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Evaluated density estimates of young forest stands using high resolution 2D imagery from UAV

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ABSTRACT

After more than three decades of advanced technology and methods to evaluate young forest attributes, the forestry still prefers laborious field surveys in regeneration forests. Preceding studies have virtually all successfully identified the saplings, but the cost has outweighed the benefits or at least not yet convinced the companies to step away from the traditional field surveys; high-resolution photogrammetric point clouds and ALS-data can provide accurate estimations of the biophysical properties but requires intense data processing. One way to reduce the costs could be to use less accurate 2D imagery by scaling images to the approximate altitude.

The fundamentals of using cheap low-tech UAV imagery to aid management of young boreal forests was explored in this study, the results were obtained by comparing image interpreted saplings from images processed by Dianthus Rapid Drone Map™ to Sveaskog's traditional inventory practices of young forest stands. Three main issues were evaluated: 'Camera positioning and image scale', 'Sapling classification' and 'Need for cleaning assessment'. The study area included 57 forest stands and 290 sample plots within the county of Västerbotten, northern Sweden. The material & methods in the study were mainly predetermined by available equipment and field instructions from Sveaskog to enable efficient data collection through combined labour- and research work.

The results revealed that manual interpretation of the acquired images could discriminate between forest stands in need of cleaning and not with 82% accuracy, though the individual sapling counts comprised large errors, (Overall RMSE 6568 stems ha^{-1}). Possible advantages compared to traditional surveys are the production of up to date high-quality maps for the brush-cutter operators, improved planning of retention delineation and most of all reduced time spent in field since over 1 million hectares are estimated in need of cleaning in Sweden annually.

This study indicated that simple UAV imagery without proper photogrammetry could be an alternative; the quality might be bad but possibly sufficient.

Keywords: UAV, forestry, inventory, survey, cleaning, tending, PCT, pre commercial thinning

SAMMANFATTNING

Efter mer än tre decennier av utveckling av ny teknik och avancerade metoder för att inventera ungskogar med hög precision, föredrar skogsbruket fortfarande att genomföra tidskrävande fältundersökningar för ändamålet. Tidigare fjärranlysstudier har identifierat ungskogsstammar och röjningsbehov med bra resultat, men de har inte övertygat företagen att lämna de traditionella fältundersökningarna som uppfyller kraven på noggrannhet och hittills har varit konkurrenskraftiga i kostnadskalkylen. Högupplösta fotogrammetriska punktmoln och ALS-data kan ge noggranna uppskattningar av ungskogens biofysiska egenskaper men kräver också intensiv databehandling. Ett sätt att minska kostnaderna kan vara att använda mindre exakta 2D-bilder genom att endast skala bilder till den approximerade flyghöjden.

Denna studie har utvärderat grunderna för att använda enkla drönarbilder till inventering av boreala ungskogar och resultaten jämfördes med Sveaskogs nuvarande fältbaserade inventeringspraxis av unga skogsbestånd. Syftet var att utvärdera precisionen i tre huvudfrågor: ’Kamerans positionering och bildens skala’, Trädslags- och stamantals klassificering’ samt ’Bedömt röjningsbehov på beståndsnivå’. Studieområdet omfattade 57 bestånd och 290 provytor i närheten av Vindeln, Västerbottens län. Materialet i studien och det praktiska tillvägagångssättet bestämdes huvudsakligen utifrån tillgänglig utrustning och fältinstruktioner erhållna från Sveaskog.

Resultaten visade att manuell tolkning av de förvärvade bilderna kunde skilja mellan skogsbestånd som behöver röjas och inte med 82% noggrannhet, även om tolkat antal stammar per provyta omfattade stora fel (t.ex. RMSE 6568 för totalt antal stammar ha^{-1}). Möjliga fördelar jämfört med traditionella inventeringar är; framställning av uppdaterade kartor av hög kvalitet för röjningsarbetarna, förbättrad planering och avgränsning av hänsyn och framför allt minskad tid i fält eftersom över 1 miljon hektar beräknas vara i behov av röjning i Sverige årligen.

Denna studie indikerar att enkla drönarbilder utan korrekt fotogrammetri kan vara ett alternativ till dagens manuella fältinventeringar. Kvalitén av bilderna kan vara låg men möjligen tillräcklig.

Nyckelord: drönare, skogsbruk, inventering, röjning

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ABBREVIATIONS

3D	Three dimensional
ALS	Airborne laser scanning
CMOS	Complementary Metal Oxide Semiconductor
DEM	Digital elevation model
DSM	Digital surface model
GCP	Ground control points
GNSS	Global Navigation Satellite System
GPS	Global positioning system
GSD	Ground sampling distance
ha	Hectare
Lidar	Light detection and ranging
mp	Megapixel
NFI	National forest inventory
NRMSE	Normalised root mean square error
Radar	Radio detection and ranging
RMSE	Root mean square error
RTK	Real Time Kinematic

1 INTRODUCTION

1.1 BOREAL SILVICULTURE

One-third of the world's forest cover makes up the world's largest terrestrial biome, the boreal forests, (Figure 1). Forests are more than trees, it is also home to 80% of the terrestrial biodiversity (WWF, 2018). However, the reigning silvicultural method in the boreal European nations aims to maximise stem volume production through conifers with a crop cycle between 45-100 years, where better site fertility allows for earlier clear cutting (SVL 2014: 890, 10§). A remarkable example of efficient forestry is Sweden. Despite of its small size, Sweden is the world's third-largest exporter of pulp, paper, and sawn timber (Swedish forest industries, 2018). The pursuit of higher yields and revenue is constrained by law to also aid other forest services like reindeer husbandry, biodiversity, carbon sequestration, renewable energy, and recreation. The forest resource and all its potential assets can be considered to depend on how the forest is regenerated (Hallsby et al., 2015; Enander, 2007; Park & Wilson, 2007). In addition to the financial factors, psychological and socio-economic factors also affect the willingness and duty to manage the forest in accordance with the law and societal goals (Enander, 2007; Park & Wilson, 2007; Insley, 2002).

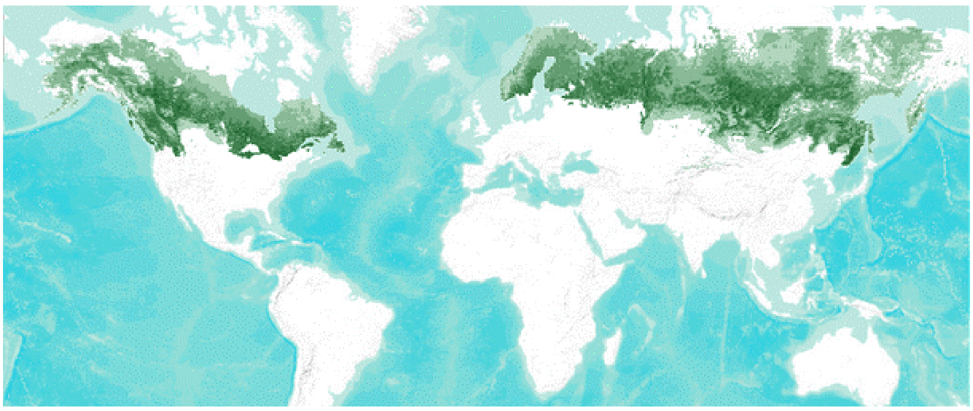


Figure 1. Illustration of the boreal forest distribution, where most of Sweden is included.

The human interference on Earth's key system processes, causing ecosystem change and biodiversity loss (Newbold et al., 2016; Newbold et al., 2015; Steffen et al., 2007), is now recognised as a new geological epoch, the Anthropocene (Rounsevell et al., 2018), also known as the sixth mass extinction. Forest managers have traditionally reasoned timber supply oriented sustained yield (Wiersum, 1995), and Sweden has successfully neutralised its carbon emissions in the process (Skogforsk, 2019), but forest managers need to "develop from being crop managers to ecosystem managers" (Farrell et al., 2000 p.6) to mitigate the anthropogenic effects on biodiversity. There is an increasing focus on integrative approaches in forest management (Brunialti, 2014) through green tree retention, identification of small valuable forest habitats, and promotion of mixed forest stands (Brang et al., 2014; Johansson et al., 2013), though the boreal forest of western Europe is expected to be increasingly fragmented with intensively managed stands and only scattered remnants of old-growth forests set aside for biodiversity conservation purposes (Claesson et al., 2015).

Throughout the regeneration phase the future forest characteristics are determined about a century into the future, making it the most critical silvicultural phase in terms of shaping the future stands and attributing them with desired assets (Hallsby et al., 2015; Enander, 2007; Park & Wilson, 2007).

1.2 SWEDISH FORESTRY: REGENERATION ENTAILS CLEANING

The dominant regeneration method in Sweden is clear-cutting with soil scarification and planting. More than 70% of the regenerated area has been planted during the last ten years (SFA, 2018a) mainly with Norway spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*) (SFA, 2018b). Various size, provenance and degree of refined breeding of seedlings can be ordered from nurseries. There is also sowing of processed seeds.

Since 1903 the Swedish forest owners are obliged to reforest (SVL 2014: 890, 5§). Generally, young Swedish forests grow into a stage of dense stands where pre-commercial thinning (PCT) are applied. PCT is synonymous to tending, clearing and cleaning and ensures the main stems unrestrained growth. The treatment, onwards denoted as cleaning, is intended to allocate the natural resources of sunlight, water and nutrition to the future timber yielding stems by reducing adverse effects from competition (Cannell *et al.*, 1984; Ford, 1975). The timing and extent of cleaning is ecologically and economically important. Browsing and risk of snow damages are examples of parameters to be considered when determining at which mean tree height cleaning should be performed. Late cleaning will risk bigger trees that are more time consuming and hence more expensive to cut, while too little competition followed by an early cleaning will risk more and bigger twigs, impairing future timber quality.

Some conditions call for several cleaning treatments. A typical procedure in the boreal pine forests would include two treatments, one at around 1 m mean height keeping about 3000 stems/ha and a second at 5 m mean height down to about 2100 stems/ha (≈90% pine, ≈10% birch).

According to Forest statistics (2019), provider to the Swedish official forestry statistics, a young forest requires cleaning when the number of stems seriously impedes the development of main stems. If the number of stems exceeds the requirement for density-unit 1.0 with 50%, there is a need for cleaning, likewise when deciduous trees inhibit the development of conifers. The need for cleaning is categorised as time of when cleaning should be performed; 'Immediately', 'Within five years but not immediately' or 'Within 6-10 years'. The area of forest (cutting class B1-B3) which has 'Immediate' cleaning needs are today about one million hectares while roughly 200 000 ha is cleaned every year (Figure 2).

