ASSISTING OTTAWA VALLEY FOREST TRANSITION TO T2 FRI

A project undertaken by:
JWRL Geomatics Inc.

For:
Forestry Futures Ontario
Enhanced Forest Resource Inventory
Knowledge Transfer & Tool Development Program

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FINAL REPORT

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1.0 PROJECT DESCRIPTION

1.1 Rationale

Ontario's Forest Resource Inventory process and products are expected to change dramatically. Three aspects of the possible "T2" (2nd 10-year cycle) changes, based on the Penner and Pitt paper (reference below) are:

- a move to LiDAR data as the main source for many forest attributes and derived metrics. This includes heights, closures and volume related metrics.
- an eventual move to rasterized vs polygonal inventory.
- a continuous forest inventory model.

The Ontario Growth and Yield Program Status and Needs – Report to the Forestry Futures Trust Committee; Margaret Penner and Doug Pitt; under the section "Emerging issues & opportunities for the G&Y Program", subsection "The new FRI – an opportunity and a challenge", Report available from FFTO site.

In addition, in the transition to T2 there is an interest in automated approaches to tree species classification including the use of Sentinel-2 (S2) imagery ((for example KTTD program, SkyForest and GSI initiatives).

In the short, 1–5-year, term, it is likely that existing FRI polygonal products will continue to play a role in forest management planning efforts and in the transition towards new inventory models and products. In addition, key inventory attributes such as tree species, mixedwood characteristics and multi-tiered stands may present challenges to new inventory approaches, especially in the Great Lakes St. Lawrence Forest region (GLSL). Unfortunately, the quality of the polygonal FRI for these attributes can be inconsistent. In the case of the Ottawa Valley Forest (OVF), a key collaborator on the proposed project, the eFRI was rejected due partially to interpretation quality. It is suspected that other Management Units in the Great Lakes St. Lawrence (GLSL) forest are dealing with similar situations. This project is intended to help them.

1.2 Outcomes

The project is expected to facilitate OVF's transition to the T2 eFRI in several ways:

- Improve the baseline polygonal FRI base which can be incorporated into calibration/validation processes related to the T2 FRI.
- Provide operational alternatives to FRI attributes which may be challenging for T2 approaches in the GLSL, such as species identification.

1.3 Project Collaborators

Ottawa Valley Forest (OVF), the Sustainable Forest License (SFL) holder for the area agreed to participate in the project, to provide comments on work-in-progress and to and to make data available as appropriate.

Aeroquest Mapcon, a leading supplier of geospatial data from remote sensing and related products such as 3-D modelling. They have been actively involved in various Ontario orthophotography projects including the 2019-20 DRAPE project. They provided a CHM derived from DRAPE products covering the OVF test area.

1.4 JWRL Geomatics Inc.

JWRL is a technical support group specializing in the collection, manipulation and analysis of geospatial data (softcopy photogrammetry, remote sensing, GIS, cartography, etc.) in particular related to forestland resources. The company has considerable expertise related to the mapping and attributing of land cover.

JWRL was formed in 2011, following the closure of Dendron Resource Surveys (Dendron)Ltd. Dendron had been one of Canada's top forestland survey companies. Approximately two thirds of the 600 plus Dendron projects completed between 1978 and 2011, with the involvement of now JWRL personnel, were forest inventories or inventory related, some photo-based, some satellite based, some both. The JWRL Team has worked across Canada, in several US States, and abroad, for numerous private and public sector clients, and is experienced with a great variety of forest inventory requirements, specifications and data uses, as well as with diverse ecological conditions. Considerable Ontario Forest Resource Inventory work has been undertaken for the province and for forestry companies.

2.0 APPROACH

The project had 1 major task:

