A study comparing the resolution of Single Photon LiDAR and Traditional Linear Mode LiDAR in order to detect boulders over a region in Klyftamon, Västra Götaland

Abdulaziz Busuri

Degree of Bachelor of Science
with a major in Earth Sciences
15 hec

Department of Earth Sciences
University of Gothenburg
2023 B-1234

UNIVERSITY OF GOTHENBURG

Faculty of Science

UNIVERSITY OF GOTHENBURG
Department of Earth Sciences
Geovetarcentrum/Earth Science Centre

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ISSN 1400-3821

B1234
Bachelor of Science thesis
Göteborg 2023

Mailing address	**Address**	**Telephone**	
Geovetarcentrum	Geovetarcentrum	031-786 19 56	Geovetarcentrum
S 405 30 Göteborg	Guldhedsgatan 5A		Göteborg University
			S-405 30 Göteborg
			SWEDEN

Abstract

This study aims to compare two sets of LiDAR, one being Single Photon LiDAR and the other one being the regular LiDAR with 2 meters resolution. The two LiDAR datasets cover an area over Klyftamon, a nature reserve located in Skara, Västra Götaland, known for its geological history with the Baltic Ice Lake. Two areas were selected in Klyftamon that were abundant in boulders, with the aim is to test which of the two sets of LiDAR data can detect the boulders. Aside from the main purpose, it is interesting to see if the relatively new technology of Single Photon LiDAR can be used in the field of geomorphology.

What can be noted from this study is that it is possible to detect boulders, adjustment from *hillshade* maps to *slope* maps had to be made for the detection of boulders. However, given the fine pixel resolution of 0.2 meters, not a lot of boulders were detected with the SPL. What was shown in the study was that Single Photon LiDAR worked better for analysis in bouldery areas that lacked vegetation, some boulders could be identified, but not all. In the tree-covered area, no boulders could be seen. However, the use of drone photos turned out to be useful. The drone data gave a high-resolution image, where the boulders that were measured could be identified more easily than it could with the SPL data alone.

Keywords: *Drone, SPL, LiDAR, Hillshade, Slope*

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1. Introduction

1.1 Background

Remote sensing has undergone astonishing technical development, from a balloonist picturing the ground in the 1840s with the newly invented camera to the usage of drones today. Today, drones, aircraft and satellites are used for remote sensing, but despite its wide usage there are few studies investigating the data quality from different sets of LiDAR.

LiDAR (Light Detection and Ranging) is a remote-sensing technology that uses laser pulses to measure distances and create precise 3D maps of the surrounding environment. By combining the principles of light and radar, LiDAR systems provide accurate and detailed information about the shape, size, and location of objects, making LiDAR invaluable in geology. An appropriate area where LiDAR came in use in this bachelor thesis was in the outlet of the Baltic Ice Lake in Klyftamon, Skara, where the drainage left behind boulders in a range of sizes. The drainage of the Baltic Ice Lake is dated to be 11,600 Cal yr BP; a few decades before the beginning of the Holocene. At that time, southern Scandinavia was covered by a thick ice sheet (Johnson et al., 2022). The meltwater in turn formed The Baltic Ice Lake and rivers which deposited large amounts of sediment in the surrounding areas. Alongside the sediments deposited there are also some glacial landforms, such as drumlins, eskers, and De Geer moraines (Johnson et al., 2022).

For this paper, remote sensing and geomorphology was used to answer the following theses:

I. Is it possible to detect boulders in the drainage deposits with Light Detection and Ranging (LiDAR) with 2-m resolution and Single Photon LiDAR with the 0,2-m resolution.
II. Is it possible to determine the size of the boulders across both study areas with the Single Photon LiDAR data?

Identifying boulders with SPL would be an advantage for forestry industry as well as defense purposes. A similar study was made by Sandra Dahlgren (2014) where a survey was made to see If LAS data could be used to localize block-rich terrain.

1.2 Single Photon Light Detection and Ranging (LiDAR)

Single photon Light Detection and Ranging (SPL) is a technique used in remote sensing where laser pulses are sent out to create 3D modeled maps of areas (Zorzi et al., 2019). SPL works by sending out short pulses of laser light, and the time is measured from the pulse being sent out, hitting an object, and bouncing back. This time delay is measured to determine the distance from the object with high precision. SPL systems typically use specialized detectors, such as photodiodes or single photodetectors.

The name "Single photon" means that the system is so sensitive that individual photons can be detected and be reflected back to the main source, even in very low light conditions (Zorzi et al., 2019). This distinguishes SPL data from other LiDAR datas which have significantly weaker pixel-resolution than SPL. SPL is useful in remote sensing where autonomous vehicles and drones make accurate distance measurements that are crucial for navigation and obstacle avoidance. What makes Single Photon LiDAR useful is that the SPL sensor has a higher point density and an increased spatial coverage compared to the traditional linear mode LiDAR (LML) systems (Irwin et al., 2021). The reason why single photon LiDAR's spatial coverage is high due to its maximum flying height which is 4500 m above ground level (Mandlburger & Jutzi, 2019).

1.3 Study area

Klyftamon is a nature reserve located in Skara municipality, west of Billingen. According to *Länsstyrelsen*, the nature reserve is 413 hectares (Länsstyrelsen, 2023). The drainage that took place in connection with the Baltic Ice Lake influenced Klyftamon where parts were eroded, which in turn left coarse-grained sediment and exposed rock in the area (Dreyer & Johansson, 2013). This makes Klyftamon an interesting place considering Its geology and how boulders and sediments were transported during the time the ice lake was active. The general topography of Klyftamon is created as a horst of minor relief with faults on both sides. Faulting along the eastern side is more evident (Andersson, 1995). *Figure 1a* illustrates a hypothetical reconstruction of the Scandinavian Ice Sheet. The Baltic Ice Lake, to the east, was 150 m a.s.l, and the drainage went to the sea to the west, which was 125 m above current sea level. On the southern part of Klyftamon there is a topographic trough which was below 125 m. That was where the largest amount of water ran; the area above 125m a.s.l. still has moraine sheets unaffected by the drainage.