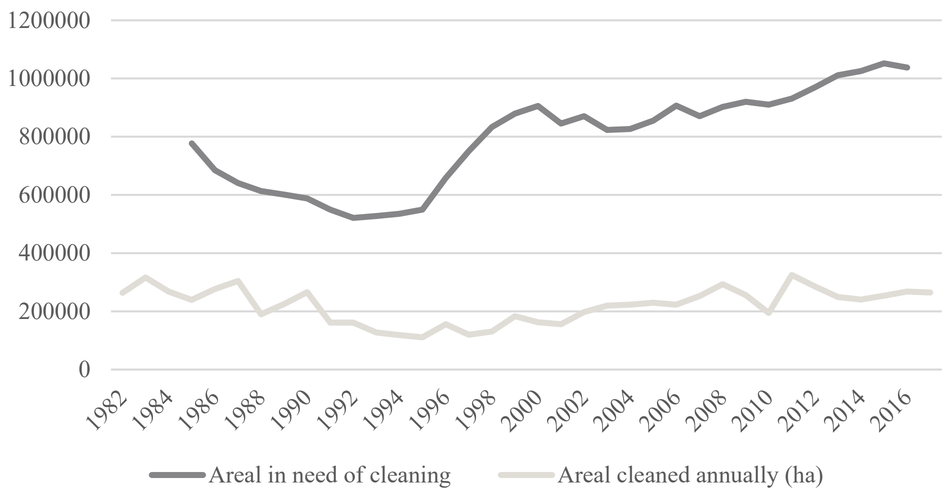


Figure 2. Areal in need of cleaning and area cleaned annually, plotted together. (Forest statistics, 2019)

The increased knowledge of plant physiology and the development of technology in the second half of the last century rationalised and mechanised forestry (Lieffers et al., 2008; Enander, 2007; Johansson & Naumburg, 2006). Soil preparation and planting, together with breeding programs and nurseries, could together increase production in the forest. Elfving (1981) forecasted an increase of 25% higher stem wood production over a rotation period compared to natural regeneration based on the growth in pine regenerations between 1960 – 1970. Hallsby et al. (2015) concluded that soil preparation, planting of large seedlings and cleaning during the initial 24–27 years of the stand establishment could increase the average stem volume production for pine and spruce by 79–149 % relative to natural regeneration with no site preparation or cleaning.

The increased wood production is expected to generate a higher net income from the forest, though the effects from intense silvicultural measures must relate the profit in return to the increased investment cost of active regeneration (Hallsby et al., 2015; Park & Wilson, 2007; Adamowicz et al., 2003). The foresters must balance the number of seedlings required for stand establishment with the cost of cleaning redundant saplings, simultaneously facilitating biodiversity, social values and ecosystem functions. The economic revenue has been shown to depend on the initial stand structure, that is; enough seedlings are used to optimise the stand's volume production on the site (Tahvonen et al., 2013), but it is sensitive to the economic return requirements settings that are modelled.

Refined seedlings from tree-breeding programs are expected to have a genetic gain of up to 25% better than the local seed (Skogforsk, 2010; Svenska Skogsplantor, 2018), but to reach its potential gain, in terms of increased volume, that presumes that the processed material may be developed into the trees that remain at the final felling. This means that the seedlings must stay vital after transport to the site, establish themselves quickly, dominate over the natural regeneration collectively to avoid cleaning as inhomogeneous fast-growing trees, overcome fast-growing broadleaves, and survive browsing, weather, wind and fire. Although the number of seedlings planted in regeneration exceeds the amount desired in harvest, seedlings die over time with a decline after about five years (Hallsby, 2013; Elfving, 1992), which necessitates supplementary planting to aid the regenerations and maintain a high share of refined seedlings. Roughly 20 million seedlings are produced annually in Sweden for auxiliary planting alone (Figure 3).

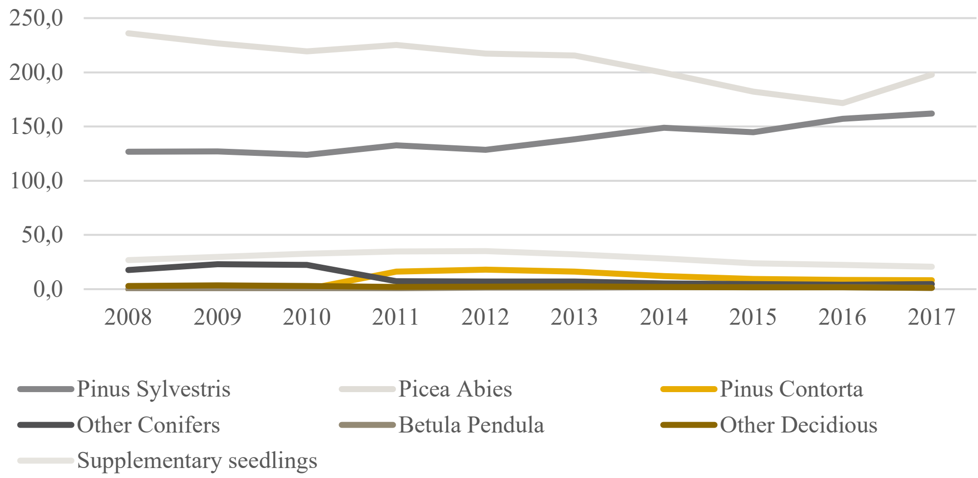


Figure 3. Number (millions) of annually produced seedlings in Swedish nurseries over the past ten years. (Swedish Forest Agency, 2018b)

Table 1 displays various results from previous extensive Nordic studies investigating survival of initial main stems remaining. The studies had between 46 and 776 regeneration stands, respectively. As shown in table 1 a substantial share of main stems from initial planting has been replaced by naturally regenerated stems.

Table 1. Share of main stems left from initial planting, the remaining share consists of natural regeneration. (Elfving, 1992, & Ackzell et.al., 1994)

Study	Time after initial planting (Years)	Share of initial main stems remaining (%)
PTAX, Hultén m.fl. 1974–1980	3	71
STAX, Braf & Ollas 1987	2	80
Hugin, Elfving 1991	7–12	81
Swedish Forest Agency, Bäcklund 1991	6–12	83
MoDo, Ackzell m.fl. 1992	10	83
Rautiainen & Räsänen, 1980	15	75
Pohtila & Valkonen, 1985	8–18	65
Saksa et al., 1987–1990	3–8	60

After 25 years, only half of the main stems originate from planted refined seedlings according to studies by (Hallsby et al., 2015; Ackzell et al., 1994; Elfving, 1992).

The Swedish Forest Agency (SFA) surveys the national regenerations five years after harvest in southern Sweden and after seven years in northern Sweden. Approximately 450 stands are inventoried every year. The regeneration is approved if it corresponds to the site index specific minimum stem number requirements of §6 SVL. The results are presented as three-year averages and 2015-2018 gave a new record in accepted regenerations with 91 % approved. Of which 92 % were approved for planting, 87 % for natural regeneration, 87 % for sowing and 48 % for no action (Figure 4).

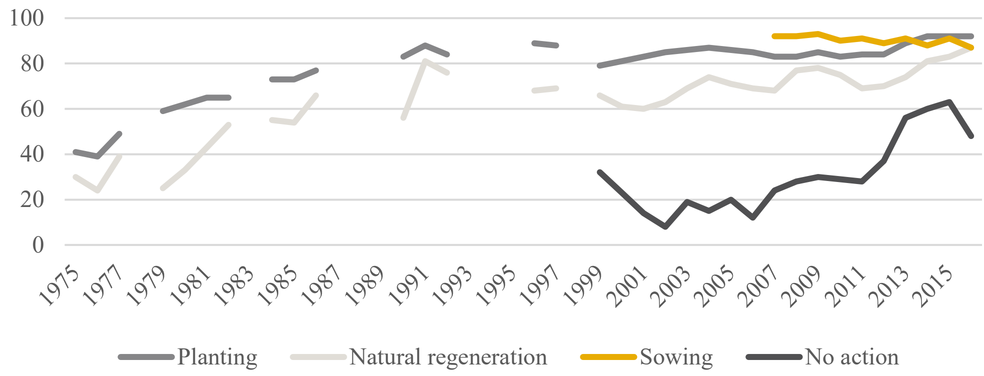


Figure 4. Percentage of accepted regenerations since 1975 for different regeneration methods. (Swedish Forest Agency 2018b)

The results indicate a trend towards more effective regenerations, which supports the reigning regeneration practice 5-7 years after the harvest, at least in terms of wood volume production. As the seedlings grow into saplings and the clear-cut develops into dense stands of mixed artificial and naturally regenerated young trees, clear-cutting obliges cleaning to ensure the main crop's continued growth.

1.3 DEVELOPMENT OF SWEDISH FORESTRY

Since 1993, production and environmental objectives (e.g. biodiversity) in the Swedish Forestry Act (SVL) are equated, which implies that the choice of regeneration method can only be chosen to maximise production if it is compatible with the environmental objectives. Pioneer tree species like pines and birches are dependent on significant disturbances like clear-cuts or fire in the mature forest to regenerate, while shadow-tolerant species like spruces are not. Continuous cover forestry, as selective felling, can be applied to shadow-tolerant species and is sometimes described to have the potential to conserve and restore biological diversity in spruce forests, while clear-felling would not, e.g. Ohlson & Tryterud (1999).

To relieve society from environmental problems before it is handed over to the next generation, the Swedish Government and Parliament established 16 environmental quality objectives, under an overall 'Generation goal' in 1999 (The Environmental Protection Agency 2016). Objectives described in the Government Bill, 1997/98: 145, refer to 'Swedish environmental objectives, environmental policy for a sustainable Sweden'. Within the environmental quality objectives, 29 interim goals include: preserving biodiversity and limiting the climate impact. An intermediate goal of the environmental quality objective 'Living forests' is 'A varied forest management', where the supervisory authority for SVL, the SFA, is responsible, and this goal has not yet been met (The Environmental Protection Agency 2016). Examples of improvements that correspond to forest management are the work with more varied forestry, like alternative regeneration methods within the concept of continuous cover forestry.

Hallsby et al. (2015) argued a review of the SVL and the prevailing principles for forest regeneration is necessary to appreciate all forest values appropriately. In October 2018, the SFA debriefed its governmental mandate to review the need to revise regulations so that they support the forest policy's equal objectives on production and the environment (SFA 2018a). It states that the production aspect has a continued strong position in the law, although other interests have strengthened their position.

The report constitutes a basis for the Forest Agency's continued work. Proposed amendments to regulations are made after the usual external referral procedure and treatment by the Board, which should be at the beginning of 2020 (The SFA, 2018a). The report includes proposals for changes to rules concerning regeneration measures, Table 2 presents the SFA's new proposal on the regeneration requirements of conifers and birch. The report also contains comments on the Forest Agency's proposal from more than 40 stakeholders, which illuminates the distinct interests that exist within the Swedish forestry when for instance The Environmental Protection Agency, Greenpeace, the Sami Parliament and WWF oppose.

Table 2. Present seedling and sapling number requirements and the SFA's new proposal on the regeneration of conifers and birch. (SFA 2018a)

Present plant number requirements			
Site Index	By the latest point of auxiliary planting	At ≈5 metres height	At ≈10 metres height
>18	800 – 2300	500 – 1250	≈500 – 1200
≤18	700 – 1150	500 – 600	≈500
The Swedish Forest Agency's new proposal			
Site Index	At 1,3 metres height	At 5 metres height	At 10 metres height
>18	1500	1200	900
≤18	1000	800	600

More broadleaves are needed in the landscape, contributing to more varied forests, food for the wildlife and higher biodiversity (SFA, 2018c). A conceivable way to more variation in the forest, in accordance with the report (SFA 2018a), would be to maintain more broadleaves in the regeneration phase. Most regeneration's attempt to utilise the soil's production capacity with conifers, since spruce and pine are most often considered to be most suitable (SFA, 2018b). The broadleaves are generally decontaminated through cleaning, apart from small elements required by forest certification standards, e.g. FSC® and PEFC™, which in coniferous stands are 5% or 10% (Anon. 2009). Additionally, at least 5% of a forest estates productive area shall be stands dominated by deciduous trees in addition to areas set aside (Anon. 2009). Reduced demands on the number of main species at the seedling stage should facilitate greater elements of broadleaves.

As mentioned, the regeneration phase is where the forest managers design what attributes and assets the forest should provide throughout the rotation period, and the essential design tools are harvest, soil preparation, choice of main species and cleaning. The political agenda, as well as the industry demands, are likely to change throughout the rotation period, which necessitates strategical ecosystem management planning, where accurate up-to-date forest information is required.

1.4 REGENERATION INVENTORIES

Sveaskog is Sweden's largest forest owner, state-owned, and holds 14% of the Swedish forest land (Sveaskog, 2019). In their young production forests, each stand is inventoried in three steps (*Inventory-I-II-III*).

