A study on measurement methods in the temperate forests of Sweden

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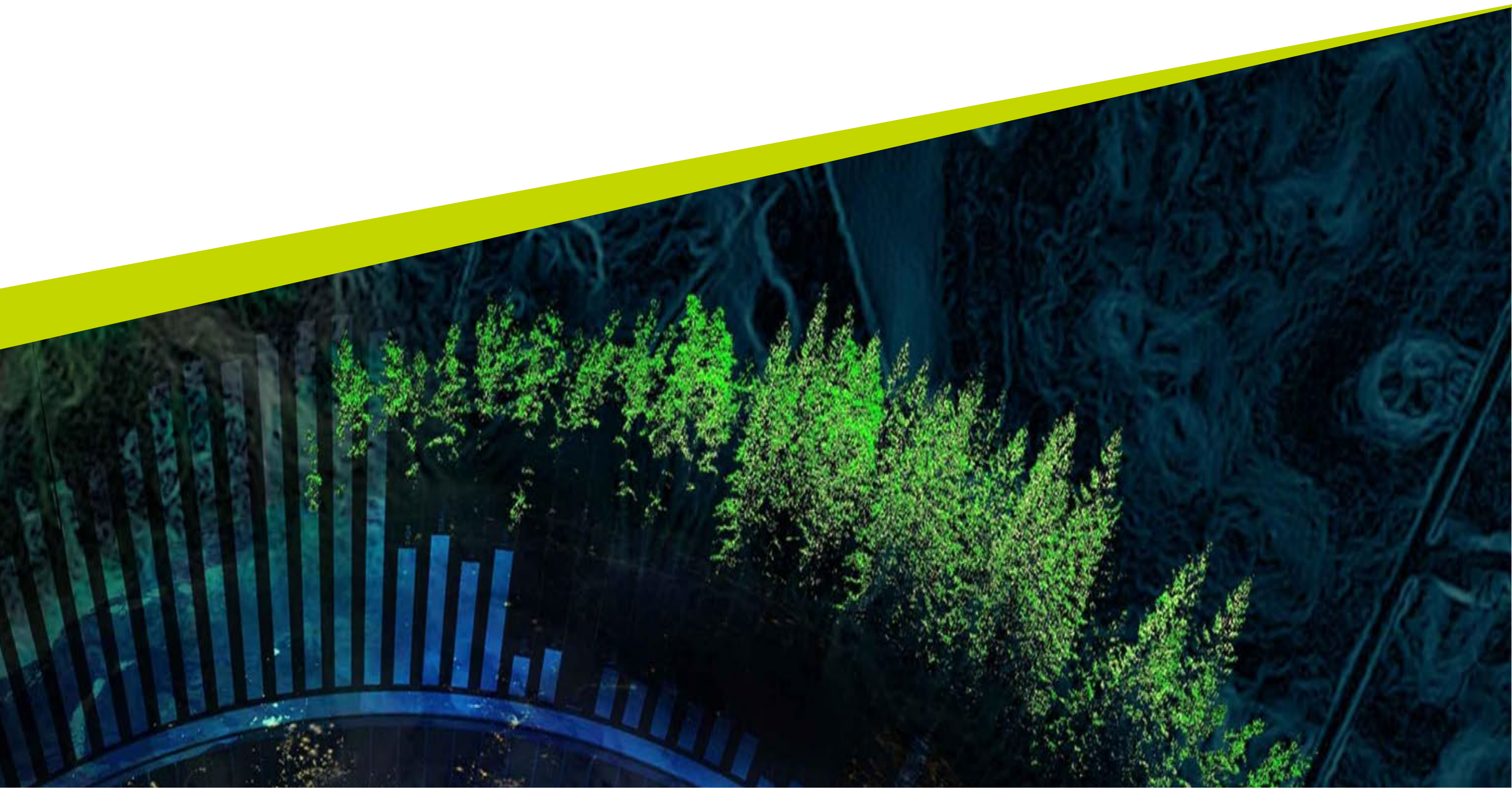

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Abstract

Forest managers and stakeholders need to know the standing volume of trees when making management plans, nature reserves or when selling timber. The aim of this thesis is to present why it is important to know the forest inventories. Especially if they are of high interest or high value like oak forests. The thesis will test if modern technology in silvicultural measurements is up to date, compared to old school analog measuring. To be able to test this, the app Arboreal will be used to provide the tools caliper, height measurer and volume calculation, in a digital format. In this report, measurements will be conducted in one oak stand and one spruce stand.