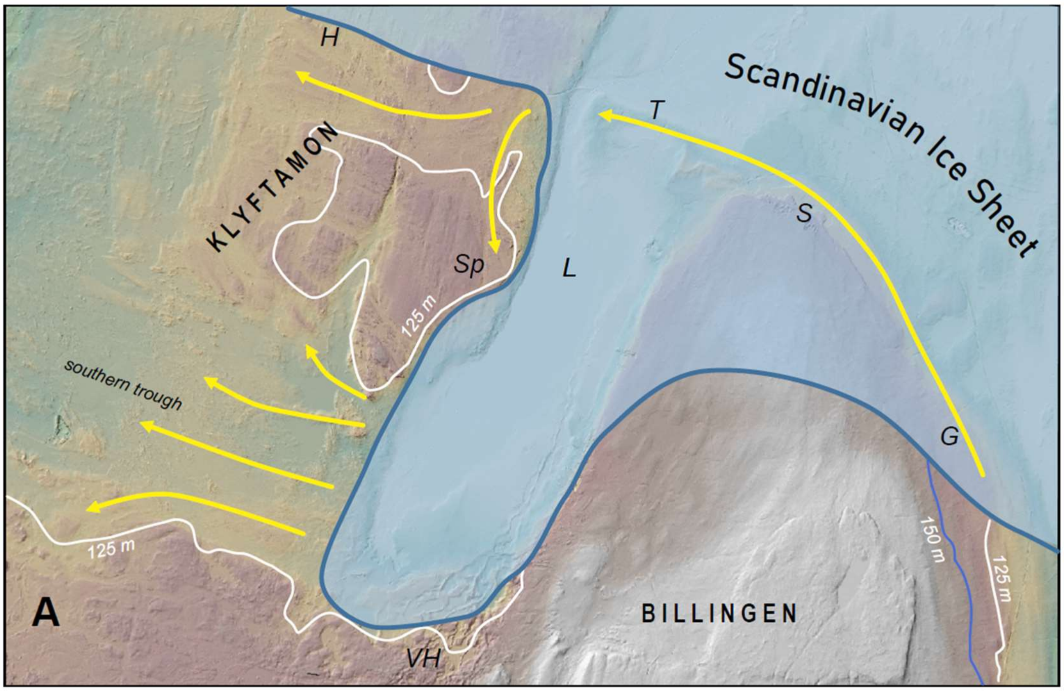

Figure 1A. *A topographical map over Billingen and Klyftamon, where the extent of the Baltic Ice Lake can be seen in the blue line bottom right. A sketch of a hypothetical Scandinavian Ice sheet in the start of the drainage. The white solid line represents the sea at 125 ma.s.l. At the same time the drainage went on. The blue line shows the water level of the Baltic Ice Lake that was 150 ma.s.l. (Johnson et al., 2022).*

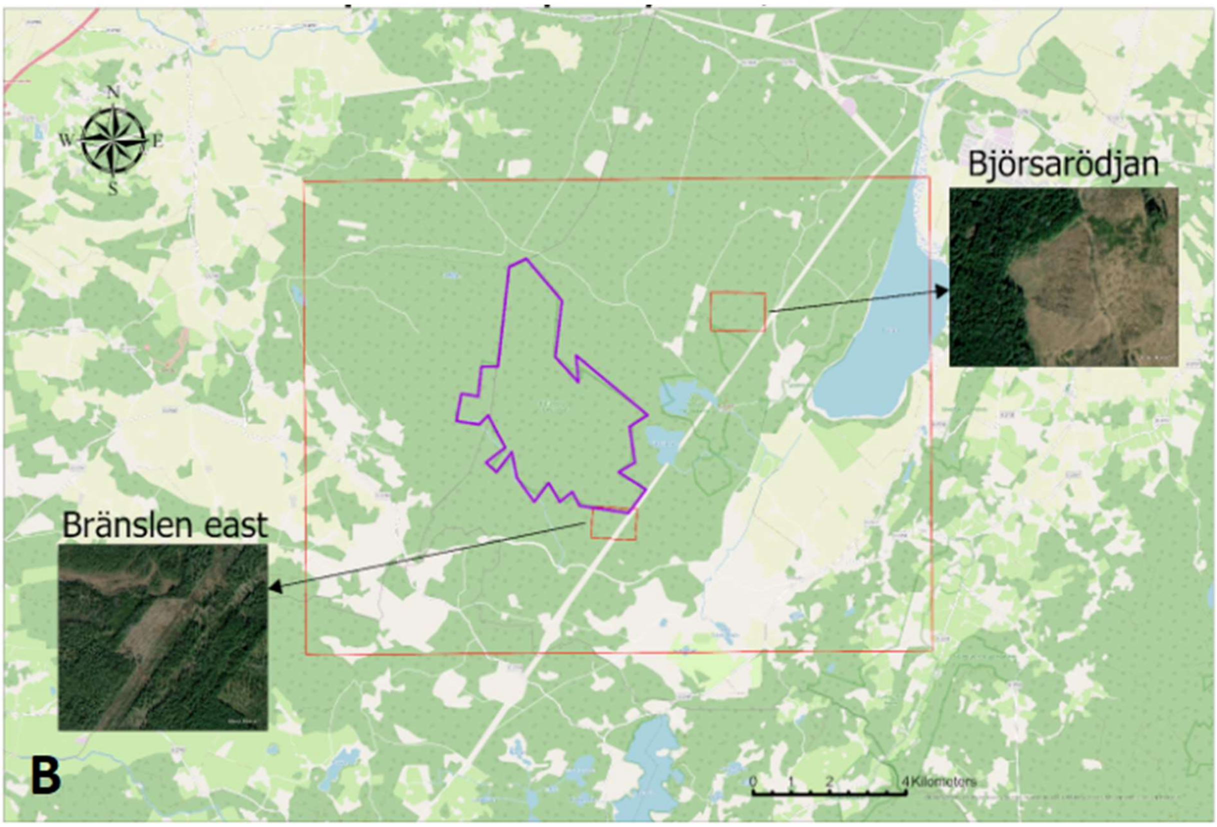

Figure 1b. *OpenStreetMap of the surroundings around the Klyftamon nature reserve (purple outline), the surrounding landscape consists of lakes and forest that surround the nature reserve. The large red rectangle encloses the study area. The smaller red rectangles are where the boulders have been measured as well as two orthophotos over the areas where the field work was done. The map was generated with ArcGIS Pro.*

3. Method

3.1 Selection of location and data retrieval

The study sites in Klyftamon were chosen because they met the criteria that were twofold: (i) having a boulder-covered area where the Baltic Ice Lake occurred (ii) and one where the drainage did not reach. And these two sites are Bränslen where the Baltic Ice Lake reached and Björsarödjan where a moraine-covered surface lies above the highest coastline (Johnson et al., 2022) see *figure 1b*. The SPL data was collected 2017-10-31, from the website Hexagon (2017). For Bränslen, a sketch from the fieldwork was used as a reference to identify the individual boulders (*figure 7)*, and for Björsarödjan, a drone photo was used as a reference (*figure 4)*.

