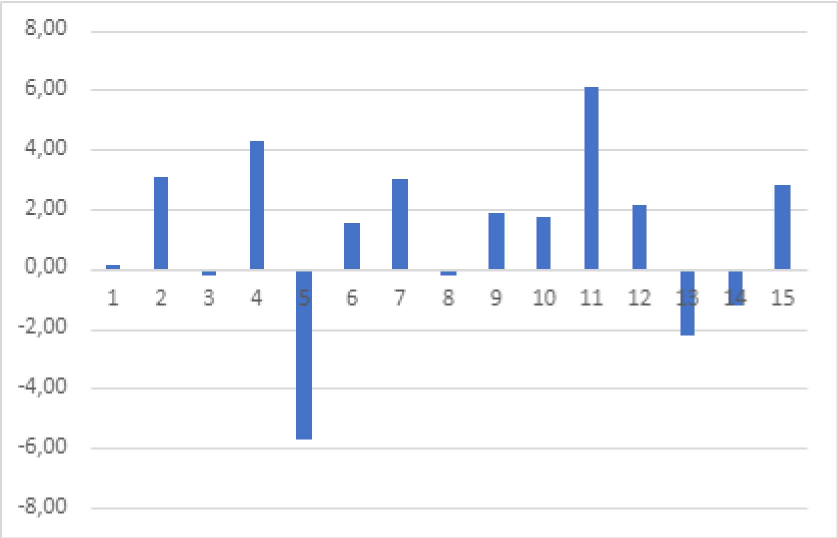


FIGURE 27 - THE DIFFERENCE BETWEEN BOTH MEASUREMENT METHODS IN THE LJUBLJANA MARSH

3.3 Rašica

TABLE 3 TREE HEIGHTS MEASURED WITH THE APPLICATION AND A CLINOMETER IN THE RAŠICA AREA

	clinometer	application	difference
1		18,5	
2	19,3	20,3	1,00
3	12,8	14,2	1,40
4	18,5	19,1	0,60
5	25,9	26,8	0,90
6	23,3	23,7	0,40
7	24,6	27,1	2,50
8	23,5	23,5	0,00
9	21,7	22,1	0,40
10	12,9	13,8	0,90
11	30,3	31,5	1,20

12	16,9	15,9	-1,00
13	18,7	17,2	-1,50
14		18,6	
15		19,6	
16		28,3	
17		23,1	
18		19,5	
19		18,3	
20		16,2	
21		22,6	
22		28,4	
23		34,7	
	20,70	**21,87**	1,17