After measuring ten plots in an oak stand the results showed that using the app was 73% faster than using analog tools. The corresponding result in the spruce forest was 68% faster using the app, compared to using analog tools.
The standing volume in the oak stand was 136.5 m^3sk when the app was used, compared to 140.2 m^3sk when measured using manual tools. The equivalent in the spruce stand was 428.4 m^3sk using the app and 319.8 m^3sk using analog methods. When analyzing the results using R, the P-value showed that the results from the oak measurements was not significantly different. However, in the analysis of the spruce measurements it showed that the P-value was significantly different from the digital measurements.

Keywords: Forest inventory, Silvicultural measurements, Measuring apps

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1. Background

This thesis is part of the Forest & Landscape BSc. It will present different silvicultural measurements and why they matter in Swedish forestry. A background of the context will be given and the features why measurements are a key in decision making, will be presented. The thesis will test if modern technology in silvicultural measurements is up to date compared to old school analog measuring. To be able to test this, the app Arboreal will be used to provide the key tools caliper, altimeter and volume calculation, in a digital format.

1.1 Introduction

The stakeholders that care for- or are governing forests, have a need for a good and trustworthy decision basis (Albrektson et al., 2012). It is important in a variety of situations e.g. when making management plans, nature reserves or when trying to build lucrative deals when selling timber etc. (Albrektson et al., 2012). To get that knowledge, the forest of interest needs to be measured to create that basis of knowledge to build upon (Albrektson et al., 2012). The cases are many where opinions on forests divide today. To know what forest inventories an area has is crucial if facts and knowledge should steer the way forward in the debates. That is why the theme throughout this report will be about forest measurements.

1.2 History

Historically, the interest in the Swedish forest has always been at a high level (Wetterberg, 2018). Forestry is an old profession that historically was employed by the Swedish state and later the Swedish forest agency (Wetterberg, 2018). During the first decades of the 1900s, a new era began in Swedish forestry as advisory services started to break through (Wetterberg, 2018). In 1903 the first forestry act of Sweden was created together with the decision to create forest management agencies (Wetterberg, 2018). Each agency board should contain one chairman provided by the state, while one chairman was provided by the county board and lastly a representative from the Housekeeping Society (Wetterberg, 2018). In this way the local farmers got a representative in the housekeeping chairman and the county board representative, which the committee thought would raise the trust by the forest owners for the newly established local committees (Wetterberg, 2018). The local committees promoted a more sustainable silviculture using encouragements and financial contributions that was acceptable and beneficial for the farmers. (Wetterberg, 2018). The foresters became the advisors and were the professionals that stamped the trees when ready to harvest. However, they were also in charge of controlling the regeneration after harvest which became a legal requirement in 1903 (Wetterberg, 2018). This is now history and the mandate to decide if harvests are allowed or not, is instead regulated in the Swedish law (Skogsvårdsförordning 1993:1096, 2024). The mandate to operate in the forest falls under the 1993-forestry act as "freedom under responsibility", with the controlling organ being Skogsstyrelsen (Skogsvårdsförordning 1993:1096, 2024).

If the time gets fast forward until today, the market looks a bit different from the early 1900s regarding advisory services. The market today consists of both companies and owner associations, focusing on managing and refining the forest goods. The knowledge previously provided by the state's staff, now turned more into the private sector being the major source of providing advice and knowledge (Roberge et al., 2020). So, if land owners were curious about planning a harvest or what the value of standing timber were, many would reach out to the associations or companies (Roberge et al., 2020). Foresters with no connections to industries are also available for hire, if land owners wish to get their opinion on a silvicultural treatment or forest inventory (Roberge et al., 2020).