Inventory-I is carried out one vegetation period after the initial reforestation action, in order to count seedlings ha^{-1} to find sites in need of auxiliary planting and to decide when to perform *Inventory-II*. The second inventory takes place when seedlings have become saplings (~one metre high) to assess the need for cleaning by counting all saplings above knee-height. The relationship between main- and secondary saplings, as well as amount and spatial distribution, is assessed to estimate the need for cleaning and when to implement the treatment. The stand can be assigned one of three different need for cleaning classes: ‘No need for cleaning’, ‘Clean now’ or ‘Clean in 3-5 years’. *Inventory-III* is normally planning of the cleaning, through delineation and production of instruction for the brush-cutter operators. If the site is visited too early, a new field visit is decided for future planning of cleaning, or if no more cleaning is desired, the time for thinning is estimated.

1.5 REMOTELY SENSED YOUNG FOREST

In forestry, remote sensing is well developed to estimate stand properties like stem volume and mean height, mainly by area-based methods through 3D data derived from images, lidar or radar with good quality in established forest (Kangas *et al.*, 2018a; Brosofske *et al.*, 2014; McRoberts *et al.*, 2010). Young forest stand parameters, on the other hand, are hard to estimate, especially stem numbers. Pitt *et al.* (1997) concluded that regeneration forests need very high-resolution Remote sensing (RS) data, and Pouliot *et al.* (2002) suggested the optimum average crown size to pixel ratio to be 15:1. The national forest ALS programmes commonly produce 1-5 points/m^2 (Puliti *et al.*, 2019) hence, regeneration forest are either cut-off from studies as outliers, or the precision is simply considered insufficient to replace the traditional field surveys (Imangholiloo *et al.*, 2019; Kangas *et al.*, 2018b; Miina *et al.*, 2018; Orka *et al.*, 2016; Valbuena *et al.*, 2016; Korhonen *et al.*, 2013; Korpela *et al.*, 2008; Naesset & Bjerknes, 2001).

Dedicated regeneration forest studies have shown promising results in binary cleaning assessment with 3D data despite inaccurate stem numbers; Noordermeer (2017) utilised 2,5 points/m^2 ALS-data with an overall classification accuracy of 83 %, and Wennerlund (2018) reached 82 % with point-clouds from highly overlapping 5cm pixel images. Other studies with denser RS-data have successfully identified individual saplings with an accuracy of 70-90 % through neural network classification with multispectral and textural image information from 2,5 cm pixeled aerial imagery (Haddow *et al.*, 2000), 2,5 cm pixeled RGB-VI-UAV point cloud imagery (Goodbody *et al.*, 2018), 1,7 cm pixeled RGB-UAV point cloud imagery (Vepakomma *et al.*, 2015), leaf-off 2 cm pixeled RGB-helicopter imagery (Pouliot *et al.*, 2006), and 159 points/m^2 ALS-UAV (Vepakomma and Cormier, 2017). Earlier studies with simple image interpretation in aerial orthophotos have also successfully identified both seedlings and saplings; in scale 1:10 000 Hall and Aldred (1992) classified saplings with 85-94 % accuracy.

Imangholiloo *et al.* (2019) made use of the condensed knowledge mentioned above when identifying seedlings with good results, using hyperspectral 10cm/pixel and RGB 2,5cm/pixel UAV-imagery derived point clouds in leaf-off and leaf-on stands, with a relative RMSE of 26,8 %. Which is no better than manually interpreted seedlings and saplings in scale 1:200 by Sylvander (1985), with a relative RMSE of 26,4 %.

Still, after more than 30 years of advanced technology and methods to estimate young forest attributes, the forestry prefers field surveys in regeneration forest, which comprises a standard error (SE) of about 25 % for the total number of stems (Eid et al., 1986). Preceding studies have virtually all successfully identified the saplings, but the cost has outweighed the benefits or at least not yet convinced the companies to step away from the traditional field surveys.

One way to reduce the costs could be to reduce the extensive data collection and data processing costs required for 3D data and accurate orthophotos including; overlapping mapping and exploiting photogrammetry to estimate precise camera positioning and scale, less accurate 2D imagery can be obtained by scaling images to the approximate altitude (A) and the known focal length (f):

$$\frac{d_{sensor}}{f} = \frac{d_{image}}{A}$$

$$\frac{d_{sensor}}{f} * A = d_{image}$$

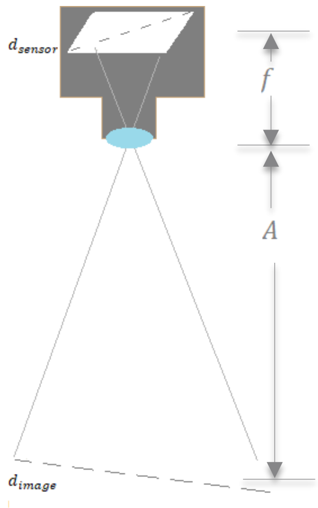
$$\frac{d_{image}}{dp_{image}} = scaling\ factor\ (m\ pixel^{-1})$$

$$d_{sensor} = diagonal\ sensor\ (mm)$$

$$d_{image} = diagonal\ imaged\ object\ (m)$$

$$dp_{image} = diagonal\ image\ (\ pixels)$$

A =altitude (m) f = focal length (mm)



Several parameter's accuracies will affect the orthophoto precision like; height above ground, camera features and camera direction.

"Raw images" (Imangholiloo et al., 2019; Feduck et al., 2018), comes with complications. Only the centre of the image is approximately correct, as you move towards the edges of the image, the trees will lean away from the centre since they are only seen from one side in the image. However, the application Dianthus Rapid Drone Map™ (Dianthus, 2018) relieves the photo missions from required overlap and enables orthorectified single images and mosaics with rapid processing time. Raw UAV imagery from low flying altitude with no orthorectification have shown promising results for seedlings (Feduck et al., 2018; Kingstad & Tovedal, 2018), their results imply that less accurate orthorectified wall to wall imagery, without processing of point clouds, could identify saplings/ha if the UAV orientation and positioning is approximately accurate.

The reason for this study was the idea of a pragmatic inventory that would combine subjective field measurements of stem height, with objective imagery measurements of density and distribution from the drone to replace *Inventory-II* and *III*. The pilot would then utilise spectral and textural imagery information together with subjective mean heights to assess the need for cleaning. This study intends to appraise the information from such less accurate 2D-imagery, with the aim of providing insights on how to achieve a cheap automatic low-tech high-resolution combined human and machine inventory.

2 OBJECTIVE

The objective of this study is to explore the preconditions for using cheap low-tech UAV imagery to aid management of young boreal forests. Manual sapling classification results from 1 cm pixeled RGB images, captured with a Dji Phantom 4 Pro drone, processed by Dianthus Rapid Drone Map™, are compared to Sveaskog's traditional inventory practices.

The accuracy of three main issues are evaluated to assess if the information from such less accurate imagery is sufficient for cleaning assessment:

- Camera positioning and image scale
- Sapling classification
- Need for cleaning assessment

3 Material & Methods

The material and methods in this study were mainly predetermined by available equipment and field instructions from Sveaskog to enable efficient data collection through combined labour- and research work. The technical gear was intended for establishment surveys (*Inventory I*) of coniferous seedlings while the data collection to this study was designed to have as little impact as possible to the everyday labour. The sites were selected since they were already planned to be inventoried.

3.1 Material

The study was conducted in the summer of 2018 at 57 sites (Figure 5) in the county of Västerbotten. All sites were located at Sveaskog's productive forest land surrounding the area of Vindeln (64°12′N, 19°43′E; 60-260 m above sea level). Scots pine was the dominant tree species, and deciduous were mainly birch.

Figure 5. Location of the 57 young forest stands in the county of Västerbotten, northern Sweden (Google maps, 2019)

The size of the studied sites varied from 0,5-30,4 ha. Preceding establishment surveys (*Inventory-I*) had projected impending 47 sapling inventory sites *(Inventory-II*) to be 1m in mean height, and 10 inventory sites were projected to be planned for cleaning with 4-6 m mean height *(Inventory-III*).

3.1.1 GROUND TRUTH DATA ACQUISITION

When performing *Inventory-II and III*, the fieldworker is equipped with a digital map and a site-size dependent grid in which each intersection calls for a sample plot. The grid has a random starting point, and the sampling frame is the area within the site, excluding retention block elements, roads and water. Resulting in a systematic random sample (Figure 6).

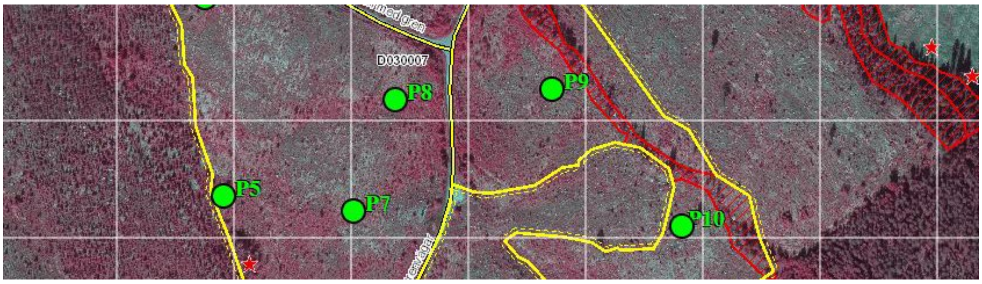


Figure 6. Screen shot from fieldworker's digital map, displaying systematic random sample aided by GIS through a sampling area dependent grid, in which each intersection calls for a sample plot.

On each circular 50 m^2 sample plot, all saplings above knee height are counted species-wise and the mean height of each species is noted. The notations in field are used to assess if, and when there is a need for cleaning.

To find the ground-truth sample plots in the drone images, circular 23 cm Ø paper plates were placed at the centre of each sample plot and its coordinate was recorded, geotagged by means of the iPad integrated GNSS (Figure 7). In total, 290 plates were put out in field.

Figure 7. Circular 23 cm Ø paper plates were placed at the centre of each sample plot and its coordinate was recorded with the iPad integrated GNSS.

As a reference to evaluate the scale of the images, known measurements corresponding to sample plot radius and diameter were painted on the ground (399 cm and 798 cm). Also, a car with a known distance between rear- and headlights was positioned in view of drone footprint (400 cm), in total 68 scale-reference objects were prepared in field.

3.1.2 UAV IMAGE ACQUISITION

At the end of each field inventory, irrespective of the varying light and atmospheric conditions throughout the day, a Dji Phantom 4 Pro drone was set to cover the sample area from 40 m altitude with 60 % frontal and 30 % side image overlap.

The drone comprises a three-axis gimbal-mounted 20 mp camera. The camera has a 1-inch CMOS sensor with 8,8mm focal length that was pointed nadir. Images of aspect ratio 5472×3648 were acquired with shutter speed 1/320. Aperture stop, focus and ISO was set to auto. The ground sample distance (GSD) from 40m altitude was 1cm/pixel with a theoretical footprint of 60 × 40 m = 0,24 ha, assuming the camera was pointing nadir towards a flat ground. Optics, compass and gimbal were optimised through Dji's calibration software.

As altitude guidance, the application MapPilot (DronesMadeEasy, 2018) created waypoints 40 m above the national ALS derived digital elevation model, DEM. The data acquisition for the DEM was carried out either 2010 or 2012 depending on location, after clearing, so no dense mature forest could have interfered with the number of ALS ground returns. The Swedish DEM (NNH) has a standard error, SE, in elevation on open hard surfaces of 0,05 m on average. SE in plane is 0,25 m on average, SE between flight lines is 0,1 m (Swedish National Land Survey, 2011).