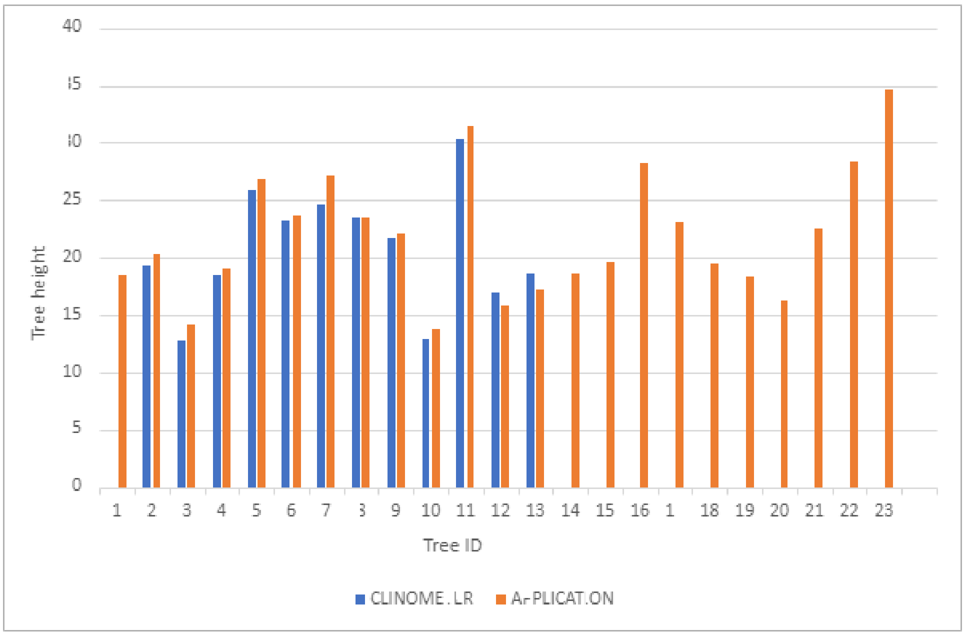


FIGURE 28 - COMPARISON OF BOTH MEASUREMENT METHODS IN THE RAŠICA AREA

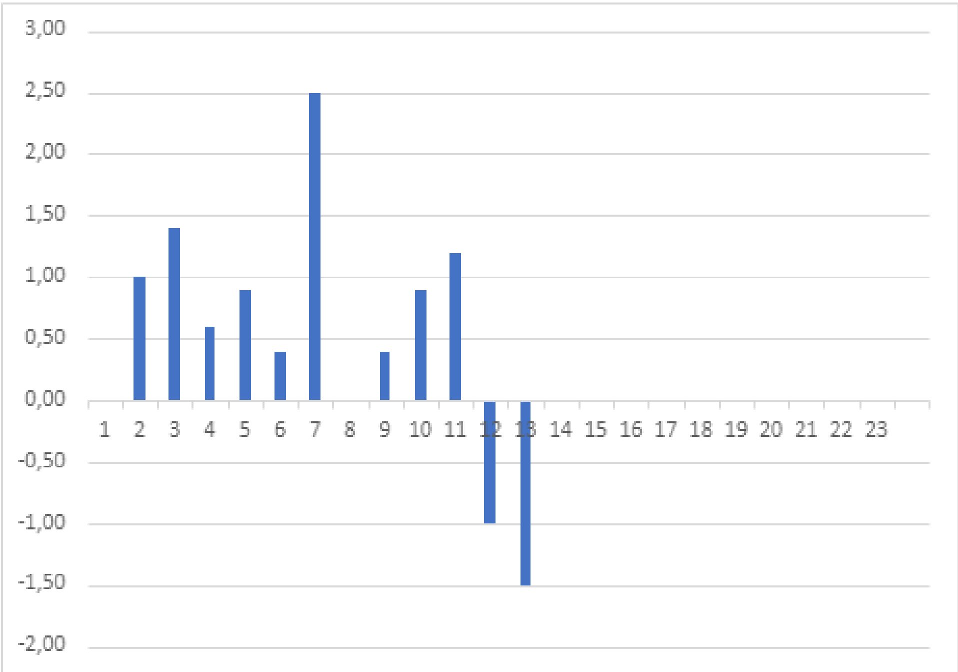


FIGURE 29 - THE DIFFERENCE BETWEEN BOTH MEASUREMENT METHODS IN THE RAŠICA AREA

3.4 VELIKE LIPLJENE

TABLE 4: TREE HEIGHTS MEASURED WITH THE APPLICATION AND A CLINOMETER IN VELIKE LIPLJENE

	clinometer	application	difference
1	30,83	31,77	0,94
2	28,7	27,24	-1,46
3	27,08	24,4	-2,68
4	30,45	30,2	-0,25
5	19,11	16,7	-2,41
6	19,1	20,01	0,91
7	14,88	13,9	-0,98
8	32,96	31,31	-1,65
9	28,8	26,57	-2,23
10	40,7	36,41	-4,29
11	21,95	21,31	-0,64
12	23,5	20,1	-3,40
13	32,86	28,91	-3,95
14	16,97	15,47	-1,50
15	18,6	19,32	0,72
16	17,6	14,47	-3,13
17	21,4	19,33	-2,07
18	13,95	8,34	-5,61
19	12,8	13,73	0,93
20	19,34	16,81	-2,53
	23,58	**21,82**	-1,76