1.3 Measuring technique

Traditionally the person that measures the forest utilize a Vernier caliper for measuring the diameter of the trees. An altimeter, or height measurer is used to get the height and lastly a measuring tape is needed to know the size of the sample plot and distance to the trees when height measuring. The caliper measures the diameter at breast height or dbh, which is 1.3 meter above ground. For best result, each sample tree should be cross measured (Skogskunskap, 2024). Cross measuring is when the caliper is rotated 90 degrees from its initial measurement angle in relation to the sample plot center. By cross measuring the tree, potential unevenness in trunk shape gets noted and an average of the two measurement values gets used (Skogskunskap, 2024). An altimeter, or height measurer, is a tool that uses angle measurement to calculate the height of the tree (Skogskunskap, 2024). Usually the tree gets measured from a fixed distance of 15 or 20 meters that gets measured using a measuring tape (Skogskunskap, 2024). The measuring tape is also used when setting up the sample plot so the plot radius is right (Skogskunskap, 2024).

The counterpart to the analog equipment is digital apps and equipment. Technology such as drones with LIDAR sensing etc. is not looked up upon in this thesis. Even if they seemingly would do the job quicker, and cover more land than in the test of this report (Willén, 2022). However, a comment that could be made is that drones and similar technical tools are great and make quick estimations of standing volume. The problem is that they require skills and have high initial investments that the everyday forest owner most likely don't have or are willing to pay (Willén, 2022).

However, the technology covered in the report is the measuring app named Arboreal. Arboreal, is a digital tool for measuring forest inventories (Arboreal, 2023). It uses the phones camera and the phones Augmented Reality - function, together with the phones position sensor to make the measurements (Arboreal, 2023). The app also has LIDAR-sensing options if the phone supports this, however the test executed in the report only used AR - technology. The app creates a 3D environment using both the AR-sensors and the phones camera (Arboreal, 2023). In the app the sensors take care of the distance to trees when setting up for making height measurements and it uses the distance sensor when sighting in the diameter at breast height as well (Arboreal, 2023). The phones inclinometer makes sure the angle is right when measuring the height, which makes it similar to the altimeter that is used in analog measuring (Arboreal, 2023). Regarding the measurements of diameters at breast height, the app demands that the user actively use the built-in pointer to make the measurement. The pointer is similar to a crosshairs and the user has to point at the tree using the crosshairs to select it. Then walk closer or back away from the tree to fit the tree into the built- in measuring zone, viewed through the screen. The user has to make sure to fit the tree in exactly in between the two measuring lines, which act as the caliper. If the phone would have supported LIDAR sensing the app would have taken care of this and less demand of accuracy would have been put on the user. The app provides the calculations regarding standing volume for the user which comes in handy if it is a person with lower knowledge on the subject (Arboreal, 2023).

1.4 Introduction to the methodology

To make a fair comparison between the analog measurements and the measuring app, a protocol for plot setup is needed. The method of choice was to utilize objective measuring which is used a lot in science. In the objective method, a pre-set route with a pre-set distance determines where the placing of the sampling plots will occur which gives a more unbiased result (Skogen, 2023). The opposing method is the subjective method, which is when the measurer actively chooses sampling plots in a stand (Skogen, 2023). The pros of this method are that an experienced forester most often could find areas in the forest that give a fair representation of the stand as a whole. However, it is a bit biased and the risk of getting unfair measuring results increases in correlation with the level of inexperience (Skogen, 2023). The subjective method is often used by forest companies and owner associations when making management plans for its members and customers (Skogen, 2023).