Before the drone ascends to the instructed altitude, the camera records an image that stores the starting coordinates to which future images can store a relative altitude. To track the waypoints, it relies on instruments recording the reference starting ground height, normalises it to the DEM in Map pilot, and ascends to the flight height. The instruments available are GPS, compass, barometer, sonar and gimbal. At 40 m, the barometer provides the altitude information (Dji, 2018). The waypoints constructed by Map pilot has a smoothing operator of ± 5 % above the DEM to optimise the flight path (DronesMadeEasy, 2019).

To evaluate the accuracy of the camera positioning- and orientation, one more dataset was acquired for photogrammetric analyses. The flight was designed to acquire a high-quality (HQ) -dataset with large image overlap. For georeferencing purposes, the clear-cut 9 ha sample area was provided with 20 ground control points (GCPs). The coordinates were recorded with centimetre accuracy by an RTK-GNSS receiver connected to Swepos. The drone was set to cover the sample area from 40 m and 50 m altitude in nadir, with 80/80 overlap (Figure 8).

Figure 8. Screenshot from MapPilot displaying programmed flight route for the HQ-dataset acquisition, 40m above the national DEM, 80/80 overlap.

3.1.3 IMAGE INTERPRETATION

Of the 290 plates that were put out in field, 130 sample plot centres could be confidently identified in the orthophotos processed by Dianthus Rapid Drone Map™. Six sample plots were randomly selected and provided with ground-truth as training instructions (Figure 9). Three image interpreters were assigned the challenge of identifying saplings within each of the remaining 124 sample plots (full instruction enclosed in Appendix 1). A GIS interpretation environment was set in Arc GIS Pro (ESRI, 2019), where each identified tree was classified species-wise with a unique point, also an assessment of the need for cleaning was performed for each sample plot. The need for cleaning was divided into three classes: ‘No need for cleaning’, ‘Clean now’ or ‘Clean in 3-5 years’. Field sampled- and image interpreted data was joined to corresponding sample plot-ID and tabulated for the evaluation.

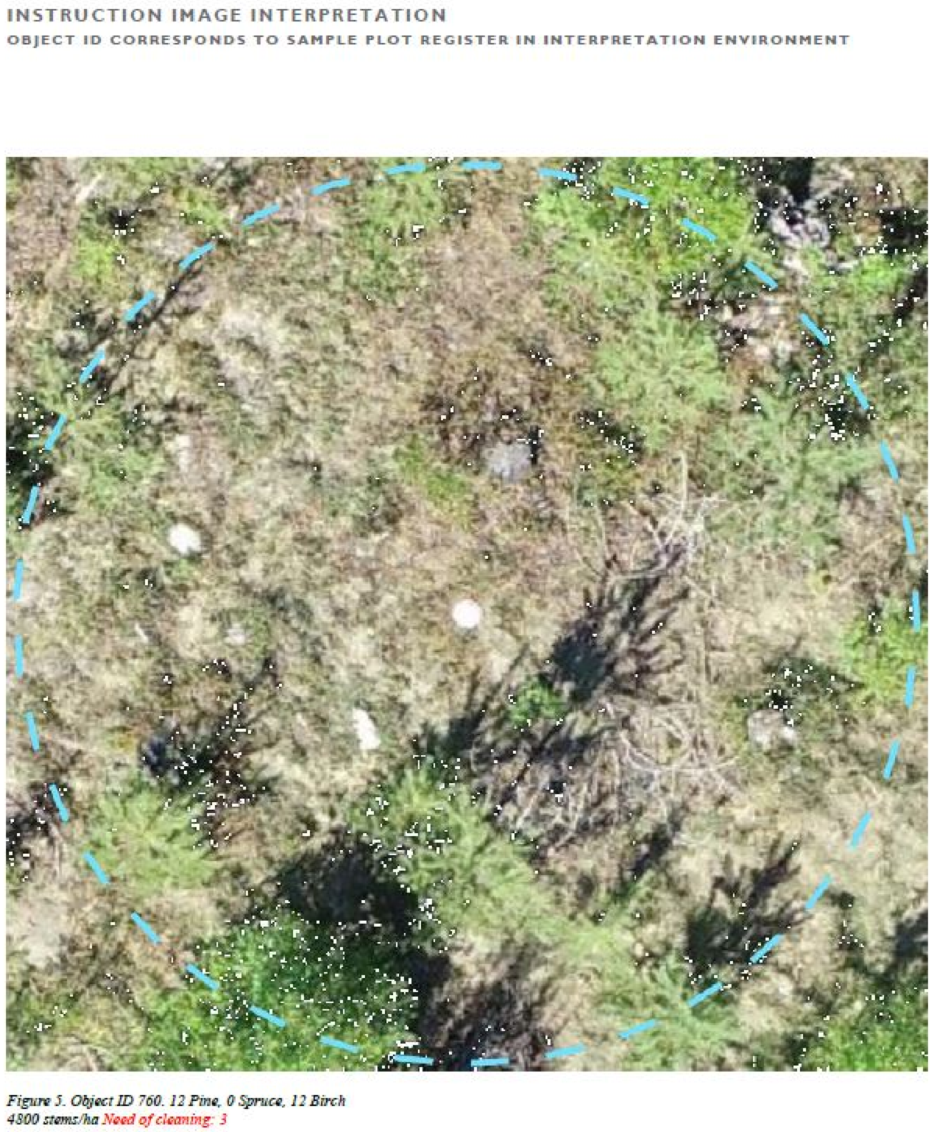


Figure 9. Screenshot from one of the interpreters’ six randomly selected training plots, provided with ground-truth data from *Inventory-II*.

3.2 METHODS

3.2.1 PHOTOGRAMMETRIC PROCESSING

The acquired images over the 57 stands were uploaded to Dianthus Rapid Drone Map™ for processing of orthomosaics to each stand. The x- and y-coordinates from image 1 was used to find the altitude information from the national DEM, from which the relative altitude of all other images could be calculated. The camera direction information (yaw, pitch, roll) from the images, together with the relative altitude enabled approximately correct scaling and projection to the DEM.

The images acquired for the HQ-dataset over the clear-cut sample area with 20 GCPs were processed with Agisoft Metashape version 1.5 (Agisoft, 2019). To evaluate the accuracy of each positioning and orientation parameter stored in the images, the camera position and orientation were recalculated. The photogrammetric reconstruction in Metashape followed the instructions from Ljungbergslaboratoriet (2019).

The first step was to import the images and enable the software to load camera location accuracy from image metadata. The software loaded GPS-altitude, yaw, pitch and roll to approximate the raw camera positions in the coordinate system SWEREF99 TM RH 2000. The next step was to filter out images with poor quality and then the images were aligned with the accuracy setting 'High' where Metashape uses the images at full resolution. The alignment utilises the overlapping images to build tie-points from common points on images and matches them. Aided by the tie-points the software calculates where the camera must have been and how it was directed to capture each image. To improve the alignment and the accuracy of the calculated camera positions the 'Optimize cameras" was iterated through with different settings to only keep tie-points with small errors, outliers were manually removed. The next step was to adjust the set of camera positions to the GCPs by manually pointing out each GCP in the images where it was visible. When all GCPs were identified and adjusted, all images were unchecked and the optimise camera procedures was iterated through once more.

3.2.2 EVALUATION OF CAMERA POSITIONING AND ORIENTATION ACCURACY

As evaluation data from the HQ-dataset, only the most accurate camera positions were utilised by excluding camera positions along the border of the study area. The estimated z-coordinates (altitude) displayed height above sea level. To find altitude above ground, the camera positions were exported to Arc GIS Pro (ESRI 2019) where height above the national DEM was extracted.

The 'relative altitude' stored by the drone was not successfully mined with Metashape, to receive this information R (R Core Team, 2017; O'Brien, 2019) was used to extract 'relative altitude' from the images. All parameters extracted to be evaluated from the remaining 737 images are listed below (Table 3), where the 'Relative altitude' and 'Estimated z' represent the cameras' height above ground.

Table 3. Parameters extracted from the drone to validate against the highly accurate estimations

Drone	X-coordinate	Y-coordinate	Relative altitude	Yaw	Pitch	Roll
Software	Est. X	Est. Y	Est. Z	Est. Yaw	Est. Pitch	Est. Roll

To evaluate the parameters from the HQ-dataset, the estimated orientation parameters were compared with those registered by the drone. To visualise the practical consequences of the results, the altitude errors were transformed to sample plot area by the law of Sines.

The differences between compared parameters were computed, tabulated and displayed graphically to present the results. RMSE and NRMSE in the results were calculated by:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}}$$

$$NRMSE = \left(\frac{RMSE}{\overline{x}}\right) * 100$$

3.2.3 EVALUATION OF SCALE ACCURACY BY KNOWN DISTANCE MEASUREMENTS

Of the 68 scale-reference objects that were set up in field, 43 objects were identified in orthophotos processed by Dianthus Rapid Drone Map™ and manually measured in Arc GIS Pro (Figure 10).

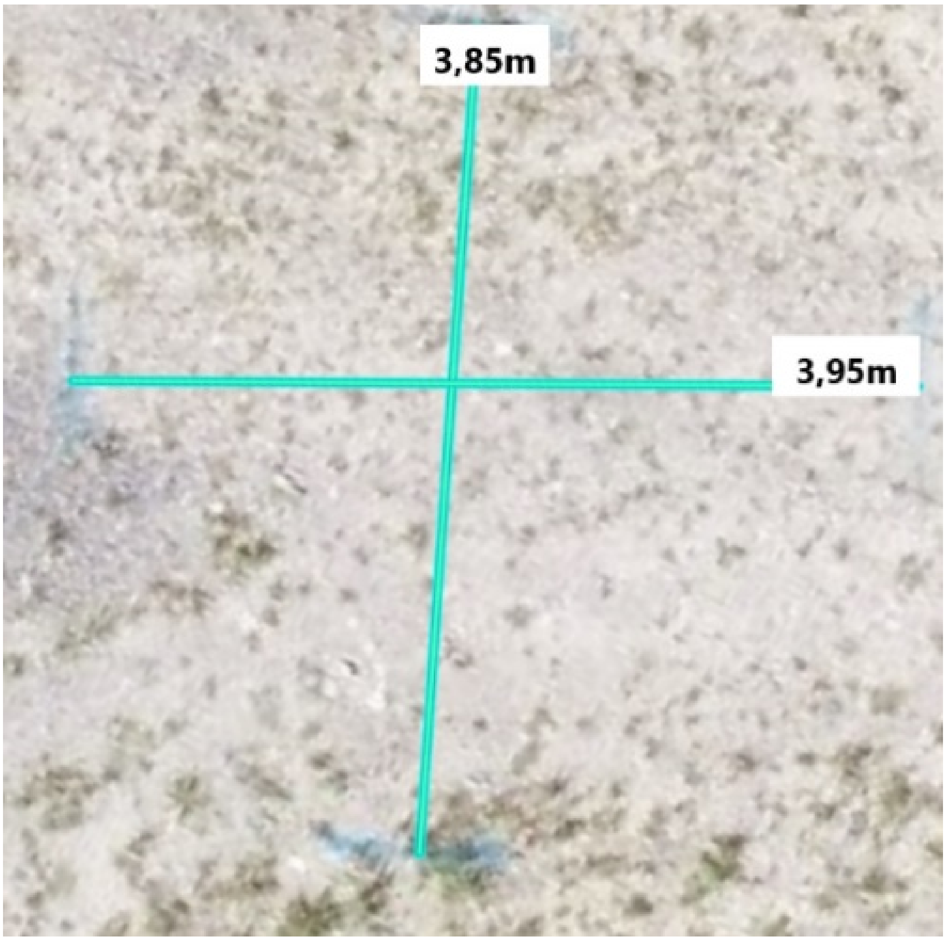


Figure 10. Two scale-reference ground markings with the distance of 3,99 m each (blue), measured manually in Arc GIS Pro (turquoise).