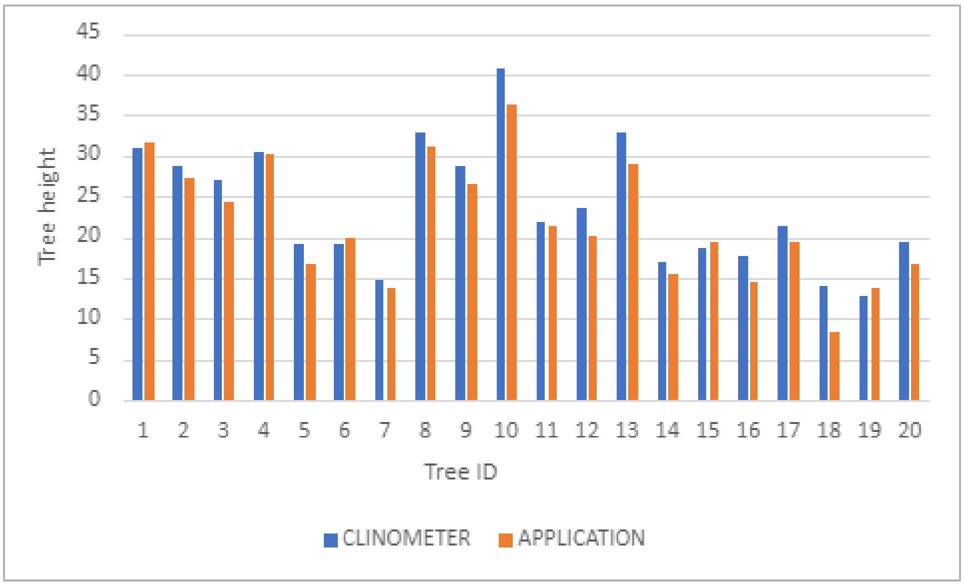


FIGURE 30 - COMPARISON OF BOTH MEASUREMENT METHODS IN VELIKE LIPLJENE

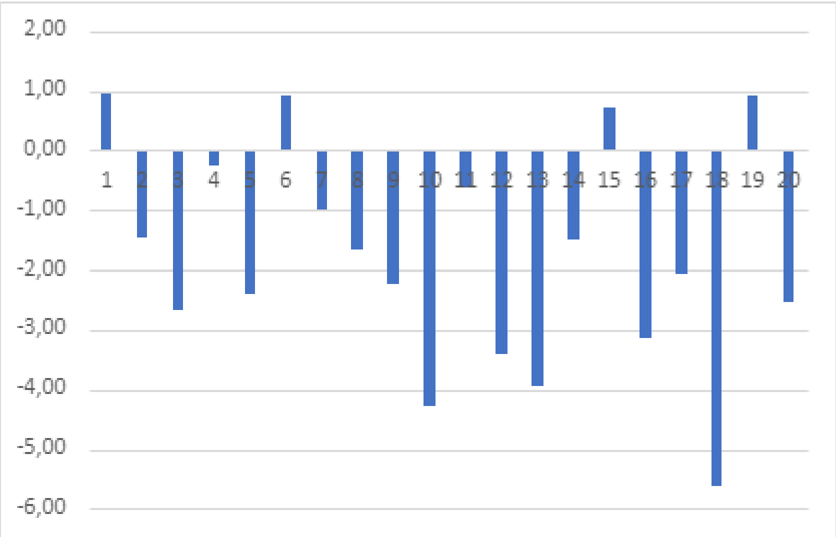


FIGURE 31 - THE DIFFERENCE BETWEEN BOTH MEASUREMENT METHODS IN VELIKE LIPLJENE

4 DISCUSSION

At the beginning of our research, we had planned to just observe the forest or trees near our home and measure the height of the trees, but we asked ourselves other questions. We also asked the district foresters who manage the trees and forest in the selected sites for answers.

We searched for answers to the following questions:

1. What is the state of the forest at this site
2. What is the forest cover, tree density
3. What are the most common diseases and damage to trees
4. Approximate estimate of the age of this forest
5. What is the average and maximum tree height
6. Use of the forest

The experts' responses were considered in the evaluation of the results and in the presentation of the sites (chapter 2).

It is interesting to note that we got similar answers everywhere except in Tivoli Park.

The trees grow in mixed stands of conifers and deciduous trees. In the forest meadows of the Marsh, however, deciduous trees predominate. It is also interesting that the average height of the trees is approximately the same, which may be due to the similar geological history of the area. These are geologically old river plains, where the forest continues into the hilly world at the edge of the Ljubljana basin.

Urbanization displays a massively increasing trend. According to data of the UN, more than half of the world's population lives in urban areas and the prediction for 2050 is that 64% and 86% will be urbanized in the developing and the developed world, respectively. Because urbanization tends to increase quickly at a planetary level, the effects of the global climate change will be critical in urban areas. With appropriate management, cities can be useful habitats for trees contributing to biological richness and the comfort of life in cities [6]

Urban forests play a fundamentally important role in building ecological cities, because they improve the environmental quality of the urban environment and the aesthetics of urban landscapes.

That is why the importance of green spaces covered with trees in cities, even smaller ones like Ljubljana, is so great. Perhaps we are not yet sufficiently aware of their value. In any case, careful management of trees and woodland in urban green oases or on the edge of cities is extremely important. We find it truly incredible that the local authorities in Ljubljana have decided to cut down more than 300 trees at the foot of Rožnik. We planted 5 small trees and a few shrubs on our school terrace to remind us of their unmistakable role in the city centre, even if it is on top of a building.