1.5 Purpose

One of the main tool's landowners could use today for decisions or to check inventories are the management plans (Albrektson et al., 2012). The management plans help landowners in their planning and are usually emended every tenth to fifteenth year, depending on the site productivity (PEFC, 2017). As far as planning goes, the plan is often all a land owner needs to be able to check their inventories etc. Together with a firm that provides the operational services and a buyer for the timber, the management process is set (Skogsstyrelsen, 2024). But from time to time it could be of interest to check the forest inventory to see if the plans are up to current conditions. It could be due to storm damage that changes the standing volume or a wish to know beforehand a deal is set, what the forest inventory is (Albrektson et al., 2012). It is also of interest for professions like biologists and ecologists to know the forest inventories, from a natural science point of view (Fältbiologerna, 2019). A lot of knowledge is available today online compared to how it was only 15- 20 years ago, which makes the opportunities for those who are interested in learning more about forest skills, larger (Roberge et al., 2020). This could close the knowledge gap to some extent for the everyday forest owner or livid forest visitor. Or simply add the “know how” when a new management plan is about to be created.

Since the best and most accurate decisions are being made using the best and most accurate data, the gathering of data is something worth investigating. This thesis will look into how modern technology can be used to enlighten stakeholders on what forest inventory they have or are interested in. The tests will be done in both a spruce stand, but also in an oak stand with the purpose to see if the measuring results differs between them. It could be of interest due to the lower abundance of productive oak stands in the landscape that mostly consist of either spruce or pine (Skogsdata, 2023). If measurements could be done easily and be available for more stakeholders, it could speed up the decision process and make the potential forest operation run smoother. Or perhaps someone just finds it interesting to measure the forests by themselves and have an interest in knowing the standing volume etc. This report will test a measuring app that includes the tools one otherwise would have needed, provided in a digital format. In the report the focus is to test a digital tool a person that's interested in forest could use with ease. The purpose is to check if the more compact alternative of measuring using an app, is accurate. More specifically will the thesis test how the app Arboreal performs between oak forests and spruce forests. Also, if there are any different results from measuring with analog equipment.

1.6 Hypothesis

I believe that the accuracy is solid and that the digital tool is good to use. Digital measuring will most likely be slightly faster than the analogue measuring and it is probably more accurate in the spruce stand than the oak stand. Mainly because the large abundance of spruce in Sweden, which would give the app more opportunity for trial and error compared to measurements on oak.

2. Method

To make a fair comparison between analog and digital measuring, the plot setup had to be equal when doing measurements. The sampling plots had to be located at the same place as its digital counterparts to be comparable. The target was to compare the estimated time for measuring and the accuracy of the measurements regarding standing volume. Therefore, the objective method was utilized for choosing where the plots should be located. The number of plots per stand was 10. To avoid human interference the distance between the plots was decided upon beforehand, together with what route the plots were supposed to lay on within the stands that got measured. The location of the stand was in the center of Blekinge county, in Southeast Sweden, see Figure 1.

Figure 1. Map over Sweden with Blekinge county being circled. Photo by Lantmäteriet.

There were two stands that were measured for this report. The first stand was an oak stand at the age of 90 years and the second stand was a spruce stand of 53 years. The oak stand was long and narrow covering 7 ha, while the spruce stand was more quadratically shaped and covering 3 ha, see Figure 2 and Figure 3. In the oak stand the abundance of trees was rather low compared to the spruce stand.