At the time Björsarödjan and Bränslen were chosen in Lantmäteriet it was not discovered that both study areas were vegetated, as the images ortophotos in Lantmäteriet were unvegetated. However, during the field work, we discovered that they had still been forested when the SPL was flown, but were later deforested, as can be seen in historic aerial photos in Google Earth *figure 2 and 3.*

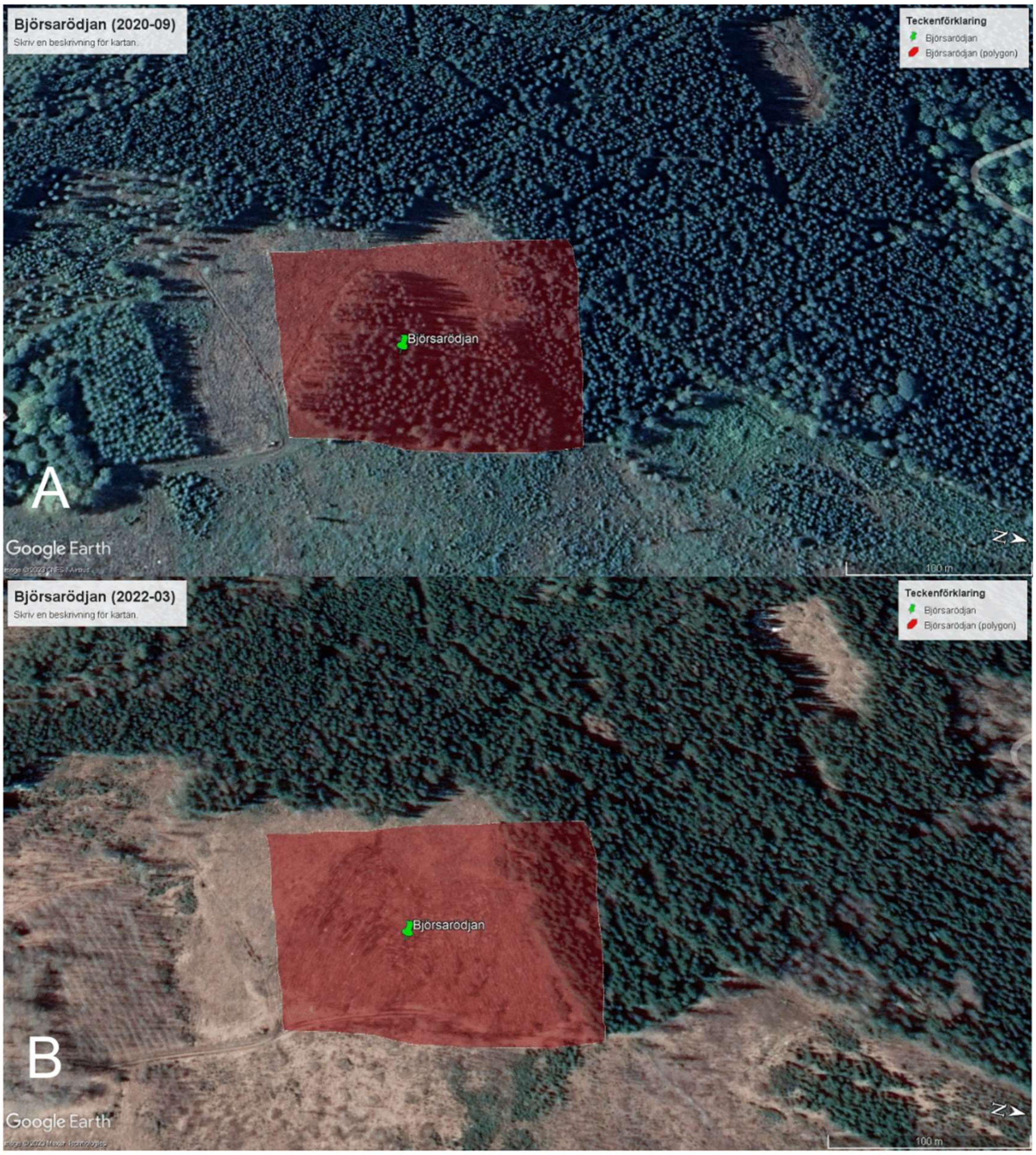

Figure 2. *A. Björsarödjan before the lumbering (September 2020) B. Björsarödjan after the lumbering (March 2022).*

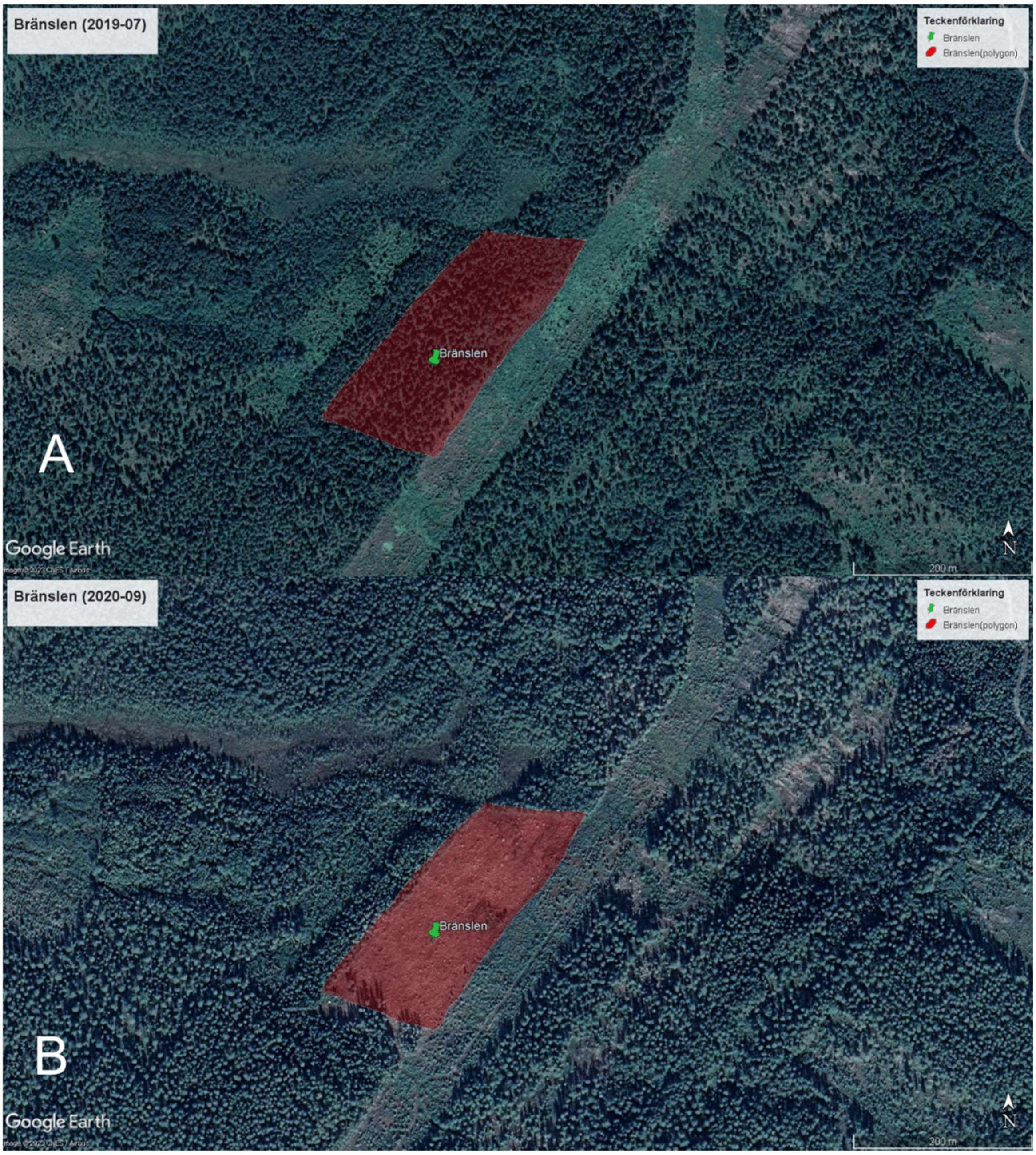

Figure 3. *A. Bränslen before the lumbering (July, 2020) B. Bränslen after the lumbering (September 2020).*

Drone photos were taken over Bränslen and Björsarödjan which can be seen in *figure 4* and *5*. The reason for this is that when the drone photos were taken, it was easy to identify which boulders in the field book we had already measured. By flying at low altitude, the drone was able to produce high-resolution images to distinguish individual boulders.