Urban forests provide ecosystem services that contribute to human health [13], liveability and sustainability. The management of trees influences the delivery of these ecosystem services and thus helps determine the total benefit provided by an urban forest. [14] [15].

"Restoring plant communities provides habitat for animals and changes soil, water, and air conditions, all of which impact on the environmental microbiota, generating a more natural microbial community, "Biodiversity restoration could be a cheap health care intervention with the possibility of enormous savings for health care sectors which can be spent in other areas of need. It also comes with benefits – like urban heat-island mitigation, pollution capture, and species conservation – which makes it a no-regrets intervention" [16].

Trees are also very interesting in terms of taking up carbon dioxide from the air. Recently, many models have been built to assess the ability of trees to take up this greenhouse gas, which is now traded globally. The calculations are far too complex for us, but we are convinced that every tree is an important living link for the assimilation of this gas[17].

4.1. Tree height data

The average height of the trees at sites 3 and 4 are similar. The average height of the trees measured by the app is 21.87 m at site 3 and 21.82 m at site 4.

After reviewing the composition of the stands, both sites are similar, although they are geographically quite distant, and both are located somewhat on the edge of the Ljubljana basin. The forest is a mixed coniferous-deciduous forest. The condition of the trees is fairly good, but, as elsewhere in Slovenia, there is an increase in the activity of bark beetles, which cause conifer dieback.

In Tivoli Park (site 1), the average maximum height of trees is approximately 20. 77m. The value does not deviate significantly from sites 3 and 4. In Tivoli, the tree load is different, as it is the impact of an urban, more heavily trafficked area, such as Sites 3 and 4, which are rural. In Tivoli, the trees grow singly and have a wider canopy, which may be why their height is slightly lower, although they have very favourable light conditions and would be expected to grow slightly taller.

In the Ljubljana Marshes (site 2), trees are relegated to the borders between the plots, the soil is marshy with a lower pH, and the average tree heights are therefore much lower than in the other sites, averaging only 13. 36m.

To get an accurate picture of the actual tree heights at all four sites, the heights of at least 50 trees of the same species would need to be measured. Our measurements were made on different tree species. In a forest, the upper canopy layer is roughly the same for different tree species, as growth in height is determined by the search for optimum light exposure.

4.2. Comparison of measurements with the clinometer and the GLOBE Observer app

The clinometer method is the classic forestry method for determining tree height. This sometimes results in a rather large subjective error, as for example at location 1. Measurements at all other locations showed a wide range of measurement error. At Site 2, the average height measured with the app was 1. 14m higher than that measured with the clinometer.

At site 4, the deviation was in the other direction, with the higher mean tree height measured by the application being 1. 76 m lower than that measured by the clinometer.

In general, however, tree height determined by application or clinometer is a fairly reliable method. In future, we will opt for an app that allows for less subjective error. However, at the start of a measurement by a group of different measurement operators, it is certainly necessary to do some joint exercises to ensure that there is uniformity in the observation and measurement procedures.

The absolute values and the error of the results could be verified by drone measurements.

It would also be useful to compare our results with satellite images and other data.

In the future, we would also like to investigate the basic phenological methods of some trees in our area. We plan to organise a team at the school to monitor phenological phases over several years, which are an important indicator of global climate variability and the associated biological responses in forests. Tree phenology data is a powerful tool in climate variability research, as it is relatively easy to collect and includes an understanding of the interactions between different tree species and the environment [18].

5 CONCLUSIONS

Trees are increasingly recognised as an important indicator of the impact of climate change. By monitoring the height of trees, we can monitor their response to these changes over the long term. By surveying our measurement sites, reviewing the literature and talking to district foresters in the field, we can conclude that the Ljubljana basin currently has sufficient green forest cover and thus quality ecosystem services. This confirms our first hypothesis. However, we must strive to ensure that the vitality of these areas is carefully protected through professional forestry management.

Hypothesis 2 on the average height of trees is partially confirmed, as we found that trees on acid marsh soils are much smaller. In the mixed coniferous-deciduous forests on the slopes of the Ljubljana basin, however, these heights are fairly even. In Tivoli Park, in the centre of the capital, where trees have good light, hydrological and pedological conditions, their height varies considerably, which is related to the tree species.

Hypothesis 3 aimed to investigate the correlation and reliability of measurements using two methods - a clinometer and the GLOBE Observer app. We found that the tree height calculations, although slightly different, are comparable. However, it takes a skilled team or individual to use the chosen method in a quality and reliable way.

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