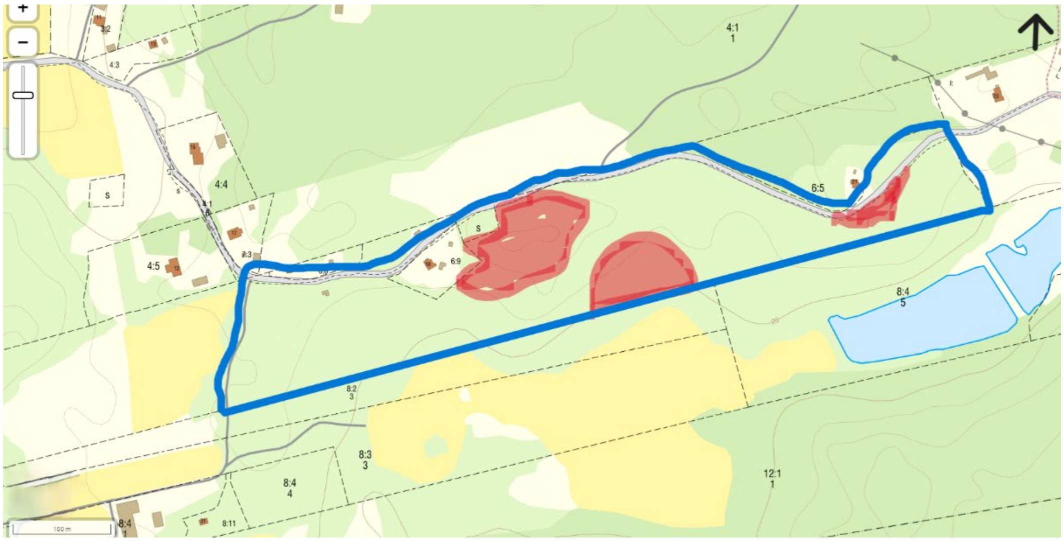

Figure 2. An illustrative map over the oak stand covering 7 hectares, with the non-productive areas being marked with red. Photo by Lantmäteriet.

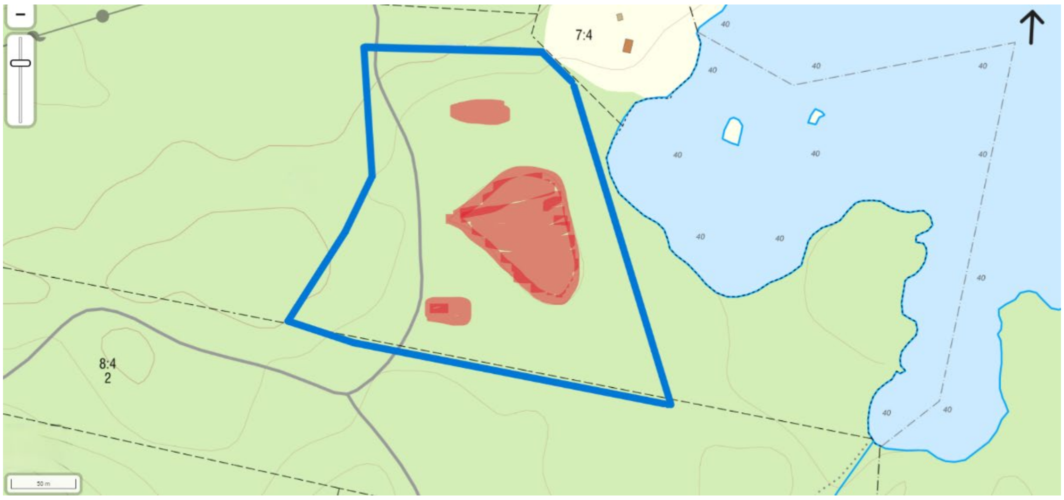

Figure 3. An illustrative map over the spruce stand covering 3 hectares, with the non-productive areas being marked with red. Photo by Lantmäteriet.

The different stand structures lead to the decision that the distance in between plots had to be different for the two stands. In the larger oak stand, the plots were scattered with 45 m between each other, while the spruce stand could not fit the plots having that distance between them. Therefore, the distance used in the spruce stand was shortened to 30 m. The route for the sampling process was determined by looking at the map over the area, making sure there was forest covering the intended route. After that a course was decided upon that ran parallel to the stand border at the distance of 45 m from the border. To make sure the line was straight a compass was used to determine the direction of the border. Then the 45 m distance was measured out perpendicular to the stand border. From this new point the route for the plots was determined. In that way a straight line was possible to maintain while passing through the forest and laying out the plots. Each plot had a radius of 10 m. It was impossible to deploy all plots before exiting the forested area of the stand. Therefore, the route had to make a perpendicular turn and move parallel 45 m similar to the initial distance to the border edge. Then do a second perpendicular turn back into the stand again at the same compass heading.

When each plot was properly placed in the stands, they were marked by using a pole with a tied-on marking strip. In this way the plots were decided upon before the measuring started and it opened up the opportunity to make more accurate comparisons of the data. Mainly due to the silvicultural measurements being done from the same plots.