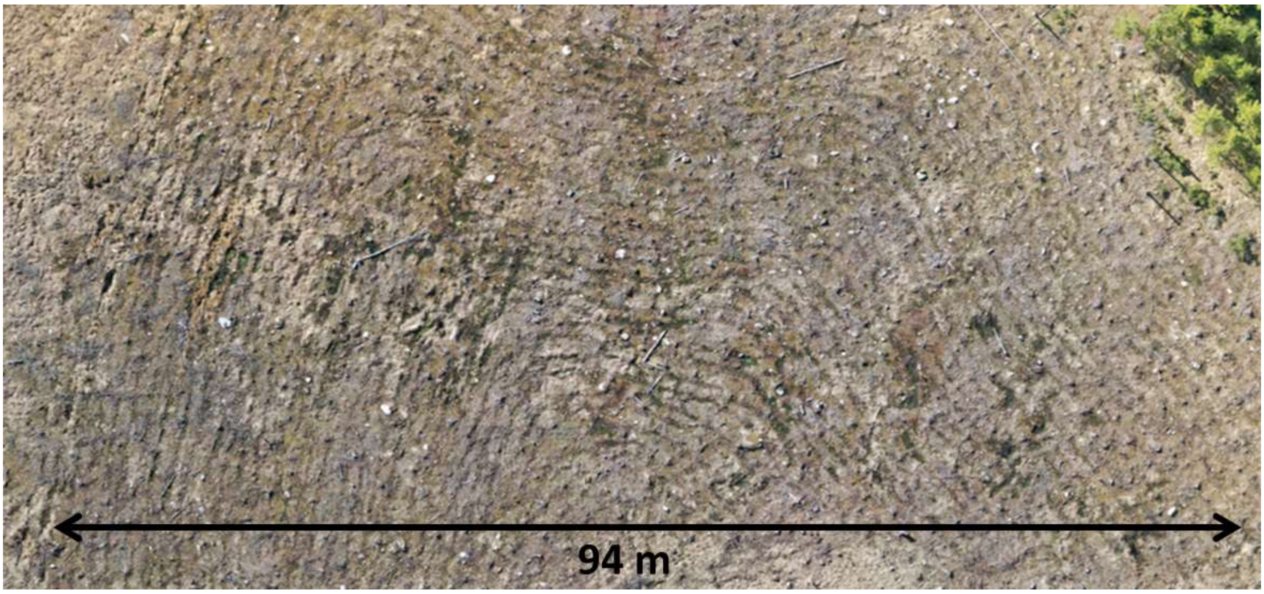

Figure 4. *An in-zoomed drone photo taken of Björsarödjan when the field work took place, a scale of 94m horizontally. The concentration of boulders is small in comparison to Bränslen (figure 5).*

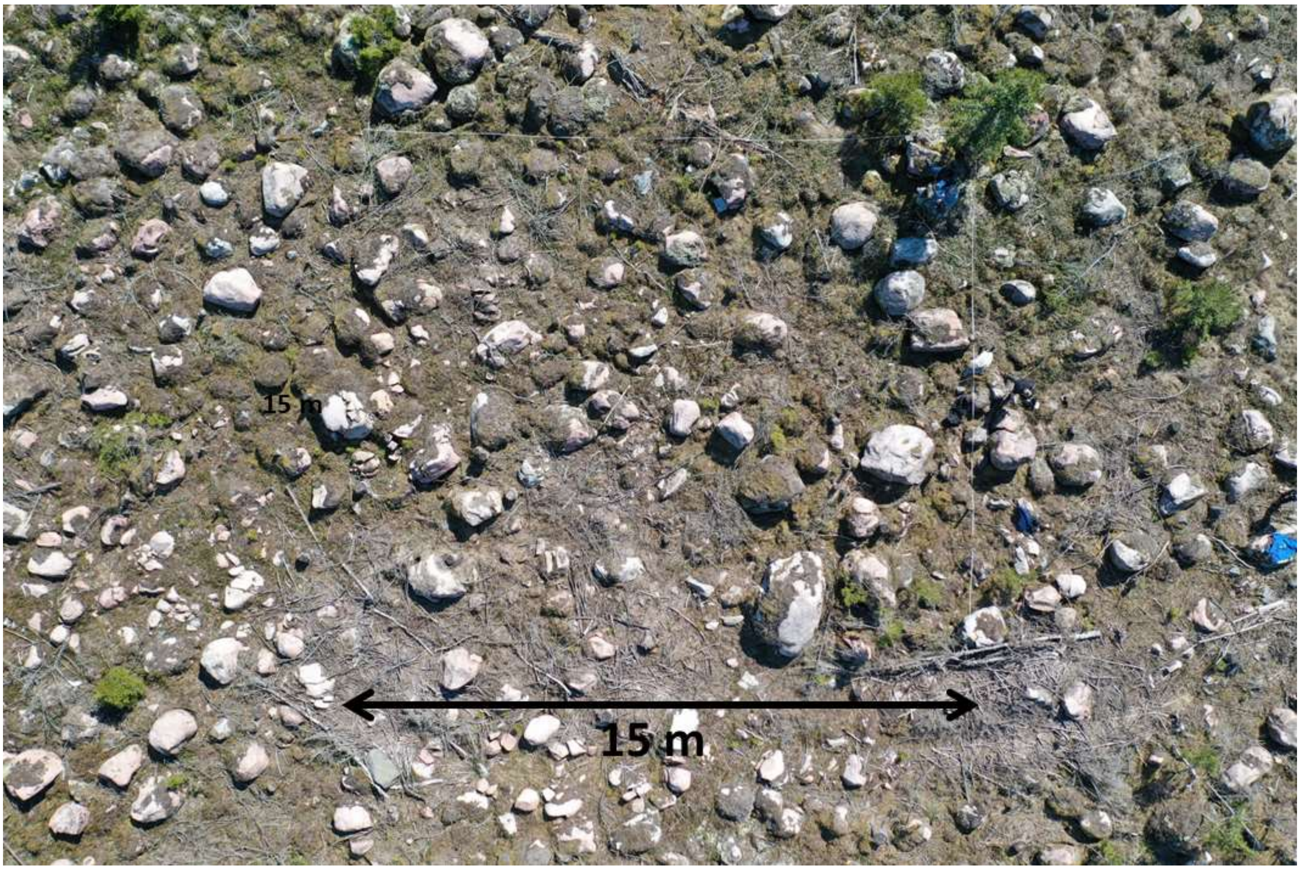

Figure 5. *Drone photo over the area in Bränslen where the 56 boulders were measured.*

3.2 Fieldwork

The fieldwork was carried out in April 2023, and the focus was the identification and recognition of boulders previously images by the Lantmäteriet. The study areas were measured in a 15 x 15-meter area in Bränslen and Björsarödjan 40 x 40-meter area. A difference in areas and this is because Bränslen had higher concentration of boulders while Björsarödjan was expanded due to low concentration of boulders. The study areas were measured with a measuring tape, where only boulders with a B- axis diameter ≥ 40 cm (*see figure 6)* had been measured.