To evaluate the scale in the orthophotos, the GIS measurements were compared with the scale-reference objects. To enable comparison with the HQ-dataset results, the scaling errors were transformed to altitude errors by the law of Sines. The differences between compared parameters were computed, tabulated and displayed graphically to present the results.

3.2.4 EVALUATION OF THE INTERPRETERS' SAPLING CLASSIFICATION ACCURACY

To evaluate the accuracy of the image interpreters' sapling counts, the registered classifications in GIS were compared with the ground truth data from *Inventory-II* and *-III*. Differences between the interpretation results and the field samples were computed, tabulated and displayed graphically to present the results.

3.2.5 EVALUATION OF THE IMAGE INTERPRETERS' ACCURACY IN ASSESSING THE NEED FOR CLEANING

To enable evaluation of the image interpreters' cleaning assessment accuracy, the median of the registered cleaning assessments for each sample plot was aggregated to stand level and compared with the assessment in field (*Inventory-II* and *-III*). Only stands with more than 70 % identified sample plots were addressed, an arbitrary limit to balance between the number of stands and fair comparison.

Differences between the interpreted assessment and the field assessment were evaluated by a confusion matrix with the 14 *Inventory-II* stands and the 10 *Inventory-III* stands that qualified to the evaluation.

4 RESULTS

130 out of 290 sample plots were identified in the orthophotos, due to problems of finding the field plot centre in the images (Table 4). In the *Inventory-II* stands, with an expected mean height of 1 m, the sample plots were identified to a lesser extent (36 %) compared to the *Inventory-III* stands (69%), with 4-6 m expected mean height.

Table 4. Share of sample plots identified in the images

	Nr. of sample plots	Identified	Percentage
Expected tree height 4-6 m	77	53	69%
Expected tree height 1 m	213	77	36%
Sum	290	130	45%

4.1 ACCURACIES IN POSITIONING, ORIENTATION AND SCALE

The results from evaluated camera positioning, orientation and image scale are presented in Table 5. In the evaluation, differences between the image stored parameter data, and the calculated were observed. The largest errors were found in registered altitude, yaw and y-coordinate. While the x-coordinate, pitch and roll showed small errors.

A mean difference of -1,1 m from the scale-reference dataset and - 2,4m from the HQ-dataset in the altitude parameter revealed that the drone was flying lower than it was instructed to do (Table 5). The largest altitude deviations observed were -5,9 m and +1,9 m, and the RMSE (m) showed values of 2,1 and 2,6, respectively.

Table 5. The results from evaluated camera positioning, orientation and image scale. The 'HQ-dataset' contains 737 photogrammetrically recalculated camera positions and the 'Scale-reference' dataset contains 43 known measurements on the ground, imaged and manually measured in GIS

	Dataset	*Range*	*Mean difference*	*Standard deviation*	*RMSE*	*NRMSE %*
Altitude (m*)*	*Scale-reference*	7,0	-1,1	1,8	2,1	5
	HQ-dataset	5,8	-2,4	1,1	2,6	7
GPS (m)						
X-coordinate	*HQ-dataset*	2,0	-0,2	0,3	0,4	*
Y-coordinate	*HQ-dataset*	9,8	1,0	1,8	2,0	*
Gimbal (degrees)						
Yaw	*HQ-dataset*	51,1	3,9	16,3	16,7	*
Pitch	*HQ-dataset*	1,6	0,0	0,2	0,2	*
Roll	*HQ-dataset*	3,7	-0,2	0,3	0,4	*
Sample plot area 50m^2	*Scale-reference*	19,1	2,9	4,7	5,5	11
	HQ-dataset	14,3	4,9	2,8	5,7	12

To visualise the positioning and orientation errors revealed from the HQ-dataset's 40 m flight, the estimated values were layered on top of the image stored values (Figure 11, 12). The larger errors in y-coordinates (direction of flight) than x-coordinates is also demonstrated (Figure 11).

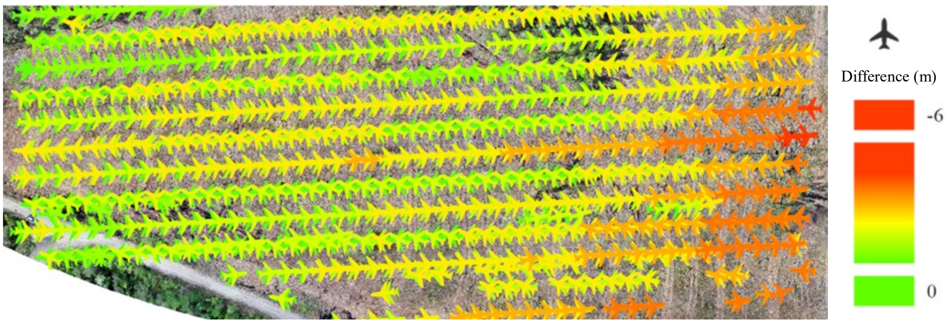


Figure 11. Overview of positioning and orientation errors from the HQ-dataset's 40 m flight, visualised by layering the estimated values on top of the image stored values. The airplane icons represent camera positions, coloured by altitude error and rotated according to yaw values. Green represents the desired 40 m altitude, while red equals to more than 5 metres below programmed altitude.

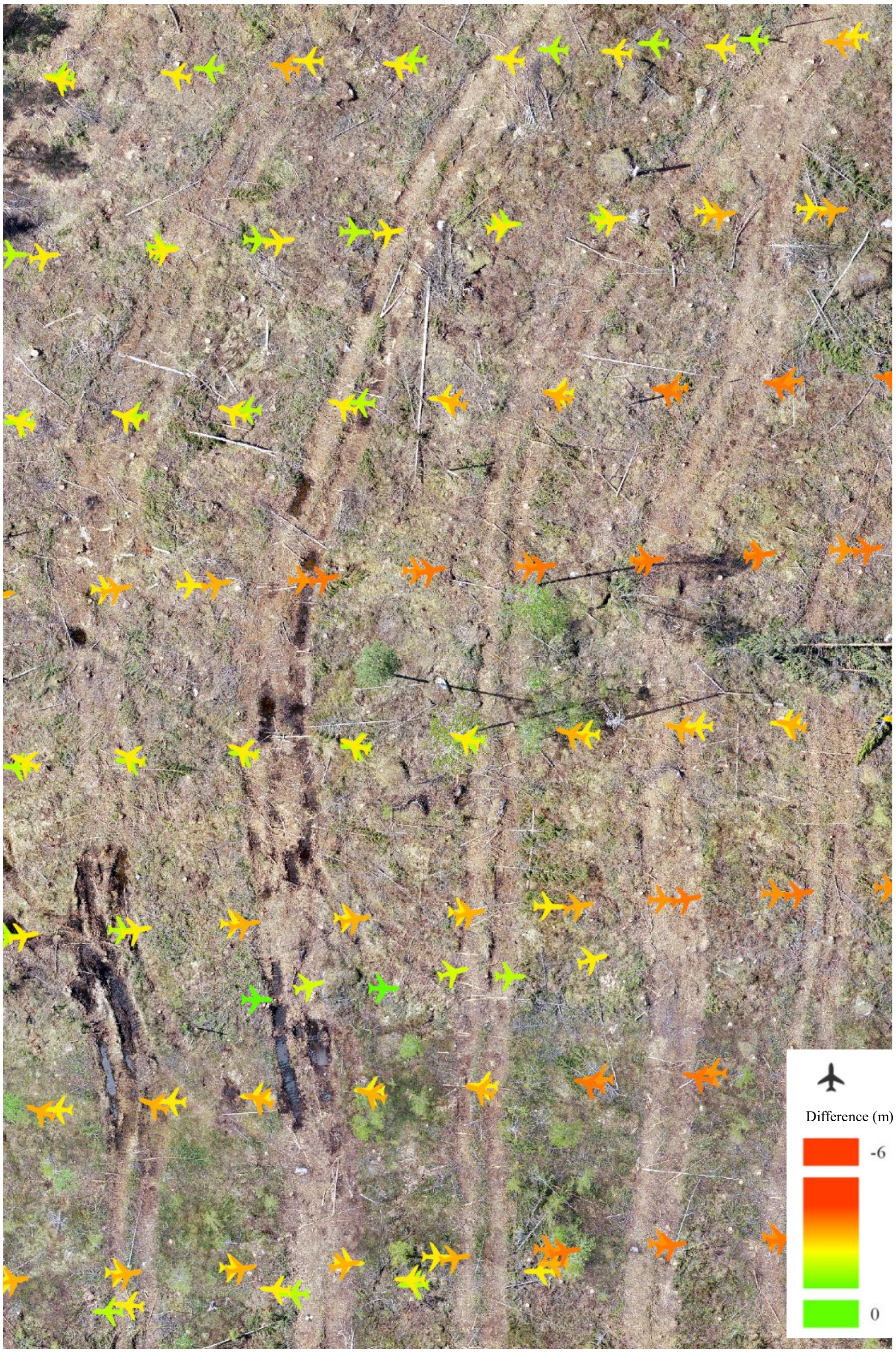


Figure 12. Zoomed view of positioning and orientation errors from the HQ-dataset’s 40 m flight visualised by layering the estimated values on top of the image stored values. The aeroplane icons represent camera positions, coloured by altitude error and rotated according to yaw values. Green represents the desired 40 m altitude, while red equal to more than 5 metres below programmed altitude.

4.2 SAPLING CLASSIFICATION

The individual interpreter’s results were on average very close to each other (Figure 13).

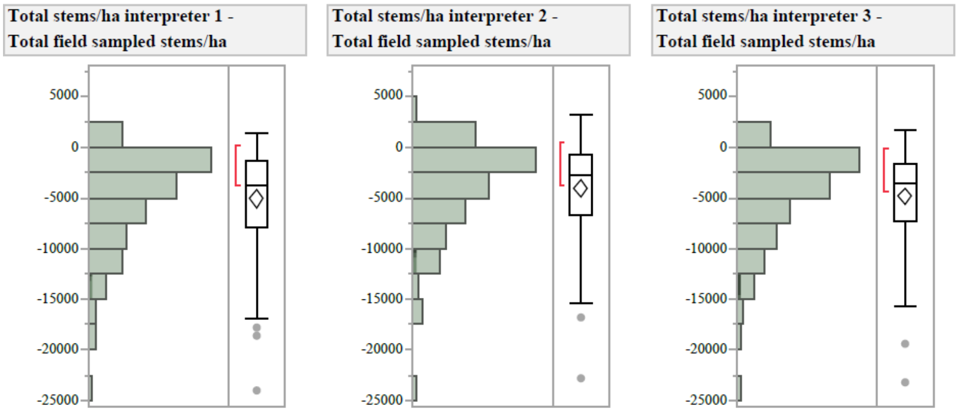


Figure 13. Distribution of each interpreter’s difference from field samples (Total stems/ha).

Since the interpreter’s results were similar, the subsequent results are displayed aggregated.
The image interpreters’ sapling count accuracy results show that saplings are underestimated, with a mean difference of -4684 stems/ha (Table 6). There are larger errors in estimations of number of deciduous trees (RMSE 4965) than coniferous (RMSE 1740).

Table 6. Calculated differences between image interpretation results of individual sapling counts and the field sampled data

Tree species	*Range*	*Mean difference*	*Standard deviation*	*RMSE*	*NRMSE %*
Spruce	3667	158	504	537	107
Pine	16800	-1824	2883	3401	638
Deciduous	17933	-3018	3958	4965	339
Coniferous	9367	-833	1534	1740	183
Total stems	24933	-4684	4623	6568	195

When the mean differences are grouped by total stems, it becomes visible that the largest errors occurred when classifying stem-rich sample plots (Figure 14).