Now the tests began, starting off by using analog measuring. The procedure was that each plot was visited. When the plot was reached, a timer started and the measuring of the diameters at breast height began by using the Vernier caliper. The tree facing closest to North in the plot was always the first to be measured and then the trees were measured in a clockwise scheme. Each diameter was noted down on a piece of paper before moving on to the next tree. When all diameters were measured, the tree height was measured using an altimeter. When the height was measured on each tree, it immediately got noted down on a piece of paper. All trees within the plots located in the oak stand got measured due to the low appearance of stems in the stand. If not all trees would have been height measured, it would not have been a fair representation of the stand.

Then the same procedure was done in the spruce stand regarding the deployment of sample plots. However, 30 m was the new distance in between plots and borders. Also, a second exception was that not every tree was height measured. Instead every largest tree in each plot got height measured, and then twenty other trees were evenly distributed amongst the remaining diameter classes of the remaining trees. In that way a fair representation of all diameter classes got represented in the height measurements from the spruce stand.

The data from each measured plot was put into Excel to be used later in the calculations. In the oak stand the digital calculator of the app used a general formula for estimating volume. The formula was 0.45 * HGV * GY where HGV is the basal area weighted mean height and GY is basal area (Arboreal, 2023). In the app, the values get stored automatically and the app gives the user the values for each plot and for each stand automatically (Arboreal, 2023).
The app used the formulas by Brandel to calculate the volume of spruce (Brandel, 1990).

In the calculations made on the analog oak measurements, the following formula were used, $VS = 0.03522D^2H + 0.08772DH - 0.04905D^2$ (Hagberg & Matérn, 1975). In the calculations of the spruce volume, the formula for South Sweden were used, $V = 10^{-1.02039} \times D^{2.00128} \times (D+20.0)^{-0.47473} \times H^{2.87138} \times (H-1.3)^{-1.61803}$ (Brandel, 1990). Using R, a secondary volume function was made and its formula was, $V=a*D^b$ where V=volume in m^3 and D=diameter at breast height in cm.

3. Material

The equipment used in the field work and the calculations is presented in Table 1.

Table 1. List of equipment and tools for the measurements.

General equipment used to set up the test:	Analog equipment:	Digital equipment:	Tools for the calculations & analysis:
Timer	Measuring tape	iPhone SE	Excel
Compass	Vernier caliper	Arboreal Forest	R
Map	Altimeter		
Measuring tape	Pen		
Posts for plot-marking	Paper		
Marking stripes			

4. The results

The result from the field work showed that the measuring app was quicker than the analog measuring, see Figure 5. The average plot took 3 minutes and 30 seconds to measure in the oak stand and 4 minutes and 17 seconds for the spruce stand, using the app. The analog counterpart for oak took 13 minutes and 7 seconds and for the spruce measurements the average time was 13 minutes and 27 seconds. In the volume calculations, the results became relatively similar to the result from the app regarding the oak stand. The P-value showed no significant difference, see Table 2. For the stand that consisted only of spruce, the results deviated more, as Table 2 shows. In the spruce stand there were significant difference as the P-value can tell.

The digital measuring app was 73 % faster at measuring oak forest than the analog technique. In the spruce forest the digital measuring app was 68% faster at measuring spruce than the analog technique.