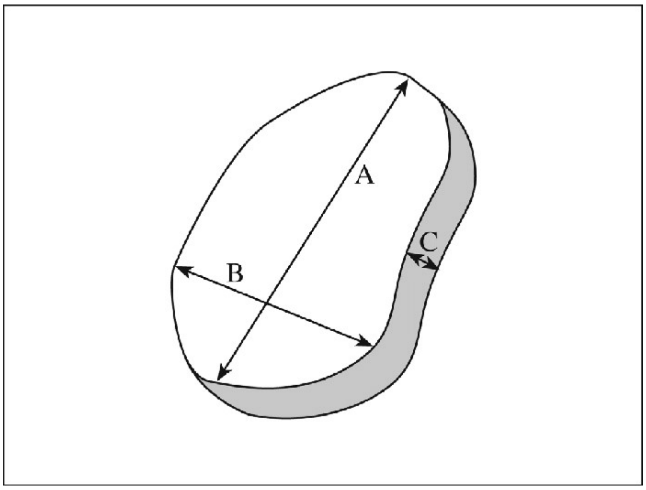

figure 6. *A sketch on the B- and A-axis over a small block. (Rosenberg & Shtober-Zisu, 2010)*

Next, the height of the boulders above the ground was measured and sketches of the single boulders were noted (*figure 7)*. Finally, drone photos were taken over the study area to get coordinates for each boulder that was within the 15 x 15-meter study area. The goal was to select an area where the boulders were easily identified, that is, areas with little or no undergrowth of vegetation, insignificant topography, and the least amount of trees. The reason why areas with little vegetation were chosen is because LiDAR cannot progressively penetrate through vegetation, which makes access to boulders difficult. However, as noted above, we later learned that these two field areas had indeed been forested when the SPL was flown.

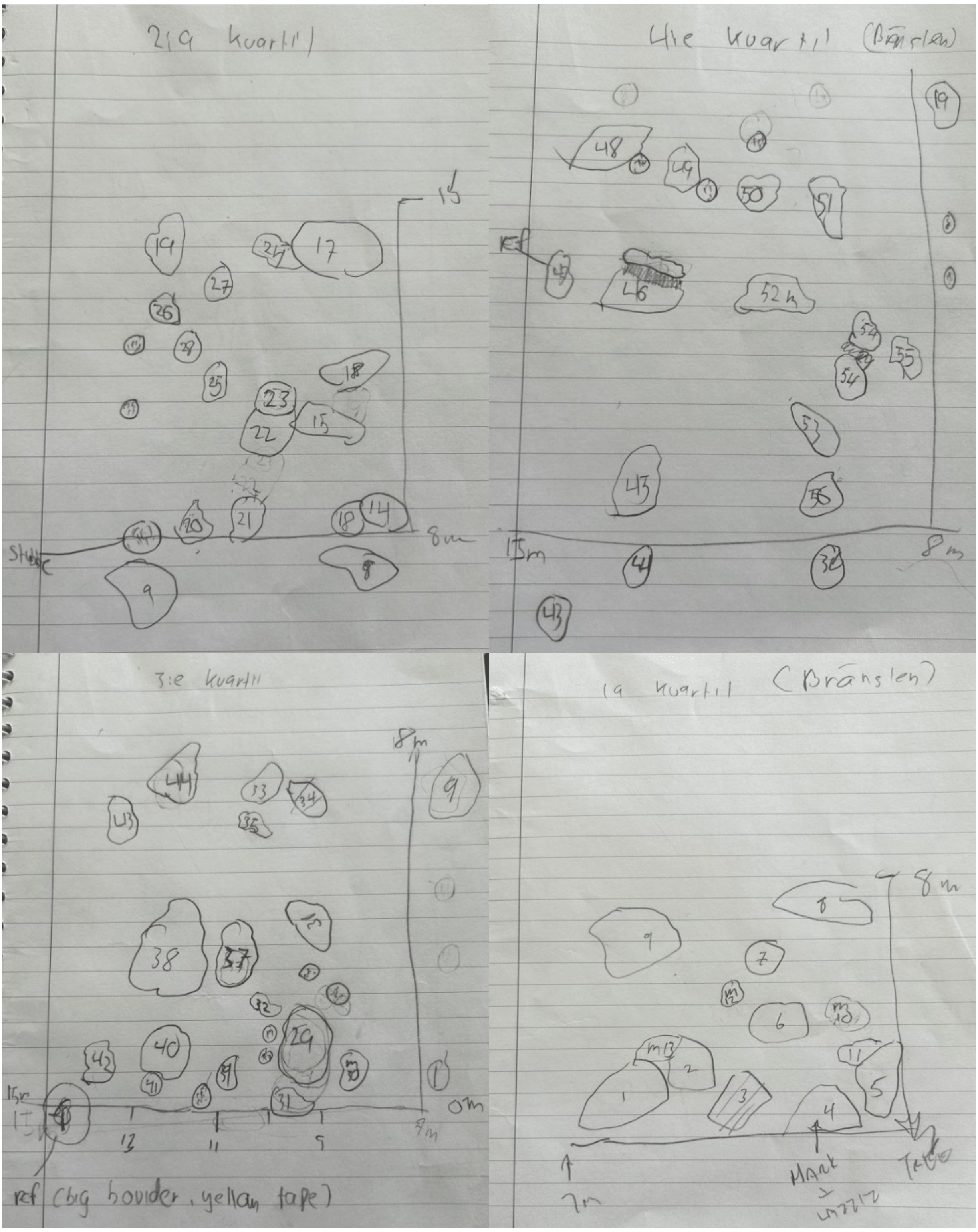

Figure 7. *A sketch of the study area in Bränslen, with all 56 measured boulders. Where a division of 4 quartiles was made which can be seen with boulder numbered in each quartile.*

3.3 Processing of data

The processing of the data was done in ArcGIS Pro. This with the help of the drone photos that were taken in the field, and both sets of LiDAR elevation data. All work in this process was done using various functions and tools of the ESRI-ArcGIS® program ArcGIS Pro. For Bränslen, the boulders measured were identified using the field notes as a reference, when compared with the drone orthophotos over the two study areas. The localization of boulders in Björsarödjan was easier because the boulders were visible on the orthophoto.