- FRI Revision

and 2 minor tasks

- Sentinel-2 (S2) Satellite Imagery Demonstration
- Volume Sampling Test

2.1 FRI Revision

2.1.1 Background Information

T2 eFRI Plans

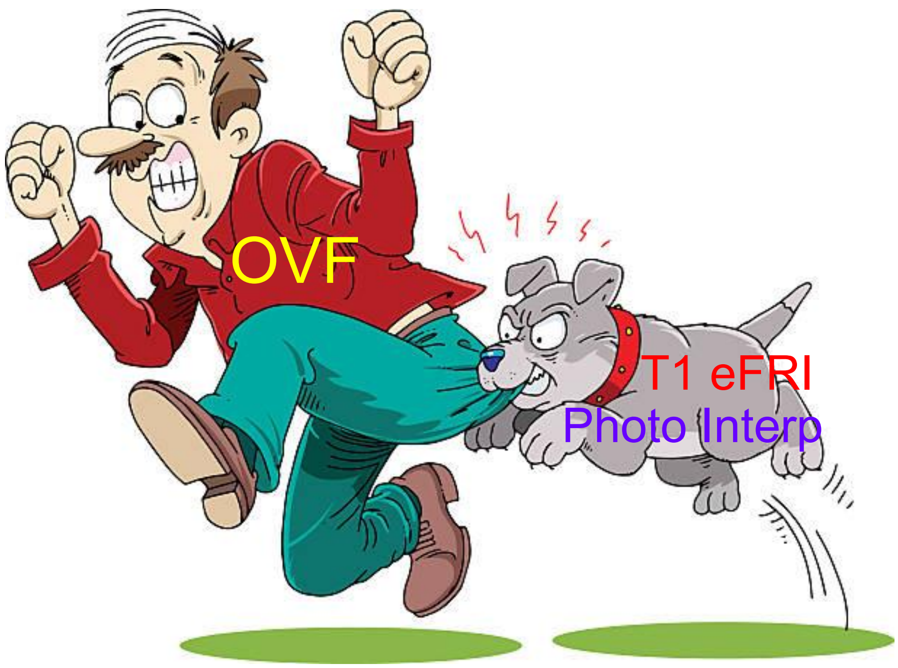
We had heard bits and pieces about Ontario's plans for a new, T2, eFRI, to be based almost exclusively on Lidar data. One puzzle in these was how tree species were going to be worked into this plan. An email to Dr. Margaret Penner, in the Spring of 2022 asked if she could provide information related to this. Her response:

"T2 polygon boundaries as well as species composition and age will be taken from the T1 inventory. Heights, volumes, basal area and most other quantitative tree attributes for T2 will be predicted from LiDAR (and field calibration plots).
These LiDAR-derived attributes will be provided at the raster scale (20 x 20m) as well as rolled up to the T1 polygons.
Some SFLs had digital photography flown alongside the T2 LiDAR. There are no plans for SFL-wide re-interpretation of the photography but I think the province will do some re-interpretation for bits of the inventory that had major changes.
There are plans (T3?) for a "living" inventory - one that will be annually updated. Forsite had a contract to do a white paper with options (completed March 31 of this year). I'm not sure where that sits."

Based on this we decided to approach forest management groups in the GLSL Forest Region to see if anyone might be interested in exploring photo interpretation to address the T2 eFRI species problem.

OVF

OVF was not the first GLSL SFL group JWRL had approached with similar concepts and they all had similar reactions: anything involving Photo Interpretation was not something they wanted to discuss.



Their reasons were good:
The T1 eFRI covering OVF was rejected by the SFL.
The best available alternative was the 1998 T0 FRI which is being used for Forest Management Planning (FMP).

The use of the '98 FRI was a compromise move for OVF and they were interested in anything which might provide improved FMP and which might better accommodate moving forward into the T2 eFRI. They decided on a test area in the southern portion of the SFL in Griffith Township.

