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“Looking for the trees in the forest“ An attempt to finding the best segmentation-based methodology to discriminate deciduous trees in the Dubbarp area, Sweden

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Master thesis, 30 credits, in Geomatics

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ABSTRACT

The profile of "trees worthy of trees worthy of protection" (in Swedish "*särskilt skyddsvärda träd*") sketched by field biologists shows that they usually have an age over 100 years, belong to certain species (usually oak) and present favourable intrinsic conditions for developing a micro fauna. Because of the high diversity of species hosted, "trees worthy of protection" are a vital element for maintaining the biodiversity of Sweden, which has been the aim of the Green Infrastructure project, conjoining some Swedish public authorities. Finding these tree specimens through fieldwork has proven to be a lengthy and costly work. Therefore conceiving a semi-automated procedure to help locating and extracting these tree specimens through remote sensing techniques has been a recurrent discussion topic for scientists and practitioners. This thesis attempts to find an adequate methodology to resolve the issue of locating "trees worthy of protection" (TWP) by using segmentation algorithms present in the eCognition software, applied to surface elevation data processed from airborne LiDAR and optical NIR data (aerial photographs) for an area located in Scania County, Southern Sweden. Thirteen experiments based on the multi-resolution segmentation procedure available in the eCognition software show how changes in the algorithm settings have effects on the performance of deciduous tree recognition. Each experiment's detection accuracy has been assessed and it was concluded that tests which include additional segmentations than multiresolution segmentation yield more accurate results. The outcomes from the tests show that additional optical data and possibly forest competition modelling are necessary to ameliorate the detection of trees worthy of protection. Recommendations for future research are given at the end of the thesis.

Keywords: segmentation, individual tree crown recognition, eCognition, Scania

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1. INTRODUCTION

The Green Infrastructure Project, coined by the Swedish Environmental Protection Agency (in Swedish: Naturvårdsverket) intends to create a network of natural corridors that would enable species to spread and move in the landscape (Länsstyrelsen 2020; Naturvårdsverket 2020a). The project work consists of actions aimed to protect, keep and restore important ecosystems in the country. The creation of natural corridors would enable ecosystems to enrich their number of species, have better post-disturbance recovery and improved responsiveness to environment modifications, such as climate change. In collaboration with actors such as regional county boards, municipalities, private companies, institutions and organisations, Naturvårdsverket intends to make the concept of green infrastructure more familiar and understandable and in the same time integrate it in the process of community planning. Among the participants, the Administrative County Board of Scania (in Swedish: *Länsstyrelsen*) with a coordinating role in the Green Infrastructure Project, has elaborated a field research procedure to identify ecosystems that might be included in the future Green Infrastructure networks and require protection.

An ecosystem, understood as an area of interaction between biotic systems and their physical support (Chapin III et al. 2011), contains many living elements, which play an important role in preserving the ecological diversity. In the ecosystems of Scania, trees have been recognized as one of those elements, and *Länsstyrelsen* has begun assessing them for protection. Parameters such as species, age and the amount of distinct entomofauna that use them as shelter or source of nutrients have been used as references.

1.1. Problem: how to identify the "trees worthy of protection"?

The biologists working for Länsstyrelsen have initiated a region wide search in Scania using some pilot working areas and identified a number of possible candidate trees which they labelled as "tree worthy of protection (in Swedish: "*särskilt skyddsvärda träd*"). This picture of a tree worthy of protection (TWP) is sketched by Naturvårdsverket (Naturvårdsverket 2020b), which classifies them in 3 distinct categories: "giant trees" (in Swedish "*jätteträd*"), "very old trees" (in Swedish "*mycket gamla träd*") and "thick hollow trees" (in Swedish: "*grova hålträd*"). The first category includes living or dead trees that are thicker than 1 m in the narrowest part of their measured diameter at breast height (DBH). The second class consists of living or dead trees between 140-200 years old, depending on species. To be "worthy of protection" the species of oak, pine, spruce or beech must have an age of minimum 200 years, with much smaller values for other tree species (140 years). Field campaigns carried out by biologists from Scania were able to confirm and simultaneously bring in additional details to the earlier description from Naturvårdsverket. Their observations identified suitable individuals as usually being old oaks, with wide trunks, a crown developed more in width than in height, thus not located in the dominating (highest) forest layer and generally over 15 m.

As regards their positioning within the ecosystem, the TWPs, are located either isolated on pastures and open meadows or in forests among other tree species. When such a candidate tree was found, a field research crew assigned by Länsstyrelsen registered the tree's approximate positioning using a GPS (Global Positioning System) device. The obtained coordinate pairs were then exported to a GIS (Geographical Information System) database as a point object. However, considering the fact that candidate tree research for the Green Infrastructure project aims to extend to all of Scania (14.000 km^2), this work would take a high amount of time and require elevated costs. Therefore, the authorities felt the need of implementing a possibly quicker, computer-based solution to distinguish possible TWPs by crowns, and they requested help from Lund University. The research work was divided in such a way that the members of the assigned team would take a pilot plot in Scania, where the presence of potentially worthy trees has been confirmed and are used to test a semi-automatic recognition methodology.

1.2. Research gaps

Semi-automatic tree crown identification is a recurring problem in remote sensing and it creates difficulties for both the forestry practitioners and academics because of the high variability of the natural environments that host tree individuals.

For example factors such as forest and terrain morphology have been indicated by several research teams (Kaartinen et al. 2012; Zhen et al. 2016) as hinders for the discovery of a universal digital solution to discriminate individual trees. Their conclusion is echoed by other scholars who expand the list of possible obstacles in finding a global solution with features such as tree density (Oono et al. 2008), (Kaartinen et al. 2012; Shataee 2013) and dominant species (Shataee 2013; Zawawi et al. 2015).

The lack of a “one size fits all” type of resolution has constrained scientists to adapt their research methodology to the environmental characteristics of each investigated region. The high diversity of forest environments on Earth and the limited amount of literature that treats trees located in different regions left quite a wide knowledge gap about effective ways for individual tree crown recognition throughout the world. Many successful attempts in semi-automatic tree crown delineation have been probed on uniform conifer forests (Zhen et al. 2016). The study of Hyyppä et al. (2001) used 3D LiDAR data managed to accurately recognize individual trees and measure the stem volume of a Finnish forest.

One year later, a greater achievement is obtained in Sweden (in the region of *Västra Götaland*) by the study of Persson et al. (2002), which managed to detect individual trees from laser scanner data using the local extrema algorithm on forested areas, where the most common species were spruce and pine. Erikson (2004) implemented different region growing algorithms to recognize tree crowns in two Swedish test sites located in *Västernorrland* county (Huljen) and *Västra Götaland* (Remmingstorp), respectively. However, these plots are also dominated by conifer trees. A nearby location to Remmingstorp was also used by a new study by Holmgren and Lindberg (2019), who introduced a new tree crown delineation algorithm based on tree crown density, which was applied on ALS (Airborne Laser Scanning) data. According to Lundmark (1986), the national territory of Sweden is divided into 5 vegetation areas (figure 1).

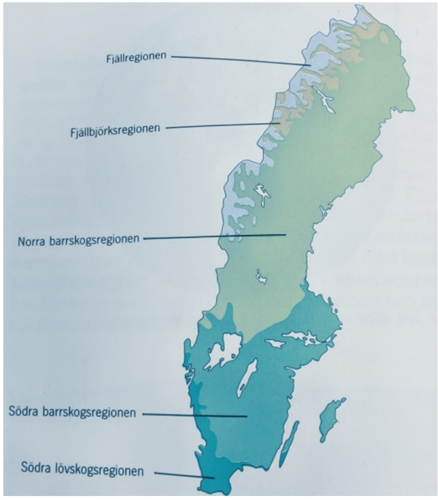

Figure 1. The vegetation regions in Sweden. Adapted from Skogsmarkens ekologi, ståndortsanpassad skogsbruk. Del 1 -Grunder (p.20) by J.-E. Lundmark (1986), copyright 1986 by Skogsstyrelsen

The first two categories, *mountain region*, *the mountain birch region*, can be geographically placed in the north-western parts of Sweden on the slopes of the Scandinavian Mountains. In a southerly and south-easterly direction, these vegetation associations are continued by the *north and south conifer forest zones*. The last one mentioned covers a vast area that starts in the historic region of *Småland* and up to the latitude of *Stockholm* and *Uppsala*. Lastly, the *southern deciduous forest region* follows a narrow stretch of land parallel to the country's western coast, starting somewhere south of *Strömstad* in *Bohuslän* and covers the territorial extent of Scania. As discussed above, many of the crown delineation attempts have been tested at latitudes higher than the one of Scania, and therefore it can be concluded that there are few studies dealing specifically with tree crown identification in a deciduous forest context. As per the author's knowledge, no studies attempting to identify tree crowns had the specifically the Scanian context in the spotlight.

The experts working for the Administrative County Board of Scania reveal in their fieldwork a possible relation between the status of trees worthy of protection and parameters such as height and species. Because of the airborne LiDAR data's high accuracy, when measuring elevations due to its advanced GNSS (Global Navigation Satellite System)-IMU (Inertial Measurement Unit) system and its continuously descending price, the technology has been more intensively put in practice by forest researchers in the modern times. The tendency is revealed by the comprehensive study conducted by Zhen et al. (2016), which analysed 212 research papers written between 1990 and 2015 and underlined the ascending trend of using this kind of data alone or alongside optical data collected with the help of satellites or airborne platforms. As per the author's knowledge, no forest studies involving LiDAR data have been conducted in Scania up to date (May 2020). This leaves a great research opportunity.

1.3. Research objective and questions

The aim of the current thesis is to test whether it is possible to accurately pinpoint the crowns of deciduous trees using LiDAR and aerial photography based segmentation in the chosen study area. The choice of the aim is grounded in the special conditions imposed by Länsstyrelsen that have to be fulfilled by the protection candidate trees and the scarcity of forestry studies concerning the zone allotted to the current research. A further motivation for the purpose of thesis is the possibility of using semi-automatic recognition on deciduous trees, a less researched subject in the academia.

As mentioned by Blaschke (2010), contemporary forest research trends tend to use the cconcept of GEOBIA - *Geographical Object Based Image Analysis*, (Hay and Castilla 2008) based methods gravitating around the eCognition package and this paper aspires to keep up with the latest in technology. Included in the eCognition software are many segmentation algorithms that assist the end-user with object recognition. Among these, the multi-resolution segmentation is an iterative algorithm that uses weights applied to spatial (shape size) and optical (pixels) parameters to calculate the optimal solutions that has the lowest variance within the members of a segment and highest between segments. Multi-resolution segmentation has not been tested as segmentation method in a south Swedish context (May 2020), despite its promising potential.

In effect, the **research question** is which is the most effective multi-resolution segmentation-based methodology to delimit trees worthy of protection crowns in the Dubbarp study area using LiDAR and optical data?

To accurately answer this question, it is necessary to take a deeper look at the available datasets that describe the area as well as to evaluate the tools that are used to get the job done. This is achieved by conducting a number of experiments using different parameter values and rulesets that start with a Multi-resolution segmentation processing.

1.4. Thesis structure

This thesis is the result of the search for an adequate solution with the purpose of identifying candidate trees within the frame of the Green Infrastructure project (Naturvårdsverket 2020a). It starts with a short historical review of studies concerning methodologies related to tree crown identification in the science of forestry (II), describes in detail the study area, argues the choice of method, presents its main drawbacks (III), illustrates the research results (IV) and discusses the obtained outcome (V). The work concludes with a chapter which wraps up the current study and presents perspectives for future investigations (VI).