The processing of the SPL data and the LiDAR data from Lantmäteriet was done in 5 steps on ArcGIS Pro as shown below:

1. The Single Photon LiDAR data was downloaded from an external hard drive, the raw data was converted from LAZ. *Convert LAS→ Compression→ zLAS compression → Define Input Coordinate System→ ALL Las files→ Input Coordinate System→ SWEREF99_TM*
2. After step 1, the now zLAS data got converted to raster data and this was made with the tool *LAS To Raster function.*
3. The next step was to make a Hillshade of the raster data and this was made with the *Hillshade* tool, where the cell size was 0,2 m.
4. The Hillshade made of the SPL data was modified in *Raster Layer Data. The Resampling Type* was modified to *Bilinear*, the *Stretch* was modified to *Esri* and the *Dynamic Range Adjustment* (*DRA*) was used. The *Bilinear setting* was used because the data gets interpolated, where the four nearest pixels gets an average of the weighted distance. The *Esri setting* was used to prevent the pixel values getting stretched beyond their maximum value. The *DRA setting* was used to adjust the stretch type when zooming in and out of the data on display.
5. To then compare if the SPL data picked up the boulders that were in the field a *Slope* map was made to see If the boulders that are seen in the drone photos could be detected. The data that was used as *Slope* was the raster data that was made in *step 1.* These following steps got done, *Raster Functions → Surface → Slope → Scaling → Degree* and the color scheme was inverted to identify the boulders easier.

4. Results

There were significantly more measurements of boulders in Bränslen compared to Björsarödjan. This is due to the contrast between boulder concentration in both areas, which can be clearly seen in *figure 8 and 4*. The measurements of the boulders in Bränslen are presented in table 1, which was divided into four tables for each quartile. A total of 69 boulders were measured across the two study areas of which 56 boulders measured in Bränslen and boulders in Björsarödjan (*table 2*).

Table 1. BOULDER MEASUREMENTS FROM BRÄNSLEN.

Quartile 1

Number	Height (cm)	A-axis(cm)	B-axis(cm)	A x B cm^2	Moss covered?	Seen on SPL?
1	90	210	150	31 500	No	3
2	125	170	138	23 460	No	3
3	80	140	90	12 600	No	3
4	60	120	110	13 200	Moderate	3
5	70	145	70	10 150	Moderate	3
6	88	147	138	20 286	No	3
7	54	130	107	13 910	Moderate	3
8	70	145	140	20 300	Moderate	3
9	67	150	110	16 500	No	3
10	45	100	70	7000	Yes	3
11	30	75	55	4125	Yes	3
12	50	80	80	6400	Yes	3
13	40	110	70	7700	Yes	3

Quartile 2.

14	35	75	70	5250	No	3
15	30	92	66	6072	No	3
16	35	100	95	9500	Yes	3
17	35	102	70	7140	Yes	3
18	35	60	45	2700	Yes	3
19	75	200	110	22 000	No	3
20	74	140	93	13 020	No	3
21	51	135	103	13 905	No	3
22	49	130	93	12 090	Yes	3
23	50	110	90	9900	No	3
24	44	100	64	6400	No	3
25	35	105	95	9975	No	3
26	30	95	60	5700	No	3
27	49	116	104	12 064	No	3
28	16	70	50	3500	No	3

Quartile 3.

29	110	222	205	45 510	No	3
30	40	100	93	9300	Yes	3
31	25	135	60	8100	No	3
32	50	90	73	6570	Yes	3
33	90	110	90	9900	No	3
34	10	120	60	7200	Moderate	3
35	46	150	60	9000	Yes	3
36	35	100	60	6000	No	3
37	115	206	180	37 080	Yes	3
38	140	328	204	66 912	No	3
39	86	113	95	10 735	No	3
40	101	220	156	34 320	Moderate	3
41	40	60	50	3000	Moderate	3
42	140	120	99	11 880	No	3
43	30	75	74	5550	No	3
44	30	100	90	9000	No	3

Quartile 4.

45	55	160	104	16 640	No	3
46	45	125	118	14 750	No	3
47	43	100	70	7000	No	3
48	90	212	165	34 980	No	3
49	100	160	110	17 600	No	3
50	50	120	80	9600	No	3
51	95	160	145	23 200	No	3
52	30	110	86	9460	Yes	3
53	30	120	53	6360	No	3
54	90	140	100	14 000	No	3
55	100	100	90	9000	No	3
56	70	120	100	12 000	No	3

Table 2. BOULDER MEASUREMENTS FROM BJÖRSARÖDJAN.

Number	Height (cm)	A-axel (cm)	B- axel (cm)	A x B cm^2
1	32	53	45	2385
2	36	100	65	6500
3	20	150	73	10 950
4	32	80	45	3600
5	30	80	85	6800
6	35	60	50	3000
7	45	157	100	15 700
8	25	72	53	3816
9	33	155	82	12 710
10	32	92	70	6440
11	20	75	70	5250
12	13	93	90	8370
13	44	80	60	4800

4.1 Drone photos

In this section we can see two drone photos from the Bränslen field area. *Figure 8* represents the area where the 56 boulders were measured, also the same area as the maps in *Area 1* is in. *Figure 9* represents the area where only the drone photo and the SPL were used, where the area was unvegetated, which is *Area 2*.

Figure 8. *Drone photo of Bränslen with all 56 boulders numbered in a red square presenting the demarcated area of 15 x 15 meters.*