TEST AREA

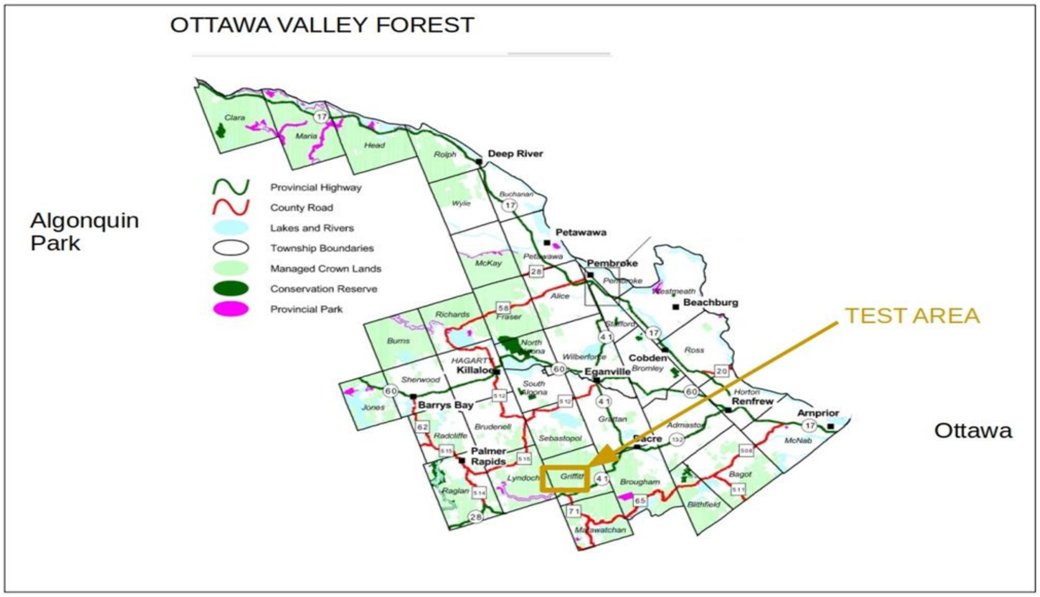


Figure 1 OVF and Test Area

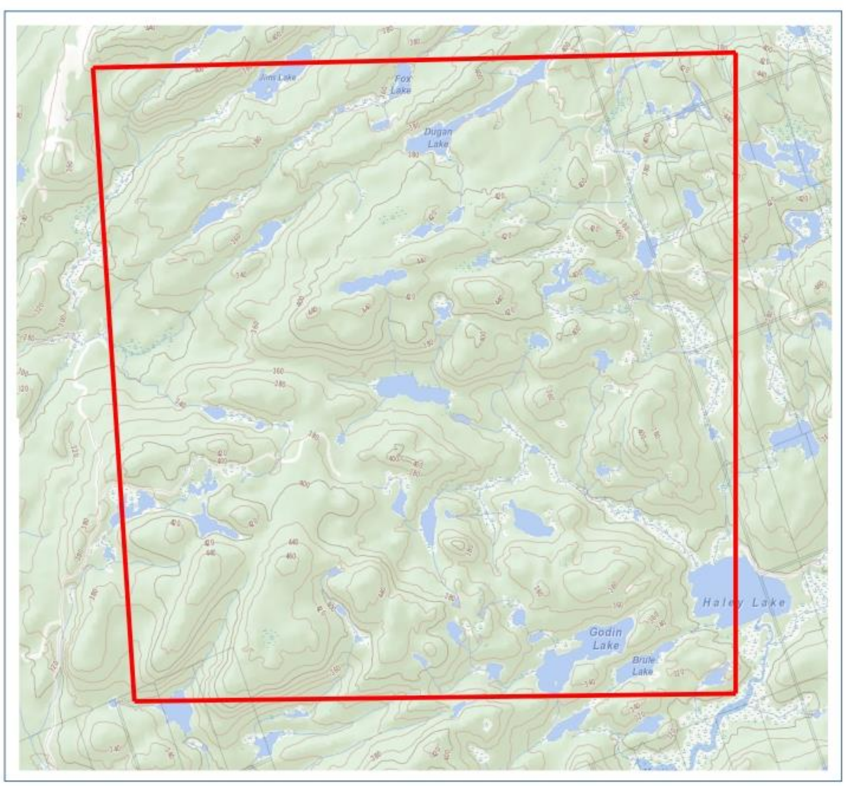


Figure 2 Test Area Griffith Township

2.1.2 Data Gathering

Relevant data covering the test area, were collected and prepared, including:

- The 1998 FRI (used by OVF as the baseline FRI), (from Ontario GeoHub). As far as we can tell the B&W photos used for the 1998 FRI were 1987, B&W photos, likely at 1:10,000 or 1:15,840 scale, i.e., 37 years old in 2022. There was also coverage of the area by 1976 photos so it is possible, given the time required to create an FRI, that the inventory is even older, i.e.: 46 years old in 2022
- 2009-2011 ADS stereo imagery (provided by OMNRF) used to create the rejected 2017 T1 eFRI
- 2017 eFRI calibration plot data (provided by OMNRF)
- 2019-2020 DRAPE (Digital Raster Acquisition Project Eastern Ontario) orthophotos and source stereo imagery, (from Ontario GeoHub)
- available OVF operational data (harvest, silviculture, etc.) from FMP maps

OVF's FRI

The nature of the '98 FRI used by OVF is displayed in Figure 3. It consists of large polygons, diverse with multiple species. The photo interpretation which created this product was likely performed on 1:10,000 or 1:15,840, B&W aerial photos, acquired in 1987 (there was also coverage from 1976). Specifications were likely similar to Specifications for Forest Resource Inventory Photo Interpretation (1991) which is believed to have had a minimum polygon size for productive forest areas of 8ha (same as eFRI).