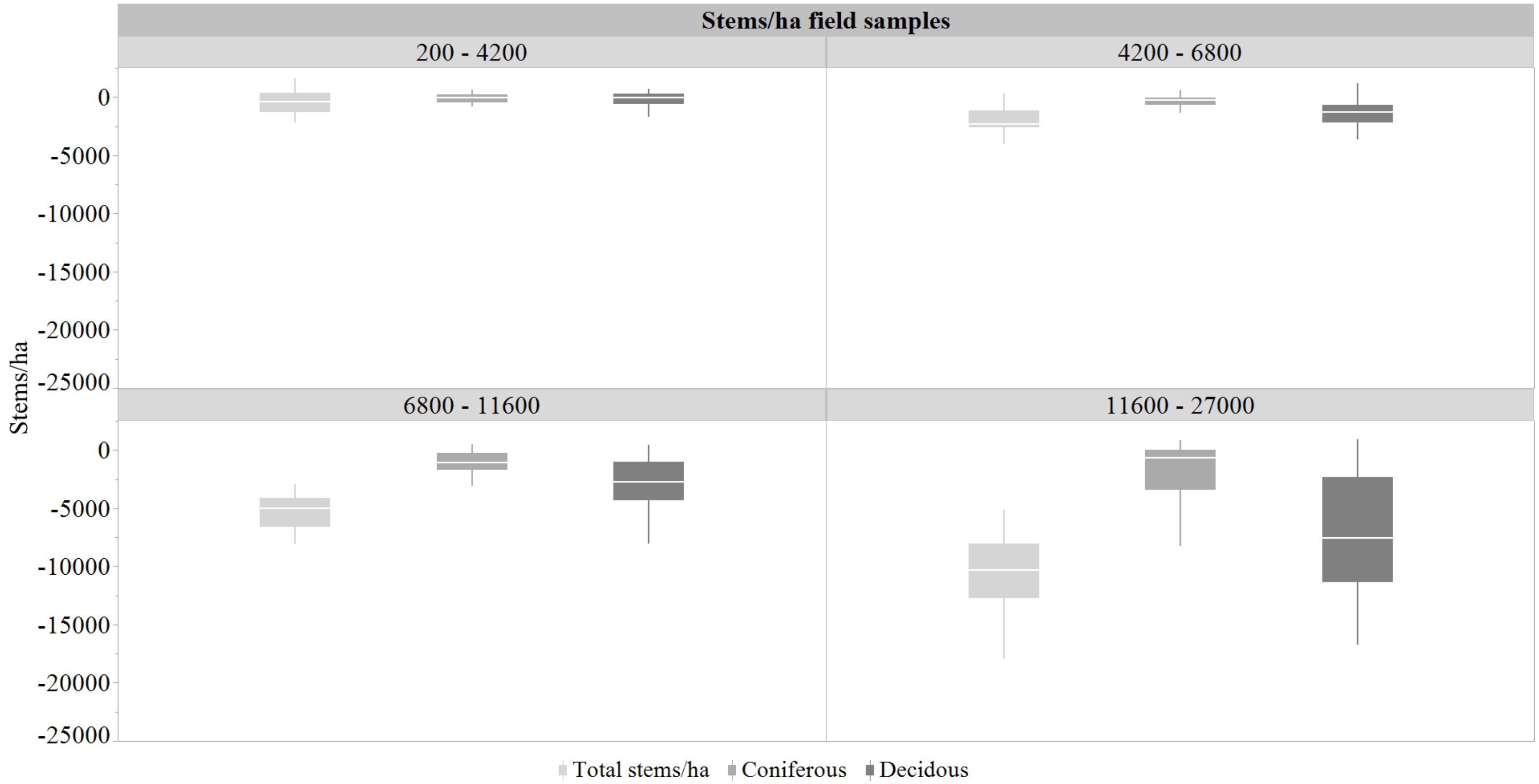


Figure 14. Interpretated error for total stems/ha, coniferous and deciduous grouped by ground-truth total stems/ha.

For more in-depth analysis, the interpreter's errors were tabulated to display how stem number and tree species composition affects the interpretation (Table 7). The poorest classifications were at sample plots with more than 8000 stems/ha and the best were the ones with moderate stem numbers of the same species, e.g. coniferous saplings were classified with a mean-difference of -281 in sample plots with 2000-3000 stems/ha in total and 25-50 % deciduous.

Table 7. Interpreted errors, grouped by total field sample plot sapling counts, and as the species-wise proportion. Bold boxes display the count of events when sample plots qualify to the conditions of the formula.

Sample plot count

Mean-difference (interpreted stems/ha)

Range	0	200	200	2000	2000	3000	3000	4000	4000	8000	8000	40000	
Pine				<- **Tot. pine/ha field sample** ->									Share of pine
	13	667	52	-433	29	-1667	15	-1600	21	-3650	9	-10038	75% -100%
		-767		-2133		-2010		-1842		-4421		-7143	50% -75%
		-1056		-1800		-3115		-2262		-3156		-5057	25% -50%
		-1091		-1521		-1901		-2200		-2590		-2474	0% -25%
Spruce				<- **Tot. spruce/ha field sample** ->									Share of spruce
	79	-	57	-	2	-	0	-	0	-	0	-	75% -100%
		-		-		-		-		-		-	50% -75%
		-		0		-		-		-		-	25% -50%
		319		-16		-433		-		-		-	0% -25%
Decidous				<- **Tot. decidous/ha field sample** ->									Share of decidous
	10	-7929	42	-7929	21	-7929	13	-8162	21	-8628	25	-10133	75% -100%
		-		-653		-1050		-1619		-3983		-7680	50% -75%
		-		-576		-1487		-2350		-1800		-6800	25% -50%
		467		-58		-1500		-		-		-	0% -25%
Coniferous				<- **Tot. coniferous/ha field sample** ->									Share of coniferous
	3	667	52	-42	36	-533	18	-617	20	-1756	10	-4641	75% -100%
		-		-52		-281		-613		-1567		-8267	50% -75%
		-		-121		-293		-1029		-1417		-	25% -50%
		250		158		-215		-467		-		-	0% -25%
Tot. stems				<- **Tot. stems/ha field sample** ->									Share of decidous
	1	-	10	-	14	-	11	-1200	43	-2522	52	-9752	75% -100%
		-		-800		-333		-1644		-2619		-7497	50% -75%
		-		-173		-144		-947		-2293		-7311	25% -50%
		1600		373		-483		-844		-2486		-8778	0% -25%
Tot. stems				<- **Tot. stems/ha field sample** ->									Share of coniferous
	1	1600	10	373	14	-483	11	-844	43	-2486	52	-8778	75% -100%
		-		-173		-144		-947		-2293		-7311	50% -75%
		-		-800		-333		-1644		-2619		-7497	25% -50%
		-		-		-		-1200		-2522		-9752	0% -25%
Tot. stems				<- **Tot. stems/ha field sample** ->									
	1	1600	10	147	14	-250	11	-1018	43	-2518	52	-8768	

4.3 NEED FOR CLEANING ASSESSMENT

Despite poor sapling count accuracy, several stands were correctly classified for need of cleaning with an overall accuracy of 63 % (Table 8).

Table 8. Confusion matrix with 14 *Inventory-II stands and 10 Inventory-III stands*, comparison at stand level of aggregated interpreted sample plots. Whereas class A is No need for cleaning, B = Clean now and C = Clean in 3-5 years

Need for cleaning		Field survey class A	B	C	Total	User's accuracy %
Interpreted class	A	2	3	0	5	40
	B	0	11	5	16	69
	C	0	1	2	3	67
	Total	2	15	7	24	100
Producers' accuracy %		100	73	29	100	63

By combining 'B' and 'C' the cleaning need can be answered by 'Yes' or 'No' with the overall accuracy of 82 %.

5 DISCUSSION

Of the 290 sample plots only 130 plot centres were identified in the images and included in the evaluation. The field plot centres were geotagged with poor positioning accuracy, plates were often more than 10 metres off the geotag, which made it difficult to track the imaged plates that could also be covered by vegetation due to the angled view close to the image edges. It is conceivable that the lost sample plots to a larger degree was placed in dense stands, since denser stands provides more vegetation to cover the paper plates, but the *Inventory-II* sample plots with the smaller mean height were identified to a lesser extent than the *Inventory-III* stands with the larger mean height. It is important to remember tough, that this only affects the evaluation; there would be no need to search for a specific field plot centre in practice. The missing field plots affected several stands into fewer field plots interpreted than measured in field, and possibly skewed the data towards less dense sample plots.

The image overlap of 60/30 could successfully provide wall to wall imagery, and due to the positioning- and orientation errors the image overlap was necessary although the frontal overlap could have been decreased. Yaw, the heading of the drone, was a big source of error when processing orthomosaics, the interpreters struggled with sample plots on the edge of images where such artefacts became evident, probably worsened by GPS-errors (Figure 15).

Figure 15. Illustration of projection error in image edge of rapid orthomosaic to the right, compared to orthophoto from more accurate photogrammetric reconstruction to the left.

One way to reduce the practical effects from yaw errors is to capture the forest stand with little to no image overlap and only rectify single images without producing mosaics. The images could still provide wall to wall imagery where it would be possible to turn on and off single images in a GIS software. The yaw issue would still interfere with the orientation of the projected image, but the reduced edge effects would improve the spatial accuracy of the spectral information.

One important finding was that the drone on average flew lower than it was instructed to do, the HQ-dataset resulted in a mean-difference of -2,4 m and the NRMSE was 7 %. The altitude deviation extremes of -5,9 and + 1,9m from 40m would affect the sample plot area to 15,8m^2 larger and 3,2m^2 smaller plot areas, respectively (Figure 16). The consequence when counting stems/ha is that the ha^{-1}-factor is altered, instead of multiplying observed stems by 200, the correct factors would be 152 and 214 to obtain stems/ha.

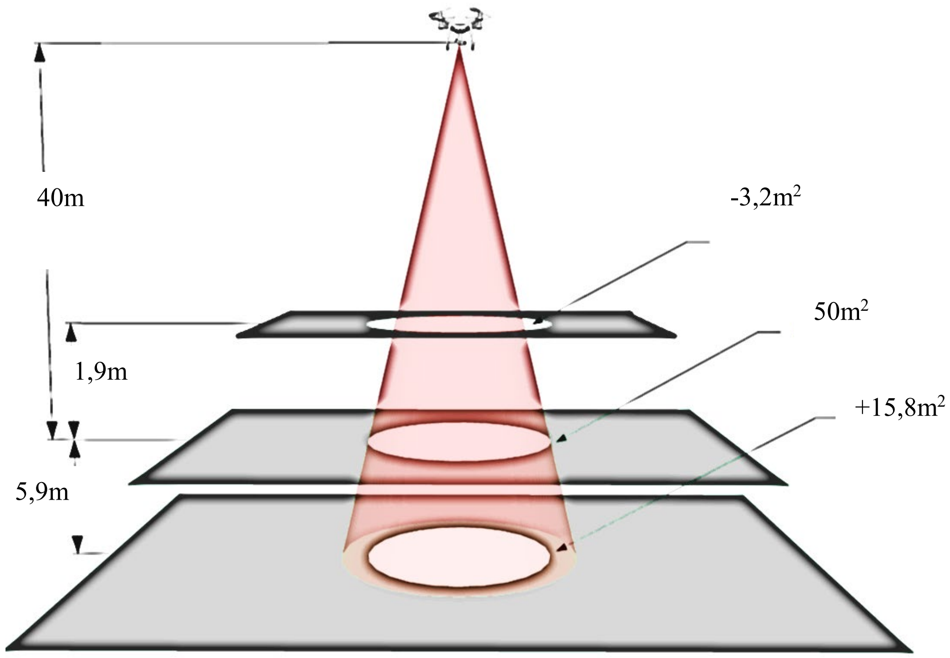


Figure 16. Schematic visualising the effects of misleading altitude when scaling an image; a 3,2m^2 smaller sample plot translates to identified saplings times 214 for stems/ha, a 15,8m^2 larger sample plot provides a factor of 152.