2. BACKGROUND

2.1. The beginnings: From manual work to satellite based remote sensing in forestry

Historically, data collection aiming to assess tree characteristics such as diameter at breast height (DBH), age and species composition, crown height and width, or wood volume, has been carried out manually through field work executed by specialists (Kaartinen et al. 2012). This was a lengthy and cost-demanding process (Kaartinen et al. 2012). In some cases, in forests and where it was necessary to cover a greater area, teams equipped with instruments provided by different manufacturers were assigned to subtract forest parameters and the resulting output data required some sort of standardization. In other cases, accessibility was a factor that extended even more the time required to execute the fieldwork. The situations described above accelerated the need for developing higher accuracy tools and procedures. To respond to the recurrent time issue caused by manual work, researchers used photogrammetry to establish forest parameters. However, the number of early studies (prior to the late 1970s) is reduced because of technological limitations such as camera resolutions, low computer processing power and difficulty of accurately establishing flightpaths (see more in section 2.2). The launch of the first satellite for civilian use, Landsat 1, in 1972, marked a new era in the field of remote sensing (Iverson et al. 1989). The possibility of satellite imagery to provide a constant high-resolution picture of Earth's surface alongside with the bettering of existent computer systems lead to a new direction in forestry remote sensing science based on analysing such data. The comprehensive review of Holmgren and Thuresson (1998), with the objective of assessing satellite-based applications of remote sensing in forestry 25 years back from the publishing date of the study, classified two main directions of research - forest inventory and monitoring. The discipline of forest inventory was identified by Holmgren and Thuresson (1998) as having a significant cartographic loading, with many papers concentrated on discriminating land use-land cover categories based on satellite imagery. From a methodological standpoint, early research was dominated by the implementation of pixel-by-pixel algorithms, using techniques such as supervised and unsupervised classification. From a technological perspective, satellite remote sensing was a step forward in providing forest managers and public servants with very precise data concerning the parameters of individual trees. Identified issues such as elevated costs for high resolution imagery, the uncertainty of data availability at regular time intervals (Chuvieco 2016) due to e.g. the presence of clouds (Holmgren and Thuresson 1998), necessity of atmospheric correction, the need for narrower bandwidths for processing smaller identifiable objects, as well as the requirement for additional data to calculate the underlying terrain elevations (Fleming and Hoffer 1979; Franklin 1986) made the scholars look for alternative solutions.

2.2. A new tool becomes available: LiDAR

The 1980s mark a bettering and a widespread usage of technologies such as Light Detection and Ranging (LiDAR). A simple LiDAR construction consists of a laser scanning instrument which can be located on the ground or airborne, which emits pulses of radiation located usually in the near-infrared spectrum. These pulses subsequently bounce off targets and then are read by a receiver, also part of the system (Nelson et al. 1984). Modern LiDAR airborne systems are provided with an Inertial Measuring Unit (IMU), Global Navigational Satellite System (GNSS), which help them produce data with higher geographic accuracy (Hyyppä et al. 2008). The outputs of a LiDAR system come in form of 3D point clouds. With early prototypes and applications since the late 1960s, LiDAR was mainly used as a data collection utensil in projects connecting to land surveying, ice sheet and oil spill monitoring (Nelson 2013). According to the same author, it was during a Russian scientific experiment conducted by Solodukhin near St. Petersburg in 1979 that LiDAR was recognized as a promising tool in forestry for automated forest canopy delineation and individual tree identification. A pioneering study (Nelson et al. 1984) used LiDAR technology to assess damage produced by the gypsy moth to a forest located in Pennsylvania and resulted in establishing that LiDAR data is very accurate for determining forest parameters such as tree height and canopy structure. However, the major drawback of the earlier setups (the one from the 1984 study included) consisted of not having a way to accurately monitor the location and direction of flight of the aircraft (Schreier et al. 1985). This limited the usability of the tool until the addition of GPS unit to the system. When the LiDAR usage, functionality and characteristics became more understood and the problem of accurately estimating the flight path, aircraft position at a certain point in time and elevation of the system bearing aircraft was solved, the science community turned its attention to putting this promising tool to work. A review conducted by Zhen et al. (2016) identifies from the 2000s an increasing interest of the forest scientists for using LiDAR technology in their pursuit of detecting individual tree crowns. However, in many studies such as the ones of Tiede and Hoffmann (2006), Maltamo et al. (2007), Heurich (2008), Oono et al. (2008), LiDAR data is used only as an ancillary source to produce elevation data. Scholars point out the necessity of combining elevation data with optical data from aerial surveys and satellites in order to capture parameters which contribute to more exact individual tree detection. These data sources have been processed using different segmentation algorithms to produce spatial objects that were subject to further analysis. More about the creation and analysis of these objects, known as object oriented classification in the next section.

2.3. Object-oriented classification

Object-oriented classification was developed in 1976 through the study of Kettig & Landgrebe. This new approach based on the statistical similarity between groups of pixels to produce homogenous elements showed more accurate results than the traditional pixel related techniques while classifying remote sensing imagery (Kettig and Landgrebe 1976). In spite of all its data processing advantages including an equal weighting of both the spatial and the spectral component leading to an increased geographic weighting, the object oriented classification system was not embraced by the majority of contemporary researchers (Holmgren and Thuresson 1998). Yet a new era in began in the 2000s when image segmentation analysis receives a broader attention from other fields of research such as remote sensing (Blaschke 2010; Chen et al. 2018), considering that prior to 1976, segmentation techniques were only restricted to the field of computer science. With the galloping advancement of computer graphic memory storage and processing power (I), the availability of very high resolution imagery (II), creation of specific software encompassing object-based algorithms for remote sensing (III) and some inherent shortcomings of the classic pixel-based data processing such as the less weight given to the spatial component (Hay and Castilla 2008; Blaschke 2010), segmentation analysis has quickly attracted the consideration of the academic community. The “explosion” of object-oriented studies in the discipline of remote sensing at the expense of the “classical” pixel based methodologies is reflected by the consistent study of Blaschke (2010), who reviews more than 1000 different papers on the subject. The same author mentions a possible naming dispute of the technology with OBIA (Object Based Image Analysis) and GEOBIA (Geographic Object Image Analysis) competing for the most accurate description. Considering that OBIA is more widely used in disciplines such as computer vision and medicine (Blaschke 2010), this thesis supports the usage of the term GEOBIA (Hay and Castilla 2008) as a viable descriptor of segmentation techniques in a spatial context.

In the field of forestry and more specifically in the researches connected to delineating individual tree crowns, the modern GEOBIA approach became quickly the new trend (Zhen et al. 2016) . Concomitantly with an ever growing literature covering the subject, increases the variety of used algorithms. Indeed, segmentation analysis can be done in different ways depending on the available data and type of study region. For example, the study of Bunting and Lucas (2006) uses the *Multi-resolution segmentation algorithm* to define forest areas and then calculates the *local maxima* from an elevation model to detect the possible treetops. From these tops, *a region growing algorithm* is applied to better distinguish the forest elements. The experiment resulted in recognizing the individual trees in the Australian forest with relative success (70% of the individual trees mapped). A methodology based on *identification of the local maxima* and *applying a region growing algorithm* have been also employed by Tiede and Hoffmann (2006) in their attempt to find individual tree crowns in a Bavarian forest composed of mixed coniferous and deciduous species. Nevertheless, the authors note, this algorithm fails to produce adequate results when the tree crown is not pointy, such as for the case of the coniferous trees. Two years later comes the research of Heurich (2008), who was aiming to produce a detailed map of the individual trees in the Bavarian Forest National Park, as to be able to evaluate the wood volume. The author used the *watershed delineation algorithm*, which processes on the elevation model data. The elevation values of the model are inverted and thus a "digital negative landform" is obtained. This negative landform, which in practice is an identified tree, is subsequently "flooded". Thereafter it is "dammed" by using special algorithms in order not to "spill the water" and reach other basins. The rationale behind the damming operation is to increase tree recognition accuracy.

This classification produced good results; nonetheless problems such as the difficulty of correctly identifying the deciduous trees and an overestimation of the 5.4% of the number of trees could not be resolved. Unconvinced of the accuracy provided by the classical methods involving the calculation of a Digital Surface Model, a Japanese research team, led by Oono devised a new strategy.

The Crown Shape Index was, according to the authors, a new way of identifying tree crowns based on calculating the Canopy Height Model.

Its five step calculation method is presented below:

a) Calculate a 0.5 m Canopy Elevation Model from the Triangular Irregular Network (TIN) obtained from the points of the LiDAR data.
b) Calculate an angle ("phi 1"), known as the "upper open degree" (Oono, Numata et al.) between a vertical line and a line starting from each grid point and touching the crown surface
c) Obtain an angle ("phi 2), with the name "lower open degree" (Oono, Numata et al.)
d) Compute an angle "phi3" by halving the difference between "phi1" and "phi2", thus obtaining such angles in all the 8 directions surrounding of the current cell
e) The Crown Shape Index was estimated by averaging the resulting phi3 angles

The object of identification was cedar trees belonging to the species *Cryptomeria japonica*. The results showed that in a low density forest, this method was able to identify up to 80-90% of the trees, and decreased up to 10-20% in higher density stands.

On Swedish land, notable are the studies of Persson et al. (2002), Erikson (2004) and Holmgren and Lindberg (2019). They worked mainly on stands dominated by conifer forests (see the Introduction chapter) and apply a wide variety of algorithms from the classical watershed segmentation to the innovative Brownian motion, random walk and fuzzy rule-based (for more details see (Erikson 2004)). For the case of Erikson's work, the results are displayed as a method comparison sequence, subject to several trials on the Remmingstorp test site. Segments that cover more than 50% of manually delineated tree are judged as a correct representation by the authors. Having this in mind, shows that the applied methodologies (fuzzy logic, Brownian motion and random) yielded at least 80% of correct tree crown identifications. However, the percentage of identified trees is not treated species wise, so it is difficult to conclude whether the proposed methodologies would work the same for the case of a deciduous forest. Holmgren and Lindberg (2019) choose also Remmingstorp as a test location for their new automatic tree recognition algorithm. The algorithm is based on the watershed segmentation method applied on a density model resulting from 3D ALS (Airborne Laser Scanner) data. Results show an individual tree recognition percentage lying between 40-97% for a selection of 36 study plots chosen in the area. There is no exact species information about the tree species structure of the validation plots. All the information given in the beginning is that Remmingtorp is an area "dominated by Norway Spruce" (Holmgren and Lindberg 2019, p.1145). That makes it difficult to assess the success of the method for deciduous trees, specifically.

To sum up, the work of the local (Swedish) research teams in the direction of accurately identifying tree crowns has recorded wonderful progress, but the issue of focusing only on identifying deciduous tree crowns still remains a problem that requires further testing.

3. METHODOLOGY

This chapter starts by providing a short geographical description of the study area. Next the reader shall be informed about the field data collection. Then information about the available digital data and the project workflow is presented.

3.1. Study area

The research area is located in southern Sweden, in the region of Scania, on the territory of Osby municipality, on the eastern shores of Lake Osby (in Swedish *Osbysjön*, nearby the hamlet of Dubbarp). It covers an area of 6.25 km^2.The underlying terrain is partially hilly, with elevations that range between 65.7 and 106.8 m (based on RH2000 elevation system). The general orientation of the slopes is NE-SW, with the lower elevations oriented towards the shores of the lake and those of Helge river. The highest elevations correspond to the point called Klinten (Lantmäteriet 2020), located NE of the hamlet of Ebbarp. The local land cover includes forests of conifers and conifers mixed with deciduous trees. Isolated trees located next to farmland and neighbouring the main water body have been also identified. A patchwork of agricultural lands and pastures can be noted adjacent to farms and localities. (Figure 2). Considering the local conditions, the study area has been divided into 2 zones. The first zone is located towards the northern end and adjacent to Lake Osby (Ebbarp-Osbysjön). The second is located in the south, and covers among other the Näset nature reserve (Näset). While in the first area, trees are either isolated, easy to identify or adjacent to agricultural land, in the Näset zone, they are located in a dense forest covering a wetland. Based on earlier pilot field examination, the whole research zone has been described by Länsstyrelsen as a possible location for tree candidates that might be listed as protected. The brief terrain investigations undertaken by the same institution in collaboration with experts from the Swedish Agricultural Science University (SLU) revealed the presence of old deciduous trees higher than 15 m that host important elements of entomofauna and fit as protection candidates. Examples of some of the identified candidate trees are shown in figure 3.