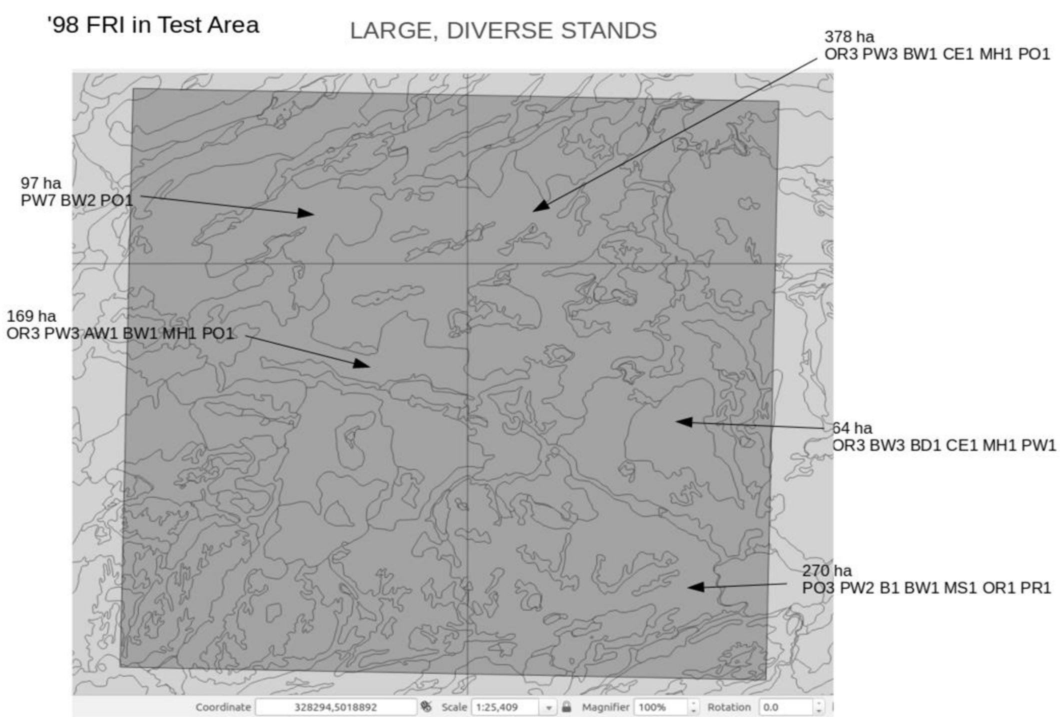


Figure 3 Large, diverse '98 FRI stands

2.1.3 Sample Reinterpretation

The first step was to show OVF what they could expect from a reinterpretation process, by a highly experienced interpreter with Great Lakes. St. Lawrence work.
To do this JWRL's Photo Interpreter selected several of the 1998 FRI stands and reinterpreted them using the stereo T1 eFRI imagery.

Attributes collected for JWRL's reinterpretation were restricted to:

- tree species,
- species composition,
- crown closure and height.

These attributes were intended to be complementary to the T2 LiDAR-based approach, except for height, to be provided exclusively by Lidar, but captured here as a means of comparison with the ‘98 FRI.

A reconnaissance visit into the test area was undertaken in Sep '21, to explore site access in advance of calibration plot planning and visits by the Photo Interpreter in Oct 2021.
Note: calibration plots here do not refer to the formal eFRI calibration plot exercise but rather to road-trail surveys undertaken at the start of traditional forest inventory exercises.

Appendix 1 contains examples of field plot planning and site pics.

Figure 4 displays several 1998 FRI stands (black lines) selected by the Photo Interpreter for reinterpretation (red lines) using the 2011 eFRI imagery.