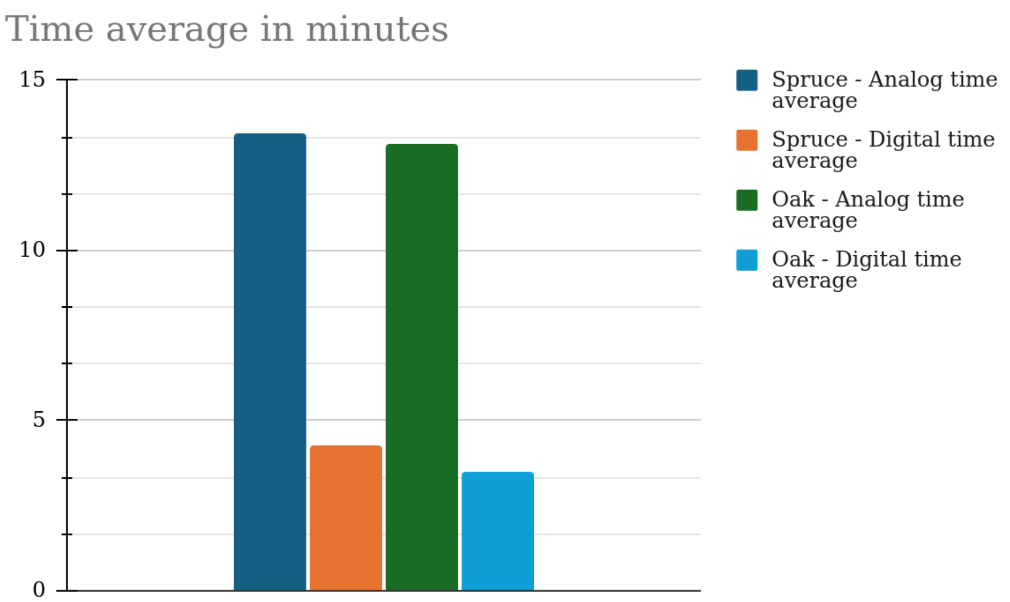

Figure 5. The results from the measurements showing the average time estimate per plot for each method.

Table 2. The results from the measurements showing the average values per plot from each stand and measurement.

	Stem number (trees/ha)			Basal area (m^2/ha)			Volume (m^3/ha)		
	Analog	Digital	P-value	Analog	Digital	P-value	Analog	Digital	P-value
Oak	162	161	0.9397	15.6	13.5	0.1443	140.2	136.5	0.7612
Spruce	557	614	0.0694	34.2	40.7	0.0101	319.8	428.4	0.0015

5. Discussion

5.1 Discussion about the results and limitations to the test

The purpose with this study has been to test how a measuring app could be utilized in the temporal forests of Sweden. The target has been to learn more about pros and cons of digital forest measurements, in both oak forests but also in spruce forests. During the tests the measuring app Arboreal was tested in two different stands of mature timber. The results from the measurements showed that the app was quick to use when measuring sample plots in the forest. The time spent measuring was 73% less, compared to measuring using the classic methodology in the oak stand. The equivalent in the spruce stand was 68%. The thesis purpose was also to investigate the app's measuring technique and compare it with classic analog measurements. Regarding the accuracy in the oak stand, the app delivered the mean result of 136.5 m^3sk per hectare. This result is to be compared to the analog measurements mean result of 140.2 m^3sk. In the spruce stand the equivalent value was 428.4 m^3sk in the digital measurement while being 319.8 m^3sk using the analog measurement tools. For the oak stand the P-value showed that there is no significant difference however, for the spruce equivalent there is a P-value doing that.

There are a couple of limiting factors in the tests that could affect the outcome of the results and give an explanation to the outcome of the measurements. When using the app, the person operating it measures all trees within the plot at breast height. When all trees within the plot are measured at breast height, the app picks the tree that is most average in diameter size. That is the only tree that gets height measured and it acts as a reference tree for the rest of the plot trees, regarding the volume calculation. Then the app calculates the HGV-value and delivers the rest of the volume results (Lindberg, 2020). In the mentioned steps of measurements, there are a number limiting factors that could mess with the results. The diameter measurements have to be correctly measured and the app have to collect the correct dbh-value. The selection of height tree could mess with the following volume calculations since the height tree is the only tree per plot that act as a reference regarding height. This is a part of the app that could create a margin of error. Mostly because the different trees in a plot could be of large variety regarding height. If not being well stratified with trees from all height classes the succeeding volume functions could be wrong. The actual height measurement could also be part of potential error in the measurements. If the sensors are having troubles to detect the angle of the phone or the distance to the tree that is measured, the result could be wrongful. That could have the following effect of giving a misleading height value for the volume calculations. The volume functions could be a margin of error themselves, that needs further research or development in future studies.