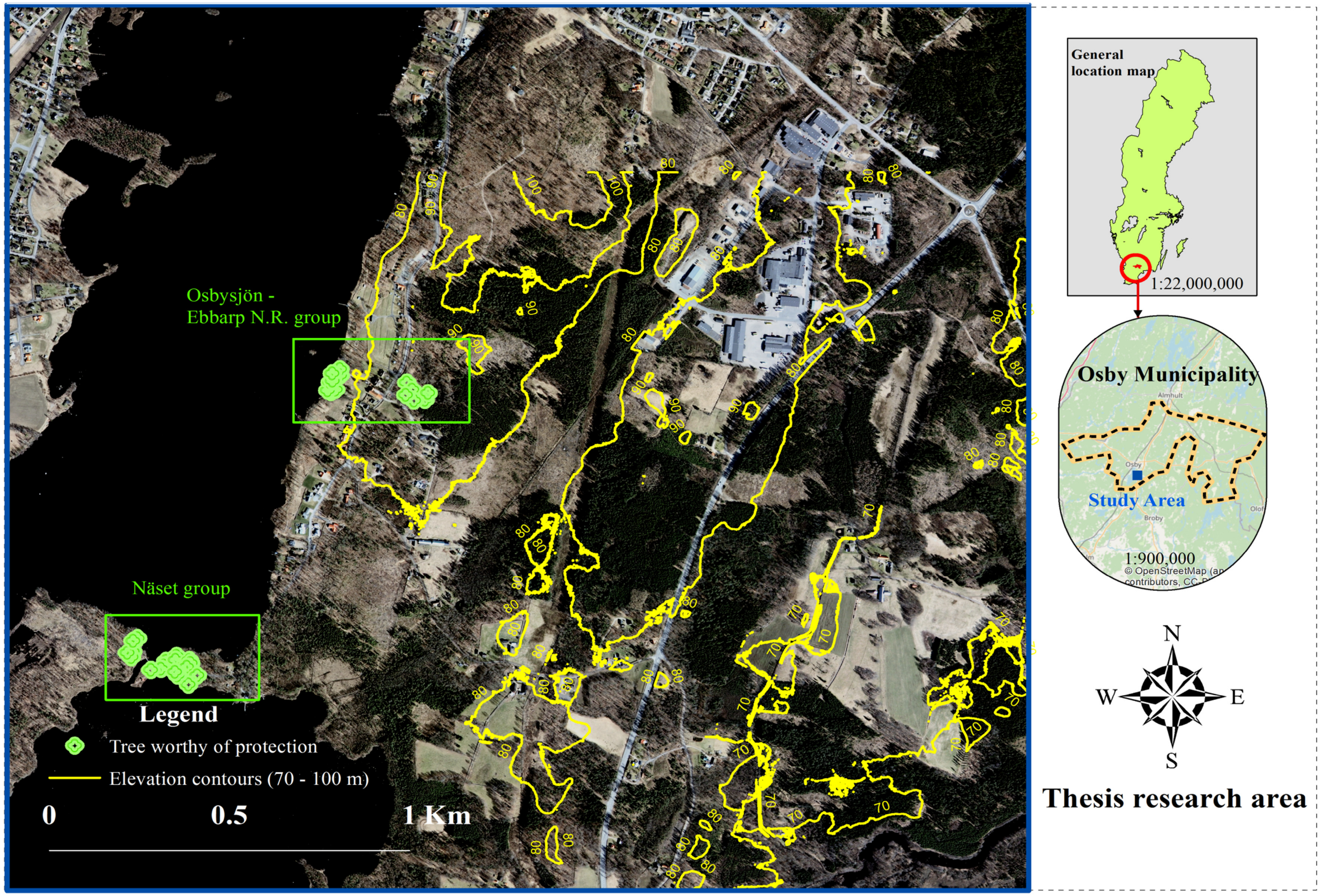

Figure 2. **Overview map of the study area (Sweden's outline and Osby municipality map ©Statistiska centralbyrån Digitala gränser + Background: Ortofoto färg 0.5 m (2010) © Lantmäteriet + © Openstreetmap contributors**

Figure 3. Collage of some field identified TWPs. All of them are oaks. Author's picture

3.2. Field observations and data processing

In order to better establish what a tree worthy of protection is and discover potential candidate trees, it has been decided to undertake a field study together with experts from SLU and the Administrative County board. During this field study, all of the trees worthy of protection in the area have been identified and photographed with a phone that had GPS location enabled. Having location information turned on while photographing leads to saving of the geographic coordinates where the picture was taken. These coordinates can be retrieved from the metadata associated with a photograph. This metadata is known under the technical name of Exchangeable Image File Format (EXIF) data. For this research, the approximate coordinates of each tree trunk have been extracted using an EXIF data reader available online (Exif-viewer.com 2020). Subsequently these coordinates were plotted on map in ArcGIS. The geographic locations as well as measuring the crown diameter and height of identified tree candidates were carried out during a later field visit. The measuring method employed for crown diameter determination consisted of calculating the distance between the widest and the narrowest diameters of the crown and then dividing them by 2. These distances were perpendicular and their metrics were obtained by placing a measuring tape on the ground at the point where the projection of the widest and narrowest crown points on the ground (figure 4).

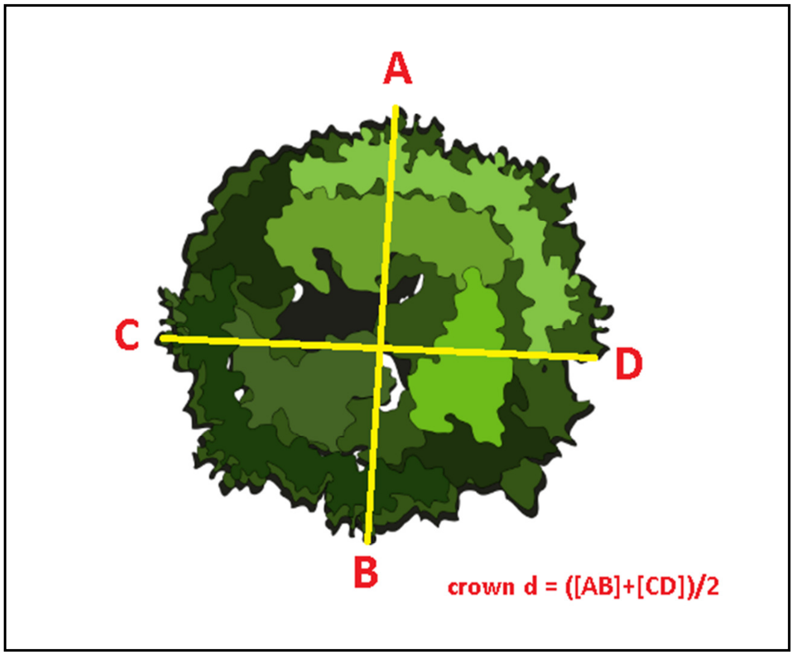

Figure 4.The methodology used for measuring the average crown diameter of a single tree

A SUUNTO® PM-5/360PC clinometer was used to determine the heights of the candidate trees (figure 5). Considering the low slope of the research area, all the trees were measured using the *slope percentage method.* This procedure consists of several steps. The first step was to find a position where the top of the tree to be measured could be clearly seen. Subsequently, the horizontal distance between the measurer's position and the tree stem was measured (horizontal distance, HD). Thirdly, the clinometer was oriented towards the top of the tree and the slope percentage was read and noted on an agenda. This percentage was multiplied with HD to obtain the *partial height* (PH). The final step was to add the user's eyeball height (measured as 1.65 m) to the resulting PH as to obtain the final tree height (Suunto 2020).

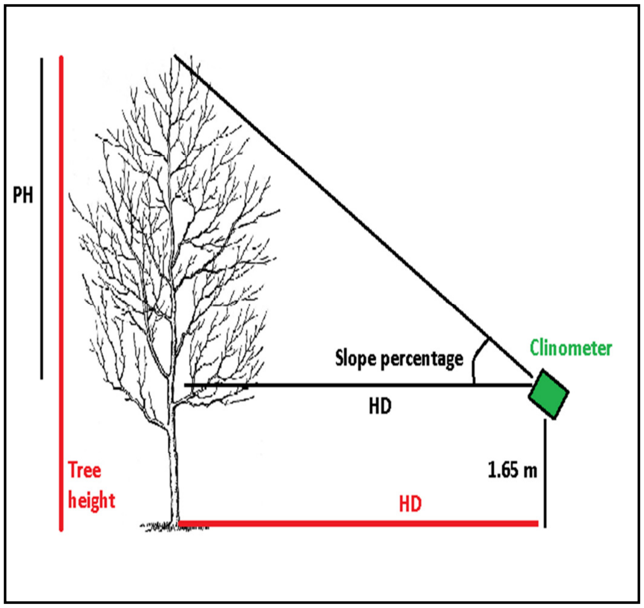

Figure 5. Approximating tree heights with the slope percentage method (own drawing)

Each candidate tree was photographed and its approximate position was registered using a GPS device.
Diameter data and height has been also attached to the GIS point layer depicting the tree location of tree crowns. For evaluation purposes (see more in the "Post-processing" section, a buffer based on the tree diameter values was applied on the point's layer.

3.3. GIS data

For the segmentation trials, the following spatial data has been made available:

- **A LiDAR point cloud provided by Lantmäteriet**. Details about its technical attributes are given in table 1.

Table 1. Technical aspects of the LiDAR data

Parameter	Value
Date of acquisition	03.04.2010
Sensor	Leica ALS60
Laser pulse rate	104100 Hz
Field of view	40°
Scan altitude	2248 m
Average point density	0.56 points/ m^2

The LiDAR point cloud is already filtered and it registers up to 7 returns of each pulse (Lantmäteriet 2019).
Simply put, a return is defined as a reading from an emitted laser signal that is bouncing off a surface. The number of returns is associated with the amount of reflective surfaces the laser pulse is bouncing off until reaching the LiDAR system's reading unit.
The *first return* depicts the highest objects encountered by the sensor. Such point data is used to generate the Digital Surface Model.
In its path from the aircraft to the ground, the laser pulse hits natural features and artificial structures. The process of data filtration is necessary in order to make a clear distinction between e.g. vegetation, man-made structures and ground (Liu 2008). Filtration is carried out

using different algorithms. The fact that the data from Lantmäteriet is filtered can be translated as that it is already classified into different subgroups. For the current research, the point data that is described as "*ground*" is the cornerstone for constructing the Digital Elevation Model.

- **Near-infrared (NIR) aerial imagery composites** of the research area, collected in two different years (2010 and 2018). These composites consist of 3 bands: Red, Green and NIR. The spatial resolution of the NIR imagery is 0.25 m. The oldest NIR photographs have been collected on the 2nd of June 2010, while the newest batch was collected on the 11th of April 2018. From a phenological standpoint, the photographs taken in April correspond to the "leaf-on" period of vegetation, while the winter photographs illustrate the "leaf-off" sequence. Using this advantage, an index called **N**ear **I**nfra**r**ed **Dif**ference (NIRDIF), which attempts to segregate between conifers and deciduous trees, has been crafted. The formula for calculating the index is displayed below:

$$\boxed{\textbf{\textit{NIRDIF=NIR (Jun) – NIR (Apr)}}}$$

Table 2 describes some of the characteristics of the 2010 NIR imagery.

Table 2. Image parameters for the "leaf-on" subset (NIR, 2010)

Parameter	Value
Collection date	2.6.2010 13:17 – 14:56
Camera	Vexcel Ultra Cam XP
Flight altitude	4.200 m
Overlap between flight paths	60 % / 30% sideways
Vertical error	0.30 m
Error in plan	0.06 m

Table 3 illustrates the values for the later 2018 NIR image set, based on the metadata provided by Swedish Land Survey Agency (Lantmäteriet).