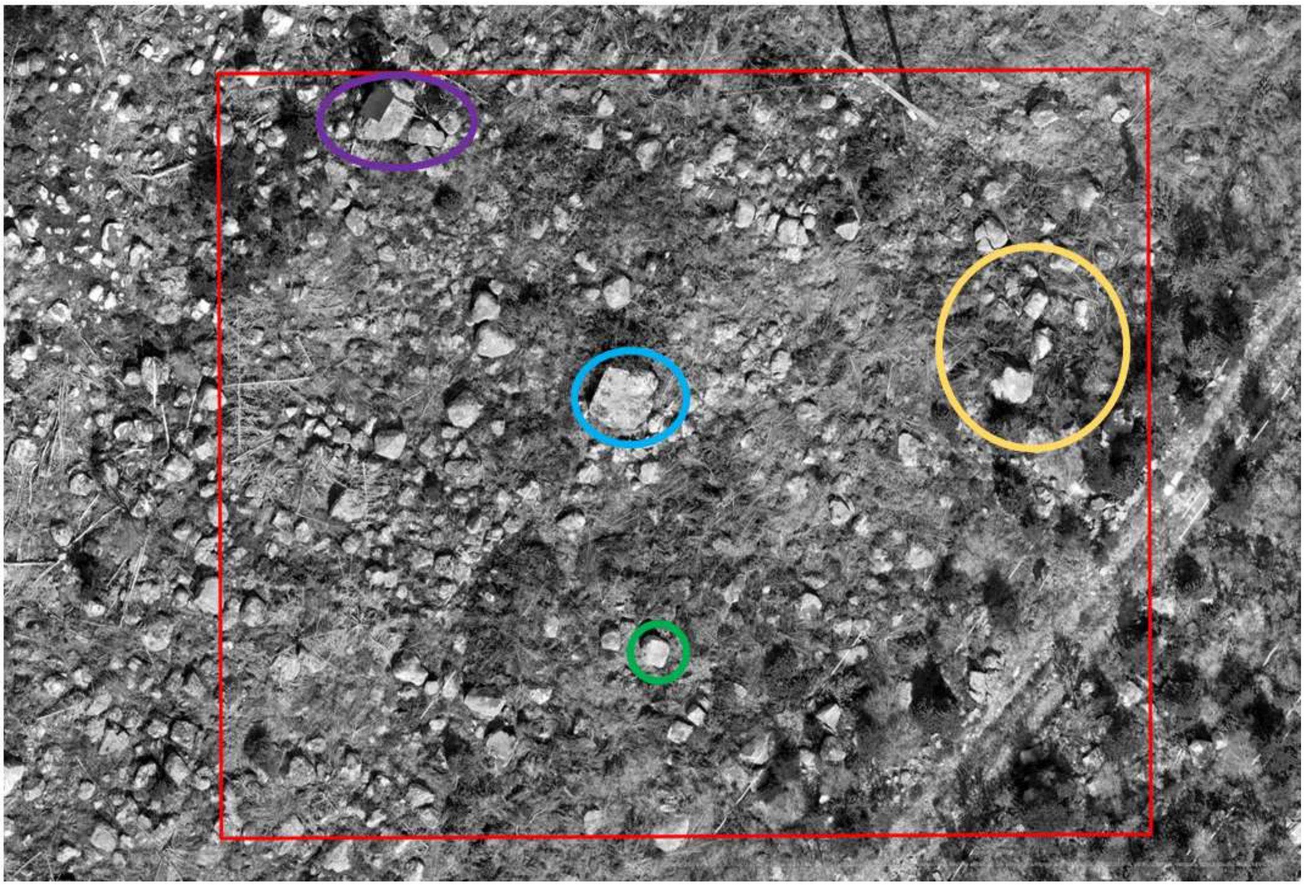

Figure 9. *Drone photo of another area in Bränslen lying 22 m east of the site where the boulders were measured. The area has been demarcated with a red square in a 50 x 50-meter area where the same boulders in figure 10 are circled in the same colors*.

4.2 Maps from ArcGIS Pro

4.2.1 Area 1

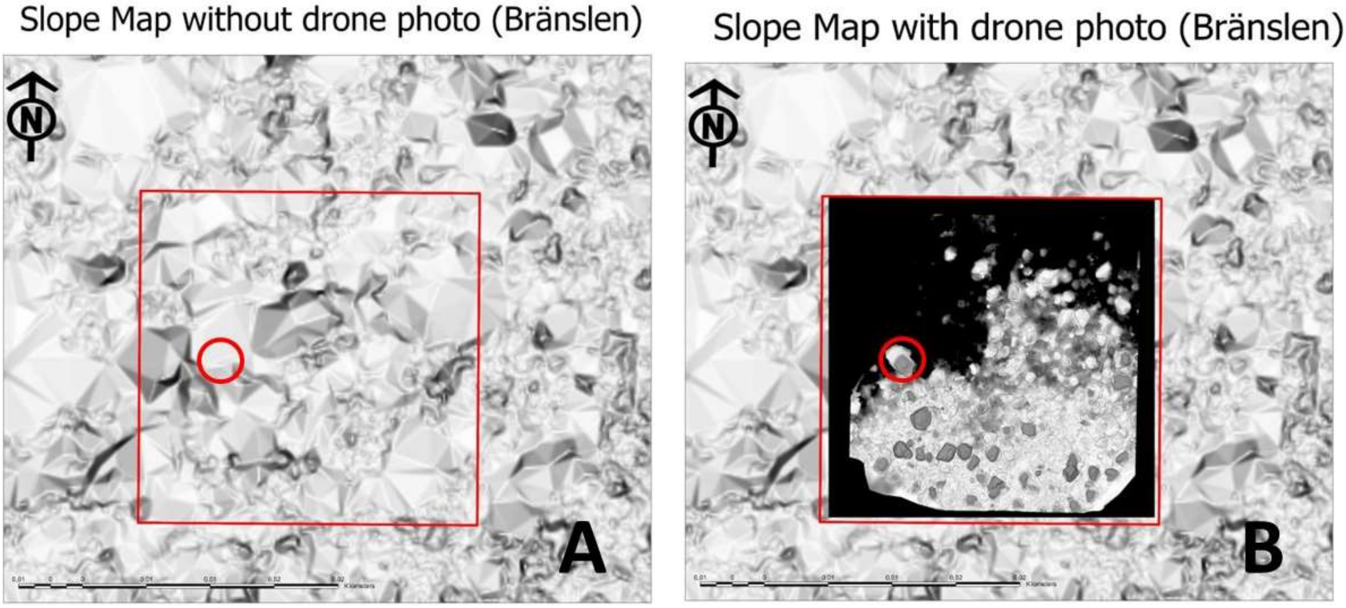

Figure 10. *A. Slope map over Bränslen without drone photo. B. Drone photo that was taken in the field, the red circle represents the boulder that has the largest a-axis measured out in the field (boulder number 38 in table 1), The red square is where the boulders were measured.*

4.2.2 Area 2

The increase in resolution to SPL does not allow boulders to be seen on the Hillshade. Boulders over can be seen on the slope map, but not all in comparing to the drone photo in *figure 9*.