One of the largest problems in this study was the error regarding the sample plot and its borders. The digital measurements depend on the positioning sensors a lot e.g. when setting up the plot radius. The built-in functions sense when the user is too close to the border of the plot and technically prohibits trees to be measured outside the plots. That feature is great, which makes the user free from running around in the forest with a measuring tape. However, for this test an older iPhone SE was used which is an approved phone model by Arboreal. It is an older iPhone nevertheless why the phone model becomes a partly limiting factor, when utilizing the measuring app. In a previous study, a phenomenon occurred where the phone and the app, accidentally made oval pots instead of circular plots (Lindberg, 2020). A thought is that in stands with a higher stem abundance, the built-in volume calculator could accidentally include more stems than in a circular plot if the mentioned phenomenon occurs. If that was the case in parts of the measurements conducted in this report, it could explain the deviating results in the measurements. Especially the results generated from the spruce stand, that was relatively high in stem number compared to the oak stand. If the accidental oval phenomenon occurred in the spruce stand, a couple of stems could have been included and explain the increase of stem number for many of the spruce plots. The basal area does also get effected in a similar way if the plot size gets changed. That is a topic worth looking into more deeply into in future studies and one explanation could be the older phone model used in the tests. The newer phone models tend to support LIDAR sensing, which would lower the liability on the user and most likely create better results (Arboreal, 2023). However, it needs to be tested to be able to draw any conclusions from it.

5.2 Discussion about the measuring techniques

The time saving aspect of using the measuring app is a large advantage. The cost for hiring a professional to do the measurements is expensive and the average person does most likely not have the skills needed for measuring forest stands on their own. That is a big advantage for the measuring app however, it is worth mentioning that both techniques require some previous knowledge of measuring trees. In the analog method a person has to operate the caliper and the altimeter together with a measuring tape, to get a result. The measurer also has to be skilled in doing volume calculations to estimate the forest inventory. To succeed in measuring with the app, the user actually has to be aware of what they are doing to avoid to inflict with the result. Since the measurer can inflict with the results by measure in an incorrect way, they need some introduction before starting the work. E.g. how to point and click where the root starts and the top of the tree ends when measuring tree height. The app-user could also face some problems with the result, if not properly understanding how to measure the tree diameter accurately. If the measurer is a bit experienced with working with calipers and altimeter, one could estimate that the accuracy of the results increases when measuring with the app as well. Mainly since the trunk has to be fitted in between to fixed measuring lines viewed through the screen of the phone. It is something that the developer of the app conveys on their webpage (Arboreal, 2023). After looking at the provided informative clips at their webpage, one gets a good sense of the technique. After some initial practice and test runs, the measuring went smoothly.

In the case of analog measurements, the accuracy and end product got better throughout both stands in the tests. Difficulties in analog measurements are e.g. to measure the plots single handed using a measuring tape. That includes both when setting up sample plots, but also when height measuring trees. It was the section of the thesis that was the most of a hassle and a lot of time went to going back and undo the measuring tape that got stuck. In the area with only spruce, the measuring with analog gear went smoother.

Interestingly though, the digital oak measurements were more precise regarding the measuring results, which went against my hypothesis. The app was faster than anticipated compared to the analog measurements.

6. Conclusion

As concluding points, the results showed that the measuring app could be used when inventorying temporal forests of Sweden. Especially, if the stand of choice is of a sparser character regarding stem number. The app had problems with making good estimations in the denser spruce stand, but was more on point in the oak stand. The app detected a larger number of spruce stems than with the analog measurements, why the plot setup function might be the causing error. If a more modern phone model would have been used, the measuring results might have been different. If the user would use a LIDAR-supporting phone, the measuring results would most likely be even more precise and potential errors connected to the human factor would probably be minimized.

The app was faster than an analog measurer with 68% in the spruce stand and 73% in the oak stand, which could save stakeholders time. However, the level of accuracy was lower in the digital measurements than when using analog tools. The P-value showed that the digital spruce measurements was significantly different from the analog measurements. The spruce forest was denser which would give larger errors than in the sparser oak forest, if the app would make an error regarding the plot borders. The P-value showed that the digital oak measurements was not significantly different from the analog measurements.

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