Table 3. Image parameters for the "leaf-off" subset (NIR, 2018)

Parameter	Value
Collection date	11.04.2018
Camera	Vexcel UCE-97
Flight altitude	3.700 m
Sun elevation	36.39 degrees
Sun azimuth	218.81 degrees
NIR wavelength	0.69 – 1.2 µm

- **A vector feature layer** that includes the previously detected candidate trees available from earlier field work conducted by Länsstyrelsen.

- **Ancillary data** such as municipal borders and the outline of Sweden, downloaded from The Swedish Statistics Office (SCB 2020). This data was mainly used as background information for the produced maps.

3.4. Software used

ArcMap 10.5 (ESRI, 2016) and eCognition Developer 9 (Trimble, 2019) was used for the current research.

3.4.1. ArcMap 10.5

One of the proprietary GIS software includes modules that can process vector and raster data, extract spatial statistics.

3.4.2. eCognition Developer 9

Trimble eCognition is software used to conduct object-oriented image analysis with applications in radiology and remote sensing (Schmidt et al. 2007) and it is built on the basis of Cognition Network Technology (CNT). Invented in 1996 by a German Nobel Physics Prize laureate, Gerd Binnig, CNT emulates “human cognition processes using knowledge based and context dependent processing”, (Schmidt, Hosrsch et al., p. 282), the rationale behind choosing the upper mentioned software its powerful ability to process spatial data using a wide variety of algorithms. Included in the package are, among other algorithms, multi-resolution segmentation, local maxima, grow region and watershed segmentation, which were shown in the previous section of this thesis that have provided promising results in the attempts of isolating individual tree crowns.

3.5. Workflow

3.5.1. Overview

Encouraged by the positive results obtained by Erikson (2004), Holmgren and Lindberg (2019) on Swedish ground and the modern research trend of using GEOBIA (Chen et al. 2018), this thesis also on using LiDAR data and image segmentation as focal employed technologies. The reason behind this choice is anchored in the fact that (a) previous research (Heurich 2008; Kaartinen et al. 2012; Holmgren and Lindberg 2019) have demonstrated that LiDAR point clouds are very accurate elevation indicators when measuring the canopy height and (b) the many algorithms included in the eCognition package offer an almost endless opportunity to compute solutions that might help with a correct identification of the trees worthy of protection that the Länsstyrelsen is looking to identify.

The workflow consists of experiments that follow a simple two-step sequence, after a pre-processing operation (figure 6). The first step is to pre-process the raw data. The second step is to produce the segmentation using methods and parameters that might differ from test to test. Note that in the following diagram the NIR values corresponding the leaf-on (June) and leaf-off (April) phenological periods have been noted as $\mathbf{L_{on}}$ and $\mathbf{L_{off}}$. Finally, the segmentation results are imported in ArcGIS for final post processing. Each of the steps is described in the following sections.

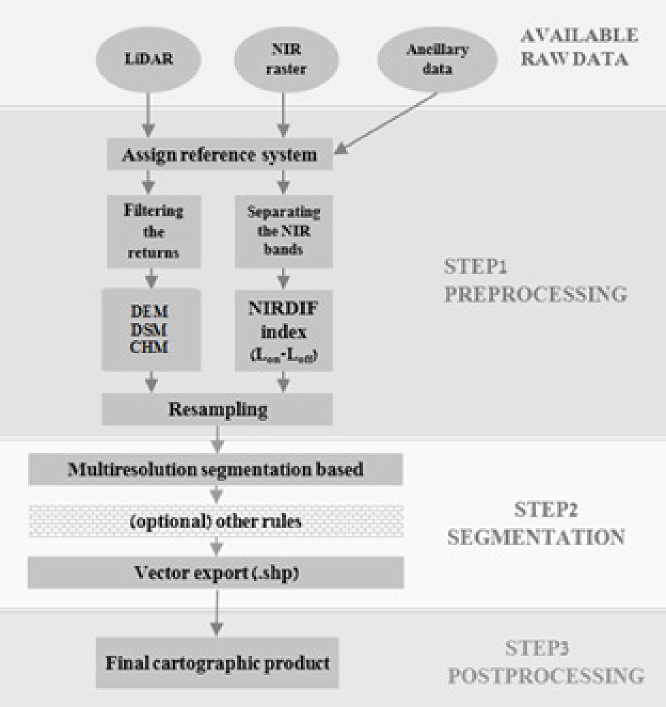

Figure 6. Description of the main moments in data processing (thesis workflow)

3.5.2. Raw data processing

Considering the available datasets and the technical requirements for the project, the raw data processing consists of two different steps that were executed exclusively in ArcMap.

Based on theoretical support from previous research works (see for example Heurich (2008)), the ***first step*** is to process the LiDAR point cloud and obtain the CHM (Canopy Height Model), which shall serve as a segmentation element.

Firstly, the LiDAR data is imported into ArcGIS using the built-in point cloud processing tools. Subsequently it was projected using the SWEREF99 TM (EPSG: 3006) and RH2000 for the z (elevation) values. Further, the points that were filtered firstly by return number and subsequently by category resulting in *two distinct features*. The first feature included only points classified as first return, while the latter's constituents were points classified as "*ground*" by the data provider. Both of the resulting features were rasterized. The raster corresponding to the "first return" (thus the highest reflecting features) was used to compute the Digital Surface Model (DSM). The raster corresponding to the "ground" features was used to compute the Digital Elevation Model (DEM).

In order to fill in for the missing values in the rasters, the Natural Neighbor interpolation method was used (Sibson 1981). This method, coined by Sibson in the early 1980s relies on constructing Voronoi polygons around all the points around the missing value. Then, a similar Voronoi polygon is constructed around the point that has the missing value and confronted with the previously created network of polygons.

The influences of the neighbouring values on the value to be calculated are obtained by calculating weights based on the percentage of overlapping between the previously displayed Voronoi surfaces. The final value of the missing point shall be given by the weighted average of the values of the surrounding points. More detailed information about the method's functionality can be found in Sibson (1981). After the interpolation operation was complete, the DSM and DEM rasters were resampled to a resolution of 0.5 m/pixel. The Canopy Surface Model (CHM) raster was obtained by subtracting the "*ground*" raster (DEM) values from the digital surface model (DSM) raster. Values from this grid were subsequently used in the segmentation procedure.

The ***second step*** is to produce an index that might help with species discrimination (NIRDIF). This assumption is enforced by studied literature, among others, Nagendra (2001), who suggests that the near-infrared radiation is a good species discriminator, and Axelsson et al. (2018)Axelsson et al. (2018) whose research points out that deciduous trees usually have a higher reflected near-infrared value than conifers.Before attempting to create the NIRDIF index, some preparation work was needed to be made. Processing of the infrared false colour composite imagery began with separation of the bands representing the NIR bandwidth. The operation was completed in ArcCatalog.

The NIRDIF index was calculated by the difference between the "leaf-on" and the "leaf-off" digital numbers. The scientific support behind this mathematical operation is that during the cold ("leaf-off") season the quantity of reflected NIR is lower in hardwood (deciduous) species compared to the summer "leaf-on" season.This happens because the absence of green leaves in the cold season, and thus due to lower water quantities in the leaves caused by the loss of leaves during the cold season (Axelsson 1993). Conifers maintain their foliage all year around and therefore greater differences in this index should be expected for the deciduous trees. NIRDIF values corresponding to conifers were considered the ones below 60. The NIRDIF layer was resampled from 0.25 m/pixel to 0.5 m/pixel to match with the CHM.

3.5.3. Segmentation

The software chosen to operate the segmentation analysis was eCognition. The plan to find the best solution for identifying the TWPs through experiments based on variations of the multi-resolution segmentation algorithm parametrizations. The *multi-resolution segmentation* is a bottom-up approach algorithm included in the eCognition software. It starts by initially dividing the whole working area into one-pixel sized segments. Based on homogeneity rules defined by the user, the initial one-pixel segments gradually extend to include their neighbours, thus resulting in customized multi-pixel units. For the creation of the segments, the user can *assign weights* to the spatial or optical components that contribute to defining the homogeneity rule. The higher the value of the weight, the more importance the algorithm would give to a certain component. Furthermore, the user can also set the values for other characteristics that govern the segment formation such as *Scale*, *Compactness/Smoothness* and *Shape/Color*.

The ***Scale*** parameter decides the size of the resulting segments. For example, a higher scale parameter value would result in a lower number of segments in the working area, in comparison with lower scale value, which would have the exact opposite effect in dividing the working area into segments.

The values of the ***Compactness/Smoothness*** parameter work together in such a way that the sum of their weights equals 1. Modifying a value of the first one, would automatically influence the other. This parameter refers most probably to the intrinsic homogeneity of a segment.

The values of the **Shape/Color** parameter work in tandem, similarly to the above described parameters. The greater the Shape parameter is, the less importance the algorithm would give to the **Color** value. The **Shape** parameter regulates the spatial homogeneity of the segments while **Color** governs the optical one.

In the attempt to find the best solution for identifying deciduous trees, 14 experiments have been conducted. They were conceived to include a wide variety of multi-resolution segmentation algorithm parametrizations, aiming to best fit the processing requirements. The functionality of this procedure is described by Bar Massada et al. (2012): "[eCognition] uses a heuristic optimization procedure that locally minimizes the average heterogeneity of newly defined image objects for a given resolution" (Bar Massada et al. 2012, p.347). Multi-resolution segmentation uses a weighing system for the input image datasets. In the experiments in this thesis (Table 3) different weight values have been applied to the segmentation components with the purpose of testing the effects of several variables on the object creation procedure. One experiment, T9 (see Table 4 for a detailed information on parameters used), is based on contrast split and watershed delineation segmentation techniques. This was done intentionally as to have a reference point, as per contrast split segmentation is a straight forward segmentation technique that considers only one parameter (the contrast difference - optical) between analysis objects. However, the multiresolution segmentation technique is based, as shown above, on several parameter values.

Considering the available digital data and the targets of interest, creating objects that would satisfy the spatial (CHM) and radiometric (DN of near-infrared) conditions for these trees would become the rule of thumb. Similar experiments, showing the importance of elevation and near-infrared reflectance in tree crown determination were conducted by several scholars (Kaartinen et al. 2012; Axelsson et al. 2018).

Usually the Multi-resolution segmentation results are assigned to classes based on their average CHM value. In the attempt of incorporating as many tree parts as possible, even the ones that are located in a lower canopy level (lower pixel values in the CHM raster), a reference height of 9 m has been chosen as the decisive threshold between "*lower objects*" in the forest and "*possible trees of interest*". The reference height of 9 m was chosen after several trial and error attempts. This height was shown to include the upper canopy of the local forest and it was higher than any man made feature in the area. After running some segmentation experiments (see Table 2 for more details), it was necessary to develop a special "*high pixels*" feature layer because the results were not satisfactory enough. Hence a mask delineating areas of interest ("high pixels") was created through composing a binary layer from the existing CHM (CHM_binary). The values greater than 9 m were reclassified as "1" while the lower elevations received "0" as value.

Experiments T7A, T8 and T9 combine Multi-resolution with contrast split segmentation or watershed segmentation. The contrast split segmentation method uses the differentiation in spectral contrast between objects to classify them in "Dark" and "Bright" based on a "threshold value that maximizes the contrast between them" (Trimble, 2019). The threshold values chosen for the experiments were based on trial and error. This procedure was used in the attempt of adding subsequent forest pixels that were excluded by the Multi-resolution algorithm (1) and remove elevation holes (objects with elevations lower than 9m) from the already determined objects (2). As regards to watershed segmentation, the main rationale behind using this was to improve/refine the existing object creation, inspired by the fruitful test of Heurich (2008), who used this technique to highlight the crown form of different tree species.

Some of the experiments have the same structure as the previous ones with only some of the parameter values changed based on the achieved result. The nomenclature of the experiments consists of the letter "T" (deriving from "test") and an incrementing control number that starts at 1. Experiments that derive from previous ones without major structural changes (the same sequence but different parametrical values) have an adjacent letter in their denominations (e.g. T1A, for a parametrical rehash of a test that is morphologically based on T1). Table 4 includes information about each carried experiment and gives a brief motivation for the choice of a method. Each experiment alongside its employed algorithms has been colour coded to ease the table readability.