The smoothing operator in Map Pilot of ± 5 % might explain the mean-difference error, but not the extremes (Figure 17).

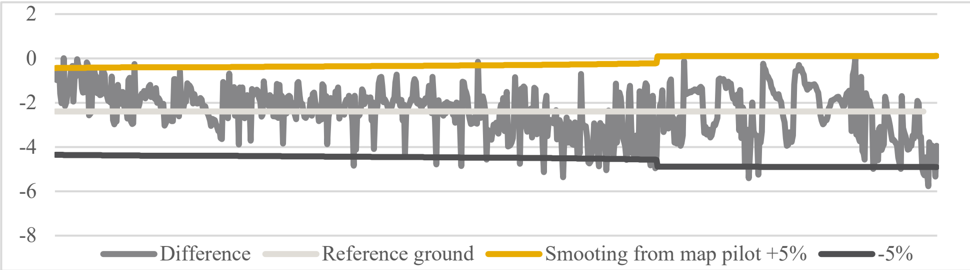


Figure 17. Illustration of the altitude errors from the HQ-dataset displayed with a theoretical smoothing of 5 % as confidence bands and a theoretical ground reference from the mean-difference.

The pitch and roll showed small errors and as displayed in figure 12, the x/y-coordinate errors were small on average and should be neglected in further progression of the inventory method.

The interpretation results showed an overall underestimation with a mean-difference of -4684 stems per hectare in total. The classifications were less successful as stem numbers increased. Compared to previous studies e.g., Imangholiloo *et al.* (2019) with a RMSE of 411 sph, for total stems and RMSE of 585 sph for conifers the results from this study's image interpretation were poor.

The interpretation errors were slightly improved when correcting for the altitude error that affects the sample plot size. The mean-differences for deciduous and conifers were -3019 and -833 sph, respectively. A recalculated mean difference when adjusting for the mean difference of sample plot size (+4,9m^2, Table 5) equals to a mean difference for the interpretation results of -2860 and -729, which is still far from previously reviewed studies. This suggests that the interpretation is a bigger source of error than the drone altitude-errors.

One explanation to the difference between conifers and deciduous could be that deciduous saplings sometimes grow so close to each other that they appear as one. This was intended to be accounted for in the study by having the interpreters also classify deciduous as 'multiple deciduous stems' when individuals were undistinguishable, but this feature was not created consistently, why the results were considered uncertain and not presented.

To find out if the information obtained by the interpreters could be sufficient to assess the need for cleaning, their sample plot assessments was aggregated to stand level and compared to the field assessed cleaning need. The accuracy of the image interpreters' assessed need for cleaning was poor, 63 % overall accuracy with three classifications, but when only considering 'Yes or 'No' the accuracy of 82 % was equivalent to reviewed studies that only used two classes assessing the need for cleaning, with 82 % accuracy by Wennerlund (2018), and 83 % by (Noordermeer, 2017).

One key factor to the outcome of regeneration-forest studies in general is certainly the spatial distribution of stems and the characteristics of the background vegetation, which is hard to evaluate but important to consider. It should be easier to classify saplings in a spatially regular pattern with a homogeneous background of mainly sand compared to clustered dense groups of saplings with a vegetation rich background mosaic.

The results of this study have proved that there is information in the evaluated imagery that have pushed the interpreters to collectively provide different classifications for different sample plots in a way that on average describes the sapling density and species composition. As author of this study I suggest one way to proceed; evaluate the possibility of better utilising the imagery information by calibrating it with training data and model it in an area based manner similar to the study of Puliti *et al.* (2019) with vegetation indices and field assessed height.

To conclude, the objective of this study was to explore the preconditions for using cheap low-tech UAV imagery to aid management of young boreal forests by evaluating the drone positioning and orientation parameters and appraise the information attainable from such imagery. The results demonstrated that manual interpretation of such imagery could discriminate between forest stands in need of cleaning or not with 82 % accuracy. This study indicated that simple UAV imagery without proper photogrammetry could be an alternative, the quality might be bad but possibly sufficient.

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INSTRUCTION IMAGE INTERPRETATION

OBJECT ID CORRESPONDS TO SAMPLE PLOT REGISTER IN INTERPRETATION ENVIRONMENT

Start by reading the instructions before you enter the GIS-environment!

As image interpreter you are instructed to count the stems of pine, spruce & broadleaves within each sample plot. The dataset contains 123 sample plots from productive young forest stands in the county of Västerbotten. The stands are expected to be ~1 or ~4 meters in mean height. 6 sample plots have been randomly selected and provided with ground truth as training data. You are allowed to use these as references throughout your interpretation session. An asterisk(*) refers to your name in the instruction. Please use both '*_Flerstammigt_Löv' & '*_Löv' when counting broadleaves.

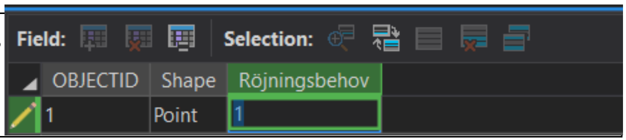
Workflow

1. In attribute table 'Provyta_Bildtolkning' find the sample plot by scrolling to desired object ID, right-click and select 'Zoom To'. Or use 'Select Layer By Attribute'.

2. Create features in your assigned feature dataset with any of the custom tools;
'*_Flerstammigt_Löv' '*_Gran' '*_Löv' '*_Tall' '*_Åtgärdsförslag'
by first clicking on the desired tool and then clicking on corresponding item within the sample plot.

Ex: 'Create Features'/ '*_Löv/-click-
'Create Features'/ '*_Gran'/-click-
'Create Features'/ '*_Tall'/-click-
'Create Features'/ '*_Flerstammigt_Löv'/-click-
'Create Features'/ '*_Åtgärdsförslag'/-click-/assess need of cleaning in attribute table; '*_Åtgärdsförslag' replace '0' with '1', '2' or '3' in field 'Röjningsbehov'.

1=No need of cleaning
2=Clean now
3=Clean in 3 – 5 years



3. Save your feaures by; 'Edit'/'Save'

4. Repeat procedure.

Training data

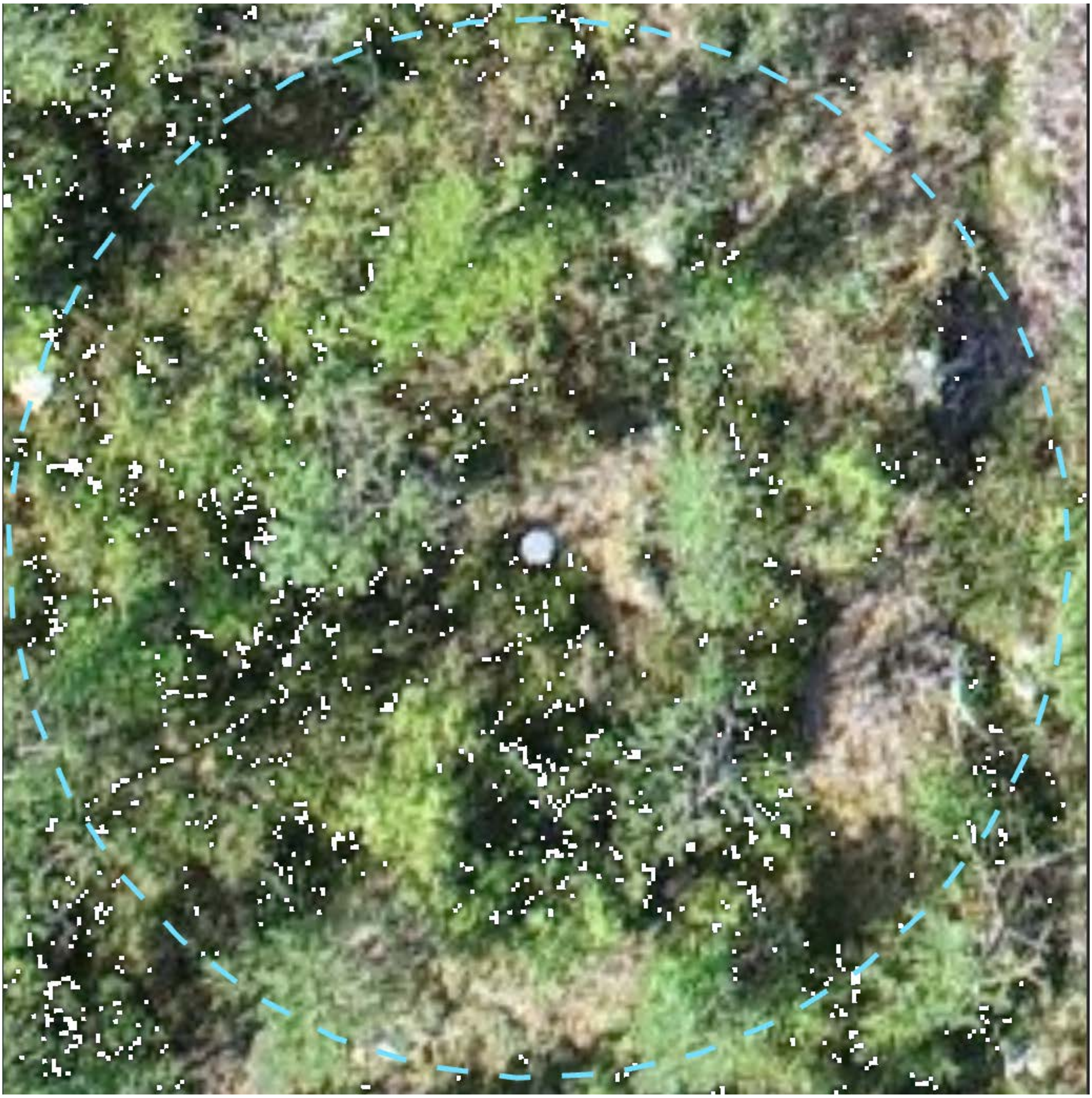


Figure 1. Object ID 5141. 28 Pine, 1 Spruce, 8 Birch
7400stems/ha Need of cleaning: 2