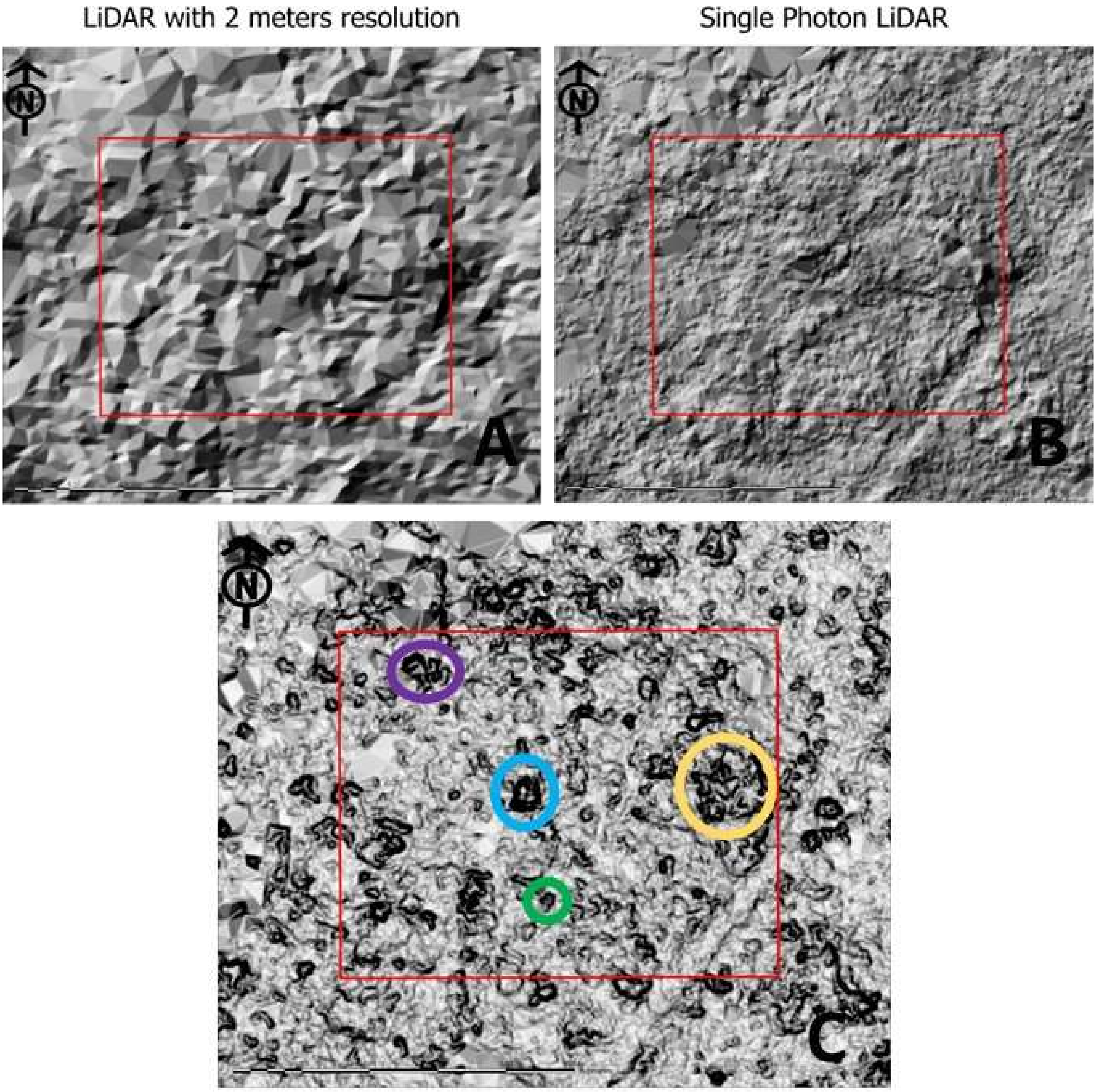

Figure 11. *A. A hillshade map made with LiDAR data from Lantmäteriet over the same area figure 9. B. A hillshade map over Bränslen with the 0,2 m resolution SPL data. The red demarcated square is the area of interest. This is where the 56 boulders were measured in Bränslen. C. Slope map made with SPL data , where the boulders circled are the same boulders seen in the drone photo figure 9.*

Figure 11 shows the 2-m hillshade, the SPL Hillshade and the SPL slope map. The smallest measurement of the a-axis that was visible on the SPL data was 1.86 meters which is the boulder with the green circle as seen in *figure 11c*. Anything below that measurement was difficult for SPL to identify as boulders. Though it was harder for the SPL data to pick up measurements below 1,86 m there were boulders that had an a-axis over 1.86 meters that were not localized on the Slope map.

5. Discussion

5.1 What can you see with the SPL

In this report, SPL has been used for the investigation of boulders where, where SPL has provided a hillshade model and a slope map over a certain area across Klyftamon.

Regarding what you can see in *figure 11* from the SPL data, there are different answers to if the SPL data is useful. In the purpose of this work, the answer is no. As can be seen in *figure 11a* and *11b,* there is a big difference between the different sets of the LiDAR data. Where the Single Photon data is clearer in terms of the topography overall, where you can see structures in the map in comparison with LiDAR with 2 meter resolution.

However, for the purpose of this paper, both sets of LiDAR data are not sufficient to detect single boulders. The hillshade maps were inadequate, instead a slope map was in order to detect boulders, where in fact it was a surprise when it detected single blocks. At the same time, it is important to remember that both Björsarödjan and Bränslen were forested during the time the data was collected, hence why all 56 boulders measured in Bränslen on *table 1* were not apparent on SPL. Since the study areas were vegetated, it was difficult for the SPL and LiDAR pulses to penetrate through the vegetation. Hence, the date when the data was collected has been a big factor in the results.

The fact that we did not know that both Björsarödjan and Bränslen were covered with vegetation during the time SPL was flown made the study more interesting. And this by a new purpose of the study was born, whether SPL could detect boulders that are covered by vegetation.

5.2 Drones and SPL

Drone photos were very helpful in identifying the boulders. In the slope maps, for example, the drone photo and the field book were used for the reference of boulders that were measured out in the field and could be detected with SPL. The largest boulder measured in the field which can be seen in *table 1* number 38 also known as Lucy was used for reference when comparing *figures 10a* and *10b,* if it was possible to see that boulder which the SPL could not. Björsarödjan unfortunately did not get a map made on ArcGIS Pro as the SPL data over Björsarödjan was not captured in the SPL data. Since Björsarödjan area was covered by vegetation too. The result from GIS was based on Bränslen where the boulder concentration was the highest.

An interesting thing that was noticed after the map in *figure 11c* was made, was that most of the boulders that SPL could detect were close to vegetation. In *figure 9* the drone photo is seen over the same area, there were boulders that were measured on ArcGIS pro that were larger than the boulder circled in green. But this may be because the SPL data did not have sufficient amount of laser pulses sent out to detect boulders that are close together. Note, this area in Bränslen presented in *figure 9* was not under vegetation when the data was retrieved, so there may be something in the vegetation that brings out individual boulders more clearly.

In Dahlgren's (2014) study, the author writes that blocky terrain increases the risk of misclassification of the land, which leads to difficulties in finding the boulders. This could be a reason as to why boulders might have been easier to be localized near vegetation than what It was near boulder rich areas.

6. Conclusion

- Boulders could not be identified using the SPL for the forested areas. SPL could be used in a study that does not require such a level of detail as this study requires. It was possible to see more with SPL than LiDAR when it is a bigger scale, but there was nothing that benefited the purpose of this work.

- Only a couple of boulders could be detected with the SPL data and this due to the slope map, all the blocks that were detected were in the part of Bränslen that was not vegetated.

- Boulders could not be identified using hillshade of SPL even in the unvegetated area, hillshade as mentioned before can be used for other purposes but to precisely detect blocks it is best to use the slope map to get the best results.

- Even the biggest boulder could not be localized with the SPL. Mainly because it was vegetated when SPL was flown. SPL cannot see boulders below trees.

- The drone was helpful in detecting blocks in general, the drone photo provided a highly detailed photo of Bränslen which facilitated the identification of individual boulders in this study.

7. Acknowledgement

This project was financed by Göteborgs Universitet. Mark Johnson, my advisor, this work would not have been this smooth if it were not for you. You have guided me throughout this journey not only as an advisor but as a human being. You were always there with wise solutions to problems I encountered along the way. I would kindly like to thank Fredrik Ottedag and Christian Öhrling for their tremendous help over the months of doing this study, whether it be random conversations to being a source of material out in the field, thank you.

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