Table 4.Technical description of the carried experiments presented step by step

Experi-ment	Steps	Parameters for each step	Justification
T1	Multi-resolution segmentation	NIRDIF:7, CHM:10, Scale: 30, Shape:0.5,Compactness:0.5	The usage of Multi-resolution segmentation creates objects that are based on a statistical weighing of the given parameters
	Assign class "Possible trees"	CHM > 9	Deciduous trees have a broad extension in width. By choosing this elevation value it is hoped that some of the lower branches of the trees are also taken in consideration. At the same time, the eventuality of "fishing" other objects such as houses or a building is low.
	Grow region (expanding the seed object with neighbouring objects satisfying user defined criteria)	CHM relative border to bright objects >10 on the "unclassified" category	Trying to include as many other parts as possible from the trees as to be able to include as much tree information as possible
T2	Multi-resolution segmentation	NIRDIF: 10 (weight), CHM: 7 (weight), Scale: 50, Shape:0.5, Compactness:0.5	Reducing the influence of the height parameter in the statistical test and increasing the object size
	Assign class "possible trees"	CHM > 9	
	Grow region	CHM relative border to bright objects >10 on the "unclassified" category (user defined condition)	

T3A	Multi-resolution segmentation	NIRDIF: 7, CHM: 10, Scale: 70, Shape:0.5, Compactness:0.5	Increased the size of the objects based on the obtained results. For more details please relate to the “Results” section.
	Assign class “possible trees”	CHM >9	
	Grow region	CHM relative border to bright objects CHM >10 (candidates: “unclassified”)	
T3BA	Multi-resolution segmentation	NIRDIF:10, CHM:7, Scale:30, Shape:0.5, Compactness:0.5	Increased the weight of the near-infrared difference index as to increase the chance of capturing deciduous trees
	Assign class “possible trees”	CHM >9	Assign class “possible trees”
	Grow region	(candidates: “unclassified”)	
T3BB	Multi-resolution segmentation	NIRDIF:3, CHM:10, Scale:40, Shape:0.5, Compactness:0.5	Based on the results of the previous test, the decision was taken to reduce the effect of the near-infrared index.
	Assign class “possible trees”	CHM >9	
	Grow region	border to bright objects CHM >10 (candidates: “unclassified”)	Grow region
T4	Multi-resolution segmentation	NIRDIF:10, CHM: 10, Scale: 40, Shape: 0.7, Compactness:0.3	
	Assign class “possible trees”	CHM >9	
T5	Multi-resolution segmentation	NIRDIF:10, CHM: 0, Scale:40, Shape:0.7, Compactness:0.3	
	Assign class “possible trees”	CHM >9	

T6	Multi-resolution segmentation	NIRDIF:5, CHM_bin:10, CHM:10, Scale:40, Shape: 0.7, Compactness:0.3	
	Assign class “possible trees”	CHM >9	
T7	Multi-resolution segmentation	NIRDIF:5, CHM_bin:10, Scale:30, Shape:0.7, Compactness:0.3	
	Assign class “possible trees”	CHM >9	
T7A	The initial logical sequence follows the exactly the parametrization described in the T7 test (see T7)		
	Contrast split segmentation	Class: “**possible trees**”, Min: 0, Max: 255, Stepping :add, Layer: CHM_bin, Bright objects: “refined trees”	
	Contrast split segmentation	Dark objects: “Trash”, Contrast mode: edge ratio, Minimum object size:20	Eliminate holes in the canopy and produce a more accurate tree segmentation
T8 (continues below)	Multi-resolution segmentation	NIRDIF:5, CHM:10, CHM_bin:7, Scale: 30, Shape:0.6, Compactness:0.4	
	Assign class “potential trees”	CHM >9	

T8	Contrast split segmentation	Class: “**potential trees**” Min:0, max:255, step:add, layer:CHM_bin, Bright objects: Trees, Dark objects: Holes, Contrast: object difference, Object size min: 20, Minimum contrast:5	Trying to define objects that are finer, and adjust borders
	Watershed segmentation	CHM based The layer was inverted Neighborhood: 8	Previous research (see the Background chapter) shows that watershed segmentation based on elevation can be a good way to separate tree crowns.
T9* **(non Multi-resolution segmentation based)**	Contrast split segmentation	Layer: CHM_binary, Dark objects: Trash Bright objects: Possible trees Contrast mode: Object difference, Smallest object:20, Min contrast:5	An attempt to firstly detach all of the holes in the layer from all of the canopy elements.
	Contrast split segmentation	Layer: CHM Dark objects: Cr_parts, Bright objects: Tree tops, Contrast mode: edge Smallest object:1, Min contrast:5	An additional contrast split segmentation based on CHM in order to possibly identify tree tops.
	Watershed segmentation (intended but subsequently discarded)		This step was intended but discarded at a later stage because of the poor results obtained during a pre-testing attempt

T10	Based on the processing in T9 and assigning a class of “high objects” based on a processing where the CHM is greater than 9		See the previous experiment for the data processing sequence
	Multi-resolution segmentation	Layer: “high objects” CHM_bin: 0, NIRDIF:5, CHM: 10, Shape: 0.6, Compactness:0.4, Scale:30	A try to segment the objects in the hoping to find the true shapes of the tree crowns
T11	Based on the results of T10		
	Merge region	Conditions: Border to high_trees >15px and Border to high_trees<30px	This pixel values were chosen as a result of several trial and error attempts to find good values to merge the segments which were visually evaluated as belonging to the same tree.

3.5.4. Post-processing and evaluation

The results of the eCognition segmentation were vector files depicting segmentation results. They were imported in ArcMap. From the visual interpretation of the objects results, some of the candidate trees (an alternative denomination for the "protection worthy trees") in Dubbarp were identified and their centre was mapped using GPS coordinates (see the "Pre-processing" chapter).

Each GPS point representing a tree recognized in the field was then buffered by a value corresponding to half the diameter calculated during the field measurements.
The value of half of the diameter was chosen because of a technicality in ArcGIS. In detail, the "Buffer" algorithm embedded in the software was used and this procedure takes as "buffer distance" input a value corresponding to the radius of the circle surrounding the input point. Choosing the field calculated diameter as a buffer distance would result in trees with double width. Then, the buffered points depicting the trees were evaluated against the segments produced in eCognition.

A visual analysis from overlaying the segments with the existing trees worthy of protection in the study zone (buffered points) has been produced for all the experiments as to test each one's tree recognition accuracy. The procedure is described below.The method is reproduced from Erikson (2004), who tests segmentation results by evaluating their coverage against digitally measured tree crowns in a table. The table measures the amount of segments that cover a tree crown. This is summarized in a proportion having the form A:B (Erikson 2004), where "A" represents the crown and "B" the number of segments covering it. The evaluation rejects segments that cover less than 50% of the identified trees and adds these results to a "missing" variable. The "missing" variable increases also when "a segment covers two or more reference segments" (Erikson 2004, p.31) -*sic*, in our case, *reference segments* depicts tree crowns. Correctly identified trees are counted when a segment is covering either more than 50% of the crown and less than 25% of another crown.

4. RESULTS

The field observations carried out in Dubbarp identified a number of 32 trees worthy of protection, out of which 25 are oak; two are pine and one beech, birch and willow (described in detail in table 5). For exemplification, figure 7 shows tree #28. From a position perspective, these trees can be found either isolated, adjacent to buildings, on pastures or farmland or in vegetal associations such as groves or forests. Two areas with a predominance of trees worthy of protection have been identified. The first one is located in the northern part of the study area, on a line oriented W-E, from the shores of the Osby lake towards the eastern edge of Ebbarp village and *Ebbarps by* nature reserve (named by the author *Osbysjön-Ebbarp*). Here is where the most individuals have been identified. The second area is located towards the southern part of the study zone, adjacent to the *Näset* nature reserve.

Figure 7. Protection worthy tree (Oak from the Näset subzone, crown diameter: 12.6 m). Own photo

The disposition of the trees in the field is shown in figure 8. Elevation wise, the candidate trees have been approximated to have a height over 10 m.

In denser vegetation associations, they are more difficult to observe because they have been overtaken by faster growing species.

Table 5 shows among other parameters, the values of tree areas calculated using the buffer procedure explained in the "Methodology" section.

Table 5. Parameters obtained for the 32 identified candidate trees

Tree #	Species	Crown area (m^2)	Crown diameter (m)	Height (m)	Location
#1	Oak	44.1	7.5	11.4	Forest
#2	Oak	86.5	10.5	13.6	Forest
#3	Oak	221.6	16.8	19.6	Forest
#4	Oak	99.4	11.25	17.8	Forest
#5	Oak	74.6	9.75	17.7	Forest
#6	Oak	70.8	9.5	17.2	Forest
#7	Oak	44.1	7.5	20.7	Forest
#8	Willow	63.6	9	19.6	Forest
#9	Oak	63.6	9	17.2	Forest
#10	Oak	82.5	10.25	23.8	Isolated
#11	Oak	56.7	8.5	21.1	Isolated
#12	Oak	41.2	7.25	21.2	Isolated
#13	Oak	60.1	8.75	26.6	Forest
#14	Oak	49.0	7.9	22.9	Forest
#15	Pine	52.1	8.15	19.5	Isolated
#16	Oak	50.2	8	18	Isolated
#17	Oak	124.6	12.6	16.7	Isolated
#18	Pine	63.6	9	15.2	Isolated
#19	Oak	92.4	10.85	23.8	Isolated
#20	Birch	20.0	5.05	17.8	Isolated
#21	Oak	43.0	7.4	27.5	Forest
#22	Oak	60.8	8.8	18.2	Forest
#23	Oak	74.6	9.75	22.8	Forest
#24	Oak	66.4	9.2	20.2	Forest
#25	Oak	50.2	8	18.7	Forest
#26	Oak	87.4	10.55	20	Forest
#27	Oak	52.8	8.2	17.1	Forest
#28	Oak	94.1	10.95	17.6	Forest
#29	Beech	124.6	12.6	17.7	Forest
#30	Oak	33.1	6.5	12.2	Forest
#31	Oak	36.3	6.8	13.2	Forest
#32	Oak	76.2	9.85	16.1	Forest