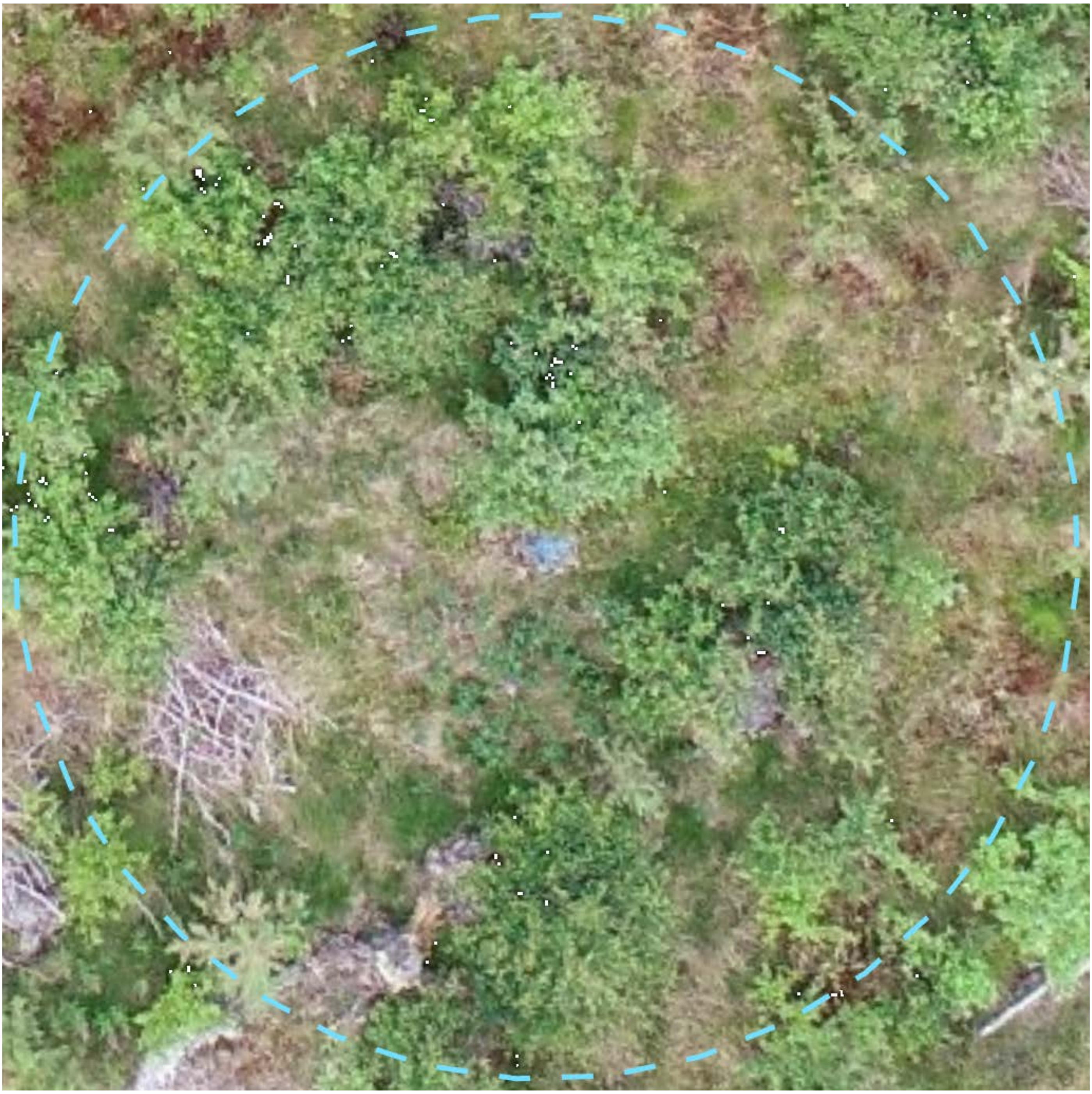


Figure 2. Object ID 3826. 7 Pine, 0 Spruce, 44 Birch
10200 stems/ha Need of cleaning: 2

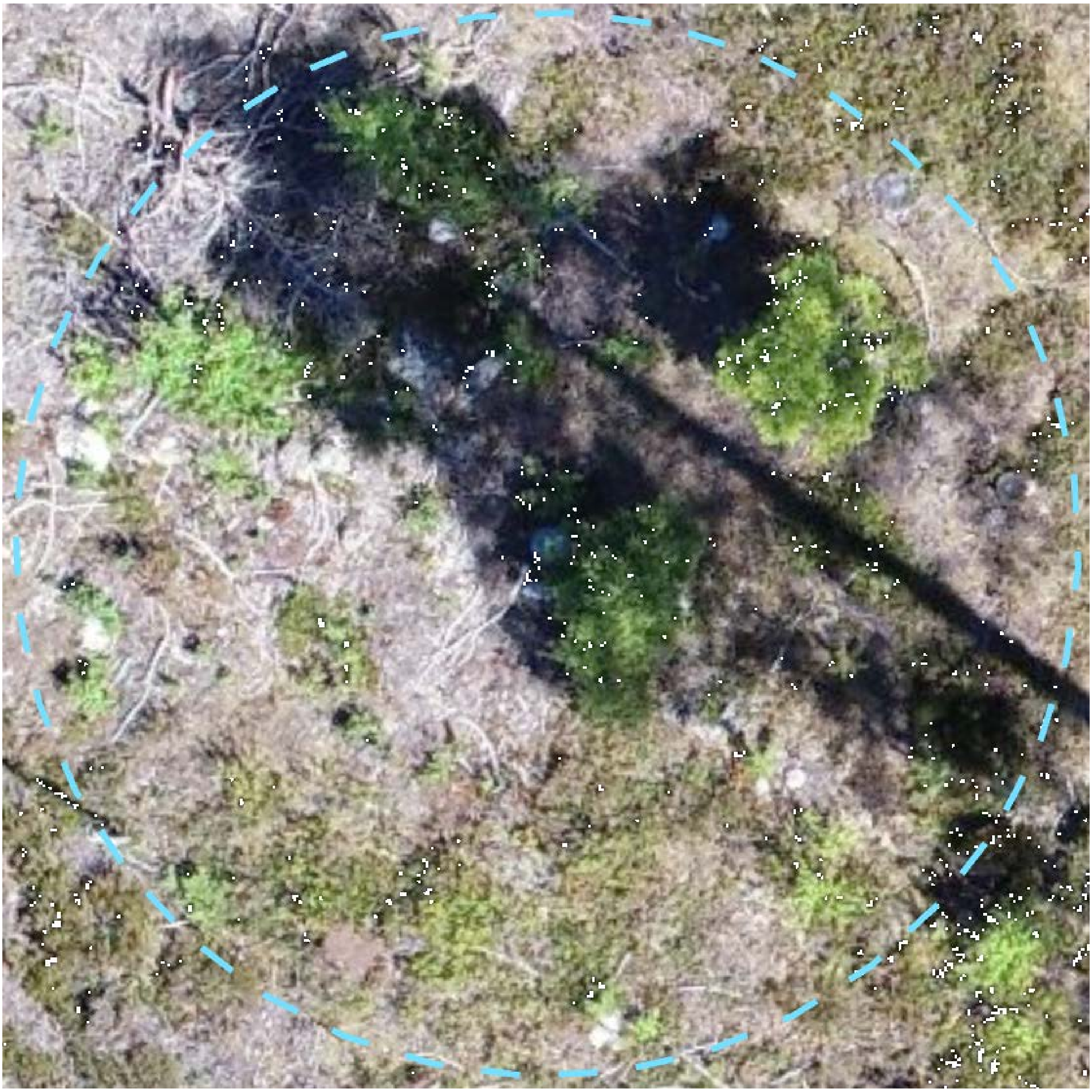


Figure 3. Object ID 3123. 5 Pine, 0 Spruce, 3 Birch
1600 stems/ha Need of cleaning: 1

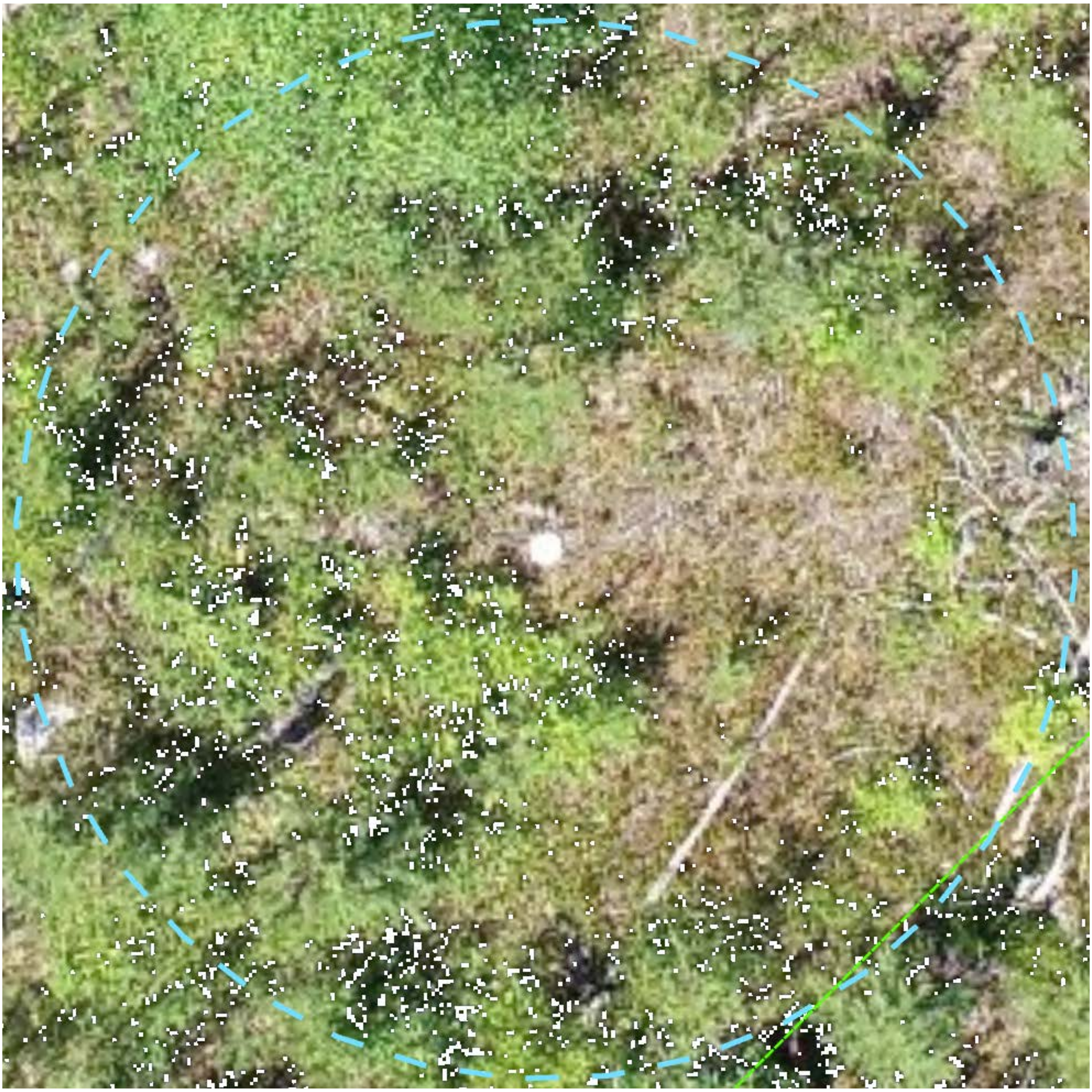


Figure 4. Object ID 3561. 28 Pine, 2 Spruce, 12 Birch
8400 stems/ha Need of cleaning: 2

Figure 5. Object ID 760. 12 Pine, 0 Spruce, 12 Birch
4800 stems/ha Need of cleaning: 3

Figure 6. Object ID 5048. 5 Pine, 13 Spruce, 12 Birch
6000 stems/ha Need of cleaning: 2

Object ID's to interpret

737	1108	3830	5126
739	1109	3831	5127
740	1110	3832	5128
741	1111	5034	5129
746	1112	5043	5130
747	1114	5044	5131
750	1115	**5048**	5132
751	1120	5050	5134
752	1121	5051	5135
760	1123	5052	5138
761	1124	5053	5139
762	1125	5055	5140
963	3121	5056	**5141**
964	**3123**	5057	5152
965	3557	5058	5153
966	3558	5072	5157
967	3559	5073	5229
968	3560	5074	5230
969	**3561**	5075	5231
971	3565	5076	5232
972	3573	5077	5233
975	3574	5086	5234
976	3577	5087	5235
982	3787	5088	5239
990	3791	5089	
991	3792	5095	
992	3796	5096	
993	3825	5097	
994	3825	5098	
995	**3826**	5099	
996	3827	5100	
997	3828	5110	
1107	3829	5111	