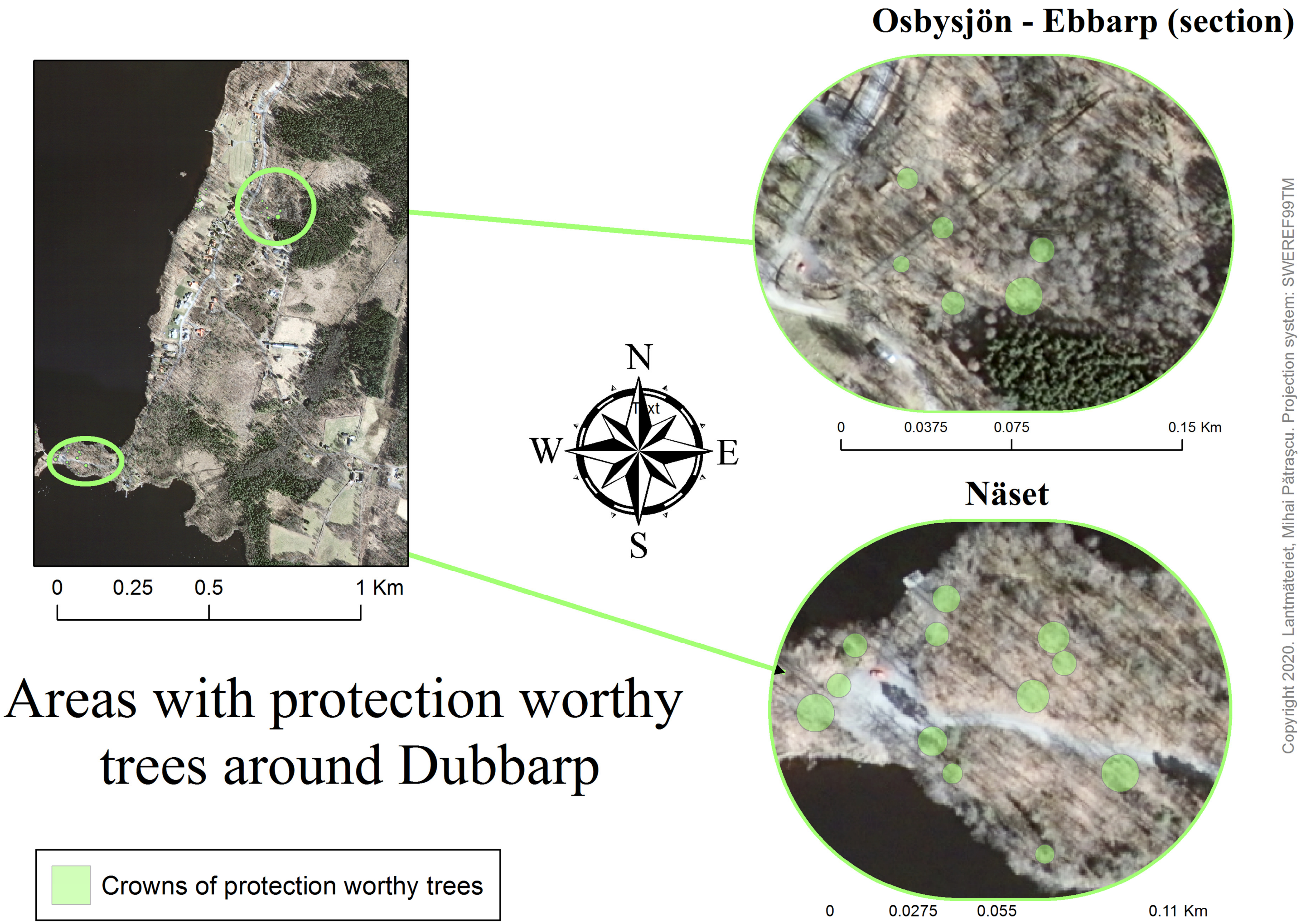

Figure 8. The identified trees worthy of protection near Dubbarp (Background: Ortofoto färg 0.5 m (2010) © Lantmäteriet)

Table 6 shows how many trees are represented by 1, 2, 3, 4 or "n" segments. The greater the amount of segments representing a tree, the higher the fragmentation. Tests T8 and T3AB have the highest fragmentation rates, with 17 and 10 tree crowns covered by more than 5 segments, respectively. At the other end, T3A and T2 have more compact segments. The accuracy metric, defined as the ratio between crown and number of segments that cover it, shows which percentage of the trees from the total amount has been precisely determined. With precisely determined it is meant that the tree crown has been represented by only one dominant segment.

Table 6. Segmentation accuracy for each test based on how much a tree is covered by a segment (T1-T11)

Experiment#	**1:1**	**1:2**	**1:3**	**1:4**	**1:n (covering more than one segment)**	**1:0 (totally missed trees)**	**Accuracy (% of non-missed trees represented)**
T1	2	5	5	6	7	7	15.6%
T2	8	8	8	-	-	8	25%
T3A	7	4	4	1	-	16	28.1%
T3AB	2	3	3	7	10	7	9.3%
T3BB	6	10	7	1	-	8	31.2%
T4	5	9	3	1	4	10	25%
T5	7	6	4	2	6	7	18.75%
T6	5	8	4	1	-	14	21.8%
T7	7	4	5	4	2	10	25%
T7A	8	5	5	3	1	10	6.25%
T8	3	-	-	1	17	11	0%
T10	3	6	6	11	6	-	25%
T11	3	6	7	10	6	-	28.1%

Generally, the conducted experiments show that tree crown representation accuracies ranges from 0 to 31.2%.

Out of the 32 selected candidate trees, the crown of tree #6 (an Oak with a crown diameter of 9.5 m and 17.2 m tall) has been accurately (1 dominant segment covering most of the crown's surface) recognized 11 times. On the second place comes the tree crown of candidate #2 (an Oak with a crown diameter of 10.5 m and 13.6 m tall) which was successfully detected in 10 experiments. Then follow three crowns #4, #7 and #14 (Oak trees with crown diameters ranging from 7.5 to 11.25 and heights ranging from 17.8 -22.9 m) which were identified in 9 experiments each. Tree crown #13 (an Oak with a crown diameter of 8.75 m and 26.6 m tall) was successfully accounted for in 8 tests, followed by the crown of #12 (an Oak with a crown diameter of 7.25 m and 21.2 m tall) which was found 7 times. Fifteen trees worthy of protection crowns were found between 1-5 times. Tree crowns #15 and #29 were only recognized only during T7, while 5 crowns (#9, #19, #22, #23 and #24) could be separated only during experiment T9. Eleven crowns (#10, #11, #16, #17, #18, #21, #28, #30, #31 and #32) could not have been accurately depicted in any of the carried tests. Figure 8 shows the trees which have been accurately represented more than 5 times.

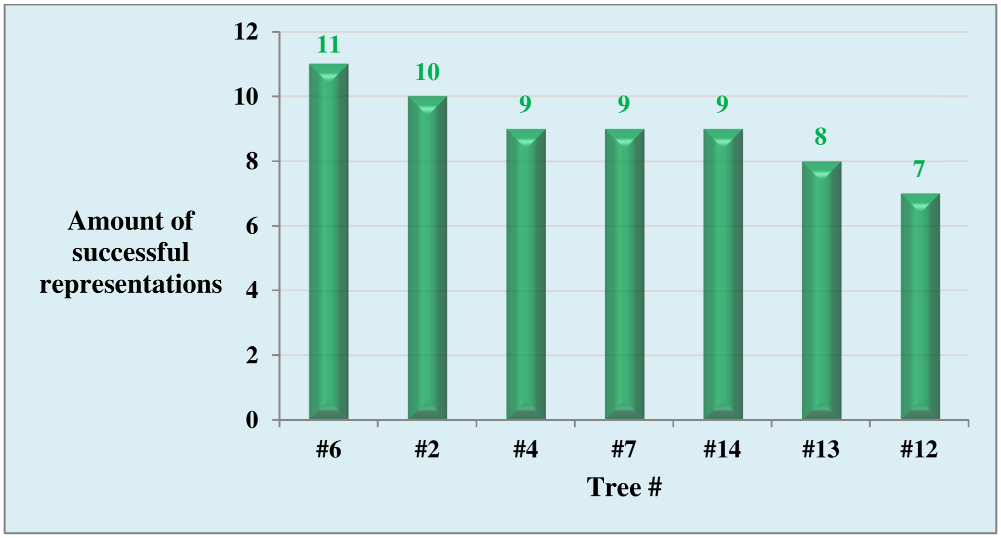

Figure 9. Experiment segmentation accuracy for individual trees

In terms of *geographical distribution*, the trees that were identified the most times are located in the Osbysjön-Ebbarp research area, while the least successful attempts regard the test zone located adjacent to the parking lot in the vicinity of Näset nature reserve. *Species wise*, the most detected trees (8-11 times) are with no exception oaks. In the case of the non-detected trees, oaks also dominate. The identified trees belonging to the species pine and beech considered also as suitable candidates for protection could not be detected by the conducted tests. In terms of height, the trees with most detections range between 13.6 -26.6 m with an average of 19.8 m. As regards the crown diameters, the trees identified the most have crowns ranging from 7.5 – 11.25 m. The next section presents the results of the most successful and failed experiments, concentrating on the particularities of each.

Experiment 1

This experiment identified correctly five trees (dominant segment covering the surface of a buffered point) out of the total 32 candidates (success rate 15%). Region wise, the majority of the trees in the area Osbysjön-Ebbarp have been spotted and some of the trees located on Näset. A general tendency of fragmentation is noted (figure 10); seven tree crowns occupied by more than 5 segments. Trees that are described by several segments are usually the ones having the widest crowns. Area wise, it is difficult to distinguish which of the segments really represent the tree worthy of protection, except for the cases of trees #2, #6, #7, #12 and #14. In these cases, a greater, dominant segment covers more than 51% of the tree's circular model. Added to that there is no clear division between species, with the segmentation resulting in both deciduous and conifers. The mean NIRDIF values for the dominant segments that cover the tree sketch range from 26.1 (#7) to 92.1 (T14). The dominant segment in T12 has also a high NIRDIF value (78.1). The mean height values in the same domain range from 15.9 m (#12) to 19.4 (#6).

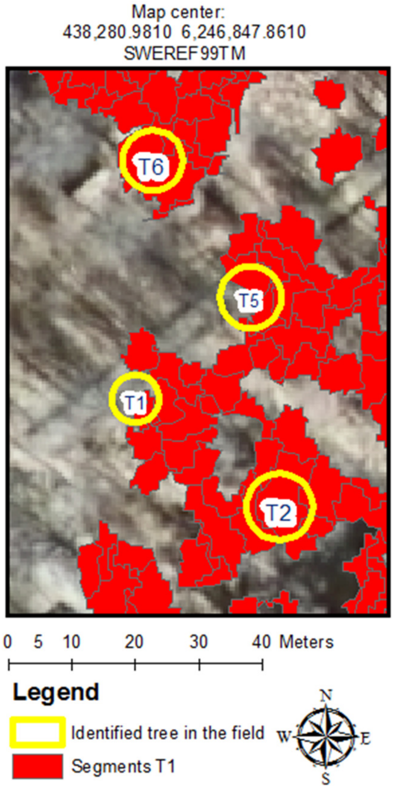

Figure 10. Experiment 1 segmentation (Background: Ortofoto färg 0.5 m (2010) © Lantmäteriet)

The preponderance of lower NIRDIF values is reported in the forest, while the higher index values dominate the more isolated trees.

Experiment 2

Overall, the effect of using the NIRDIF index with the highest weights and a wider scale parameter in the Multi-resolution segmentation procedure is that the segments are more compact, with three being the highest number of parts covering an identified crown. Eight trees from the total of 32 have been totally missed, with no segments inside the tree shape. The discovered trees are composed of several big segments which leads to an exaggeration of the crown surface (figure 11), where segments encompass a wider forest area.
Species delineation between conifers and hardwood trees is still not present; however tree #18 which belongs to the genus *Pinus* was not recognized. For the identified trees, the NIRDIF index ranges from -19 to 90.7. Three trees (#1, #6 and #26) have been accurately identified (figure 11). Their crown consists of only one segment, which stretches well beyond the delineated tree shapes. The average NIRDIF values for the most representative segments (#1, #6, #26) range to -22.7 (#26) to 50.8 (#6).

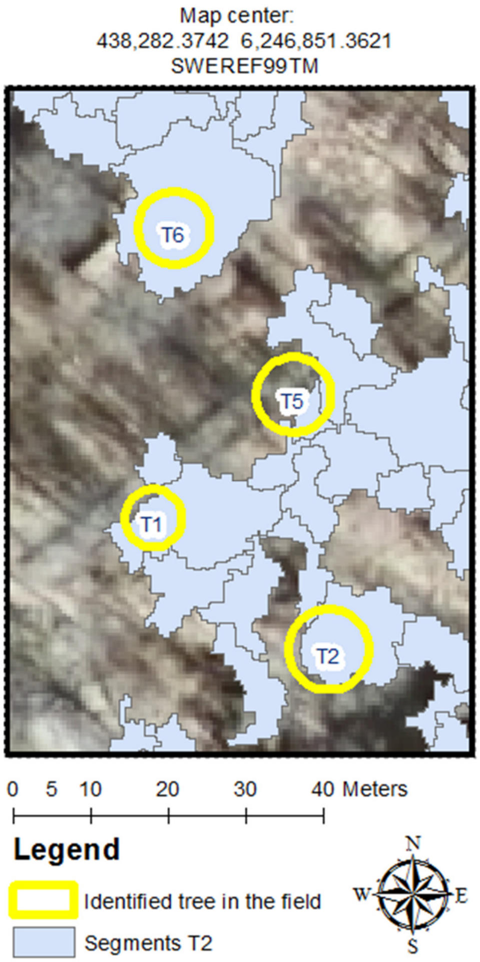

Figure 11.Exaggeration produced by over-segmentation (Background: Ortofoto färg 0.5 m (2010) © Lantmäteriet (2010))

Experiment 3A

The increased scale factor applied to this experiment resulted in compact segments. These big segments encompass entirely or partially trees worthy of protection. A number of 9 crowns have been identified, raising the accuracy for this test to 28%. On the negative side, half (16) of the trees have been totally missed. Trees #1, #5, #6 and #25 are composed of a unique dominant segment covering the crown surface in percentages ranging from 66.6 % to 100%. These dominant segments stretch well beyond the surfaces of the given trees, encompassing crowns belonging to neighbouring tree elements. Tree 6 was better isolated than in the previous two experiments (figure 12). Another five trees are composed of amalgams of 2-3 segments of similar size. For the rest of the elements, the segments were not wide enough to cover a significant part of the tree construct. The NIRDIF values for the single segmented trees stretch from 6.8 (tree #1) to 50.6 (tree #6).

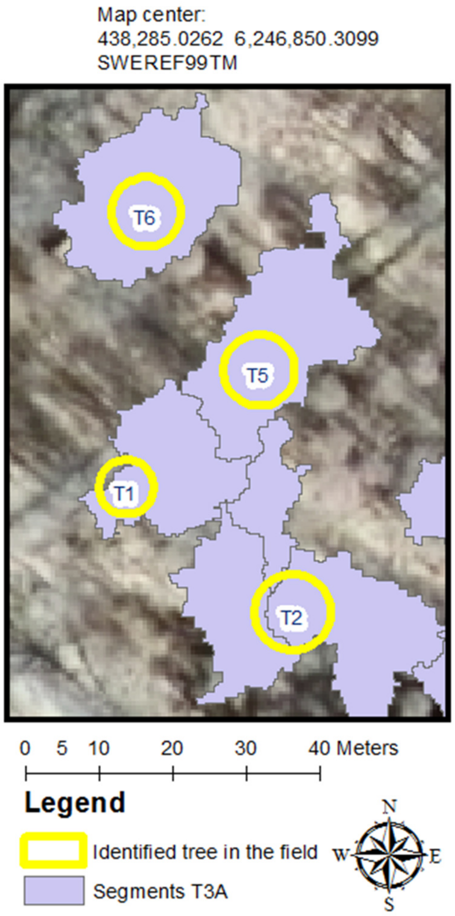

Figure 12. Experiment 3A. Better isolation of tree #6 (Background: Ortofoto färg 0.5 m (2010) © Lantmäteriet)

Experiment 3BB

Overall, the structure of the segments is very fragmented with 10 correctly detected trees (31.25% accuracy) and 8 that do not have any segments within their sketched crowns (see figure 13). From the detected trees three (#2, #5, #8) are covered by a unique segment, while the rest are covered by an association of 2-4 segments, with one that has a dominant coverage. This is the first experiment where segmentation analysis identifies a tree that is not an oak - #8, willow. Usually the great segments encompass neighbouring areas to the identified trees. The coverages (for unique segments) range from 77 – 80.2 %. In two cases (trees #7 and #10), the segmentation recorded "near misses", meaning that the dominant segment had a 40-45% coverage the candidate tree buffer zone. The NIRDIF values for the one-segmented trees range between 15.5 (#8, willow) and 44.4 (tree #5).

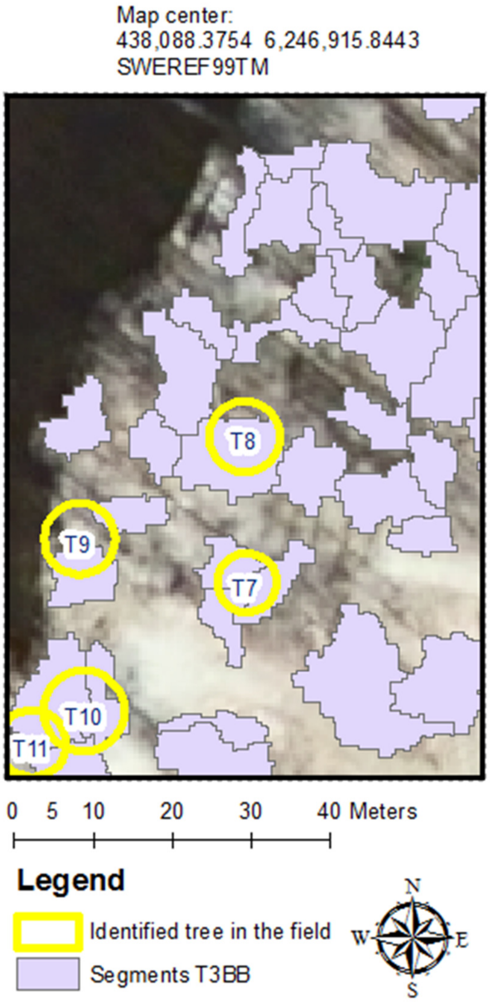

Figure 13. Experiment T3BB. Willow tree #8 (Background: Ortofoto färg 0.5 m (2010) © Lantmäteriet)

Experiment 4

In what regards segmentation, no breakthroughs have been obtained by running this experiment. As in the previous test, there is no clear distinction between deciduous and conifers and several tree surfaces are covered by several segments, although tree #18, a pine is not covered by any segment. Eight tree crowns have been accurately detected. None of them consist of a unique segment, but from amalgams of 2-5 parts (greater fragmentation) with one dominating segment that covers more than 50% of the identified tree's crown area. Even in this experiment, the willow tree (#8) has been identified, with the largest fragment covering 53% of the crown surface. Trees #1, #9, #10, #11 are "near misses", with the greatest segments covering areas between 42.5 and 45.4% of the crown areas. In the case of tree #9, the near miss is covered by a single segment.

Experiment 8

Overall, this experiment yields the poorest accuracy, with no digital identification of the measured in field trees (0%). This segmentation produces very small fragmented objects. In the case of the tree worthy of protection trees worthy of protection, each estimated crown is covered by at least two objects, where none covering the crown surface with more than 50% (figure 14). Nine trees did not include any kind of segment. This experiment was thought to be included in this research as a negative didactic example showing the effects of over segmentation.

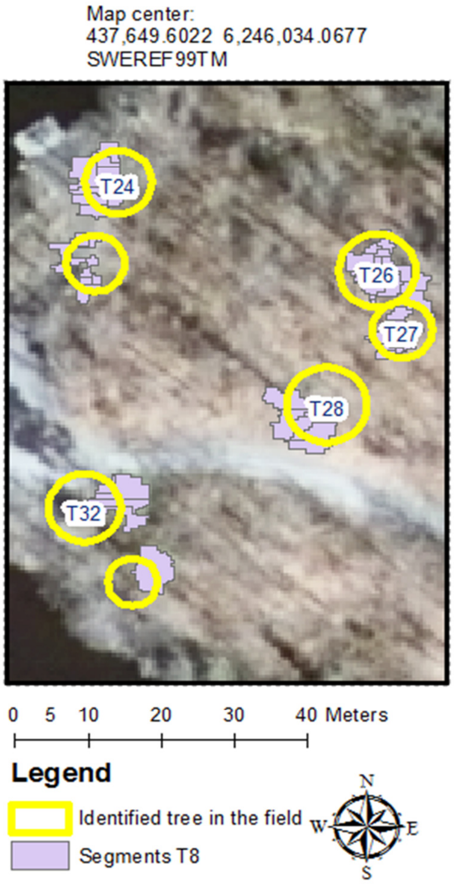

Figure 14. Oversegmentation and missing trees in Näset (Background: Ortofoto färg 0.5 m (2010) © Lantmäteriet)

Experiment 10

This is the first experiment in which neither of the candidate trees for protection is devoid of segments. The total number of accurately identified trees is 8, out of which only one (#20) is described by only one segment, which covers 63% of the tree's calculated crown surface of 20.0 m^2. The rest are composed of agglomerations of 2-6 segments, out of which one of it dominates the tree model in percentages ranging from 51% (tree #4) to 81.8% (tree #12).

Experiment 11

Experiment 11 takes advantage of the two *contrast split segmentations* tested in experiment 9 and produces a more visually overall accurate picture of the study zone than experiment 10. In detail, the fragmentation is reduced, with more compact segments occupying the identified trees crowns. Like in the previous experiment, none of the field identified trees have been omitted. Nine trees have been accurately identified. Out of these, tree #20 is represented by only one big segment which covers a surface of 63% of the calculated crown. Alongside experiment 10, this experiment is the best at detecting patterns in the southern part of the research area, Näset (figure 15).

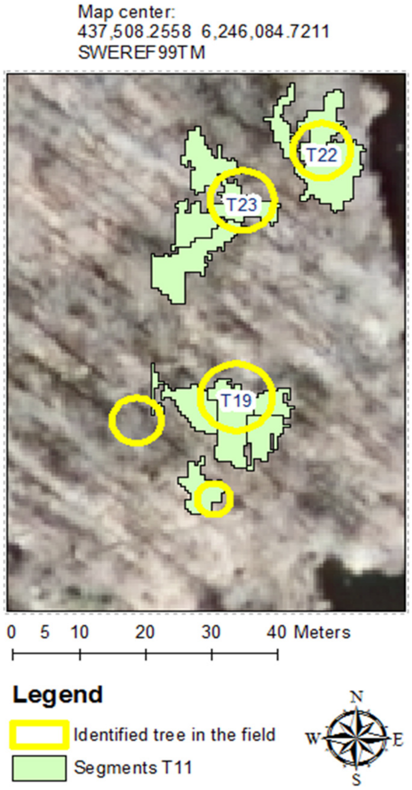

Figure 15. Segmentation on the western side of Näset.(Background: Ortofoto färg 0.5 m (2010) © Lantmäteriet)

To summarize, the best results were obtained by experiment T3BB, where it employed a Multi-resolution segmentation followed by a Grow region procedure. The accuracy of this method stands out to be 31.2%. The multi-resolution segmentation algorithm was fed with a “Scale” parameter of 40 and the values for Shape and Compactness were 0.5 each. The weights assigned were 10 for the CHM raster and 3 for the NIRDIF. The Grow region procedure perfected the already created segments with adding additional objects higher than 9m for a realistic depiction of the crown shapes.

5. DISCUSSION

The current thesis has focused on finding an adequate automatic segment-based solution to map the trees worthy of protection in a study area located near Dubbarp, Sweden, through several experiments. The structure of the chapter is twofold, with the first part dedicated to interpreting the findings and the following presenting some limitations connected to the applied methodology. This part is also where suggestions for further research are given.

5.1. Findings

Typically, all the 13 experiments were dependent on the local environmental conditions, with some of them performing better in the Osbysjön-Ebbarp area, while others adding value to the research by being able to recognize some trees in the zone around Näset. These findings are in line with what the literature has many times concluded, namely that each forest type requires a different parametrization of study for individual tree crown identification (Kaartinen et al. 2012; Zhen et al. 2016).

Moreover, the test results indicate that the identification of individual tree crowns is easier for the case of isolated trees than in the forest. This is the case for tree #7, which is located adjacent to a low field and has been represented by big dominant segments 9 times. Tree spacing and overlapping crowns in the forest can be the difference between the success and failure of a valid detection. This statement echoes the results of Erikson (2004), Oono et al. (2008), Shataee (2013), which take in consideration tree density as an important factor for a successful segmentation. In the case of the current research, many tests fail to fill the crowns located on Näset with distinctively big segments. An explanation for this failure is the presence of the trees worthy of protection in a dense canopy, among individuals with a more developed branch system, which reflect chaotically the laser pulses. The success of tests #11 and #12 in Näset is attributed mainly to the contrast split segmentation procedures that better filtered out the holes in the canopy (objects with lower height value) thus better controlling the responses from the LiDAR laser pulses.

An innovative perspective is given by the application of the NIRDIF index. Although the importance of the reflected NIR radiation is commented and demonstrated in the literature (see for example the study of Nagendra (2001) in the "Background" section), up until the creation of this thesis (2020), to the author's knowledge there was no study that used the NIR difference index ("leaf-on"- "leaf-off") imagery in an attempt to differentiate tree species as a parameter in a segmentation context. However, although the index was in the case of three experiments a good explanatory variable, in many cases the mean values of the NIRDIF layer exceeded 50 (some dominant segments covering trees #12 and #14 in tests #10 and #11). In some cases, for example in experiment T2, the segment covering more than 80% of tree #1 has a NIRDIF index value of only 6.9 (parameter range from -247 to 218). This situation is explained by the bulky form of the segment, which includes also other trees and empty spaces between them. Consequently, an increase in the scale parameter of the Multi-resolution segmentation analysis, the one that determines the segment sizes, has a negative influence on the value of NIRDIF.

This happens on one hand because of a forest containing several tree types, and reflections from different individuals belonging to separate tree species alter the signals received by the

NIR sensor. The willow tree (#8), successfully identified by experiment T3BB, and had a mean NIRDIF value of 15.5.In the upper case, ground hits and tree shadows, inherent to the imagery; lower the values of the NIRDIF index. The problem of detecting and eliminating the spaces between trees can possibly be resolved by carefully choosing a parametrization adequate to the task. In line with earlier discoveries (Kaartinen et al. 2012), the CHM value proves to be a good tree descriptor, however in this thesis, tests T1, T4 and T5 show that emphasis on this parameter's values help in identifying the trees but to a limited extent, being subject to under- or over determination of the segments. The addition of the earlier described *CHM_binary* layer (see section 2.5.3), which supresses all the elevations below 9 m, narrows down the search for the trees worthy of protection by eliminating lower-lying CHM elements and focusing only on high crowns. On the negative side, the binary CHM layer limits the search threshold, excluding possible tree parts located at lower altitudes, and such would not be an accurate description of the individual tree crown. The second part highlights the main obstacles that might have affected the experiments and their results.

5.2. Dataset and methodological limitations

5.2.1. Translating the term "protected worthy trees" into a technical language

From a semantic standpoint, the concept of "protected worthy tree" would be easy to grasp considering the definitions provided by the organizations that curate the Green Infrastructure project. Nevertheless, from a technical perspective, the situation is not easy to describe and put in practice. Although the experts from the Administrative County Board identify in the field mainly oaks as the dominant species belonging to this category, and necessarily to be protected, during the field study it has been shown that other species can also become candidates.

Moreover, observations in the field have demonstrated that "trees worthy of protection" can have a **wide range of maximum heights** and in some cases **are in competition with faster growing** species for light. The current project relied on experimenting, high dominating deciduous trees and did not consider this aspect.

The researchers working with Länsstyrelsen have also pointed out that that usually trees worthy of protection are located **in areas that historically (at least 100-150 years) used to be open land** (such as pastures, terrains used for agriculture, etc.) which subsequently changed its cover to forests. Older Swedish map data, starting from the 17th century is available in digital format from institutions such as Lantmäteriet and *Riksarkivet* (Swedish National Archives). This cartographic material is a snapshot into the past and can be used as a segmentation variable for forthcoming studies. On one hand, they can be useful for the creation of a binary raster, showing land where historical changes occurred or as a vector file, which would hinder data processing in the areas in which land cover has not been altered.
Even with the best technologies used for data collection and processing, it is prone to inherent imprecisions. The next topic discusses possible data flaws that might have altered the correctness of the obtained results.

5.3. Issues connected to the available data

5.3.1. LiDAR data

LiDAR point clouds were used to construct the terrain and surface models. This type of data has two inherent limitations in what regards *resolution* and *classification.* It is well known that the accuracy of the construction of the underlying height layers is related to the amount of points per square meter that the scanning was conducted with (Dong 2017). While the provided data had a resolution of 0.56 points/square meters, an increase in the working resolution would be interesting to test as basis for further research. More detailed data would yield a better description of the terrain and possibly improve the point classification (see a more detailed analysis in section 5.4.1). A simple explanation for this fact is that, for the case of a dense forest, a higher number of LiDAR points, would better describe the study zone and even in denser forests, might highlight spaces between the trees. Both the studies of Oono et al. (2008) and Holmgren and Lindberg (2019) use datasets with higher resolution. A workaround this problem would be the usage of a higher number of points per square meter (higher resolution scanning). Because of its reduced flight altitude compared with traditional flying vehicles and higher accuracy (Balsi et al. 2018), the new LiDAR UAV technology (Balsi et al. 2018; DJI 2020) can be put to test in the area. Nonetheless, this would result in higher data collection costs. On the negative side, collecting the data at higher resolution would reveal an even more complicated forest structure, which would possibly require a different segmentation approach.

The *classification* issue stems from the fact that the original dataset was delivered already filtered by Lantmäteriet. A filtered LiDAR point cloud means in technical terms that only some received signals have been processed using computer based algorithms to achieve the classification between ground and non-ground data (Meng et al. 2010). Using another algorithm to filter the data or even full wave – unprocessed LiDAR, might reveal important forest parameters that can help in possibly improving the existing segmentation results (Balsi et al. 2018).

5.3.2. Orthophotos and the NIRDIF index

The methodology section explained how NIRDIF index that was used in the attempt of species was produced. Although it was able to successfully illustrate this difference between conifers and deciduous trees in some parts of the study area, some technical limitations are worth to be noted. On one hand, the input data comes from different types of cameras (see the *Methodology* chapter). Data providers do not give information about the camera sensor parameters at the moment of the flight (gain, bias) so in this case the reflectance values could not be calculated. Although both of the flights were conducted from fairly low altitudes (3700 and 4200 m, respectively), it is still expected to have atmospheric absorption mainly due to the existence of water vapour and the presence of low clouds. Not calculating the reflectance values contrast the recommendation of Haest et al. (2009), who strongly suggests computing reflectance when processing remote sensing data originating from different systems. To complicate things even more, there is no calibration available between the sets produced by the two cameras and that seriously affects the segmentation since there is no knowledge about how the DN values of the two camera setups correspond to each other. On the other hand, there is a slight difference in the flying altitude (4200 m vs 3700 m), which gives more detail to the lower flight. Different flight altitudes and lens types (see the Methodology chapter for technical data) usually determine distinct levels of detail in the imagery. While the higher flight can grasp a wider area and catch less detail, the lower flight surprises a smaller area to a higher detail. Although the results do not reveal big differences between the two sets, it is ideal for this type of study to have similar flight altitudes, since the scope of the research is concentrating on detailed elements (tree crowns). Subsequent studies can use the advantage of extended image capture periods and create spatial indexes from materials produced by the same camera at similar flight altitudes.

5.4. Limitations of the employed technologies

5.4.1. Surface and terrain model generation

One of the ingredients necessary to calculate the normalized digital surface model, is the DEM values based on the last returns of the LiDAR scanner and interpolate them to obtain the elevation values for the ground under the forest canopy. Even so, there is no absolute guarantee that the last return corresponds to the actual ground level, even if classified as such by the data provider. Fisher and Tate (2006) identified some causes that lead to elevation data inaccuracies. For example, in all of the experiments described in this thesis, it has been considered that the values connected to the “last return” of the LiDAR scanner identify the ground. However, as Fisher and Tate (2006) demonstrate, the notion of “ground” is superfluous. They consider that the notion of ground should be considered the upper part of the soil, which comes in direct contact with the lower layers of the atmosphere. Wolf, Dewitt & Wilkinson (2014) reveal that generally a terrain model produced by evaluating the last return of the LiDAR has other inherent issues such as the uncertainty that the last return really depicts the “ground” layer. This adds to the complexity of the situation even more in forested areas where objects such as lower lying branches or vegetation understory, grass, small animals, rocks, fallen twigs or leaves, patches of fur or feathers can interfere with the LiDAR scanning and thus return an exaggerated image of the reality (Lantmäteriet 2019). Lantmäteriet uses an automatic system to classify laser data. Nevertheless, the terrain model in areas with dense vegetation and rugged terrain is usually prone to estimation errors, because of a lower number of point reaching the true ground surface (Lantmäteriet 2019). The same institution gives an example from a densely forested area, where the difference between the point clouds deduced and measured terrain elevations was more than 2 m. The same situation can successfully explain the low accuracy of hits in Näset, area which is covered by a thick young forest.

These inaccuracies are hard if not impossible to detect and in most cases they are used for interpolation. In relation to interpolation, research indicates that the quality of the digital elevation model and indirectly the derived CHM are related to the chosen interpolation method (Aguilar et al. 2005). For the purpose of this thesis, only the Nearest Neighbour interpolation method (available in ArcMap) was applied. Lloyd and Atkinson (2002) evaluate several DEM interpolating procedures and reaches the conclusion that Ordinary Kriging (OK) and Kriging with trending surface (KT) are the best ways to “fill in the gaps” of an area where the overlaying zone has been removed. To sum up, other interpolation methods and their effects on the DEM layer and subsequently on the tree segmentation might be useful to test in future research.

5.4.2. Segmentation methods

Probably one of the most obvious issues that arise from the results is the fact that segmentation technology is still a new tool and relies a lot on the principle of trial and error. Even in the software tutorials, available on Trimble eCognition’s official YouTube channel, the company's engineers encourage the users to "try themselves up" until reaching an adequate result. The algorithms included in the eCognition package tend to be complex and although the user interface is fairly straight forward, the underlying processes are complex and difficult to explain in a simple manner. In the case of the Multi-resolution segmentation, where the statistical processing is based on a mix between the spatial and optical data, the changes operated to of the "Scale" parameter can be easily traced in some of the experiments. Here, modifying this parameter determines the segment size of the resulting segmentation. This is the case of the "bulky" results in T2 (scale: 50) and T3A (scale: 70). Nonetheless, the mathematical relation between this parameter value and the size of the resulting segments is hard to estimate otherwise than visually. Another limitation of the upper mentioned method is the fact that as per the author's knowledge, there is no documentation stipulating the range of values that are accepted as weights for the various variables that are included in the computation of the segmentation analysis. As for the Scale factor example, the winning strategy in this case is through continuous "trial and error" attempts. Other possible ways to research the optimum solution would be employing eCognition algorithms other than Multi-resolution segmentation. Experiment T9, which was used only as a comparison factor, revealed a good separation between tree and non-tree elements. In case the optimal solution for finding the trees worthy of protection is found, there is the possibility of employing eCognition based Machine Learning algorithms (Convolutional Neural Networks), which would speed up and improve the identification process.

6. CONCLUSIONS

This study aimed to develop a way to semi-automatically recognize tree crowns that correspond to conditions established by the local nature protection authority as to get the "protected status". In this endeavour, eCognition based segmentation methods from inputs such as LiDAR; airborne imagery was put on trial through 14 experiments, which detected tree crowns with different degrees of accuracy. Based on the obtained outcomes, Multi-resolution segmentation based object creation has proven to be a useful tool in an operation to accurately represent tree crowns. The usage of the leaf-off/leaf-on near-infrared difference index (NIRDIF) showed promising results when detecting isolated tree individuals compared to the denser forest. Nonetheless, to test its efficiency more tests involving this method in different ecosystem settings need to be run. Experimental for this kind of research is also the usage of a sequence of two segmentation algorithms (Multi-resolution and contrast split) in the same test, which resulted in a better separation of the trees and canopy voids and improved crown detection. This thesis however did not resolve the problem of species identification between deciduous and conifers. Among the identified possible causes for the issue were: the heterogeneity of the study zone, characterized by locations with different tree densities, optical imagery with low radiometric resolution and LiDAR data processing. This issue of a heterogeneous forest can be resolved through implementing separate procedures for identification of hard- and softwood trees. Uncertainty issues can also be resolved by forthcoming studies where employing other eCognition based methodologies alongside evolved data such as UAV LiDAR point clouds and hyperspectral higher resolution imagery taken preferably from lower altitude which can better identify individual trees and reduce as much as possible atmospheric interference.

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