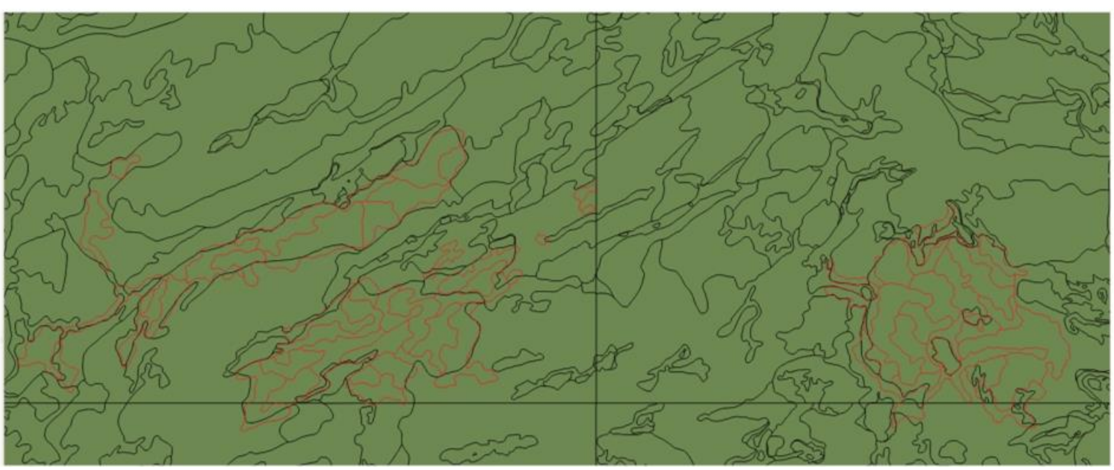


Figure 4 Reinterpreted stands (red) within '98 FRI stands (black)

Initial Results

Figure 5 displays the initial reinterpretation of one of the '98 FRI stands.
Figure 6 shows the reinterpreted stands and attributes.
Figure 7 displays these on the 2011 eFRI imagery.

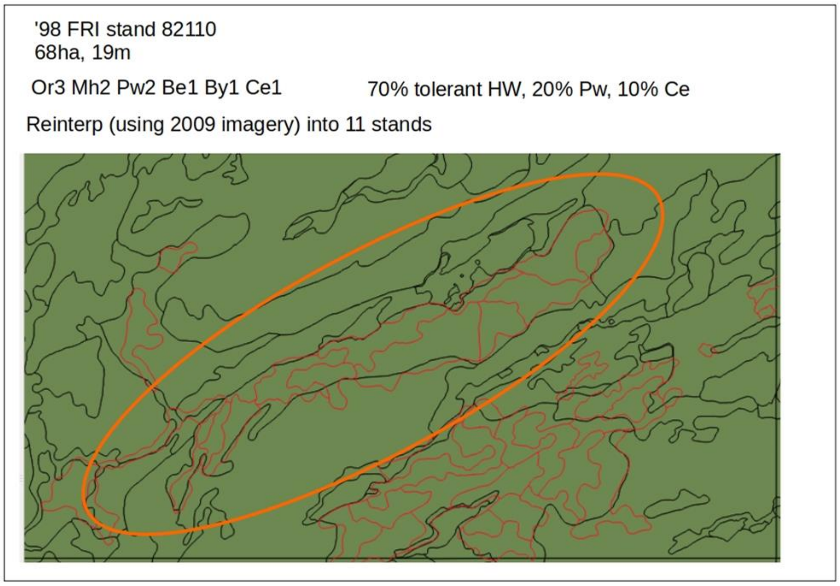


Figure 6 Reinterpreted stands (red) within '98FRI stand 82110

1998 FRI: stand 82110: OR3 MH2 PW2 BE1 BY1 CE1 – 68 ha - 19m

i.e.: OrMh stand, 70% hw

Reinterp (using 2009 imagery)
to 11 stands

poly 1 - Pw6 Pt2 Or 1 Mh1, 26m	Pw60
poly 2 - Mh4 Or2 Pw2 Pt1 Ce1, 17m	MhOr60
poly 3 - Ce4 Pw2 Pt2 He1 Fb1, 14m	sw80 with CeHe50
poly 4 - Pt6 Mh2 Pw1 Sw1, 20m	Pt60
poly 5 - Mh4 Or2 Pw2 Sw1 Pt1 – 17m	MhOr60
poly 6 - Pw5 Pt2 Mh2 Or1 - 24m	mixed Pw50 MhOr30
poly 7 - Pw7 Mh1 Pt1 Or1 -18m	Pw70
poly 8 - Or2 Pw2 Pt2 Mh2 Sw1 Fb1 – 22m	mixed OrMh40 Pw20
poly 9 - Pw6 Pt2 Sw1 Or1 – 14m	Pw60
poly 10 - Pt4 Pw3 Mh1 Sw1 By1 – 17m	mixed Pw30 MhBy20
poly 11 - Pw6 Pt1 Or1 Fb1 – 22m	Pw60

Summary with hts (m):
4 Pw stands, 26, 18, 14, 22
2 MhOr stands, 17, 17
3 mixed Pw MhOr, 24, 22, 17
1 sw (with 50% Ce & HE), 14
1 hw stand, 20

Figure 5 Attributes of reinterpreted stands

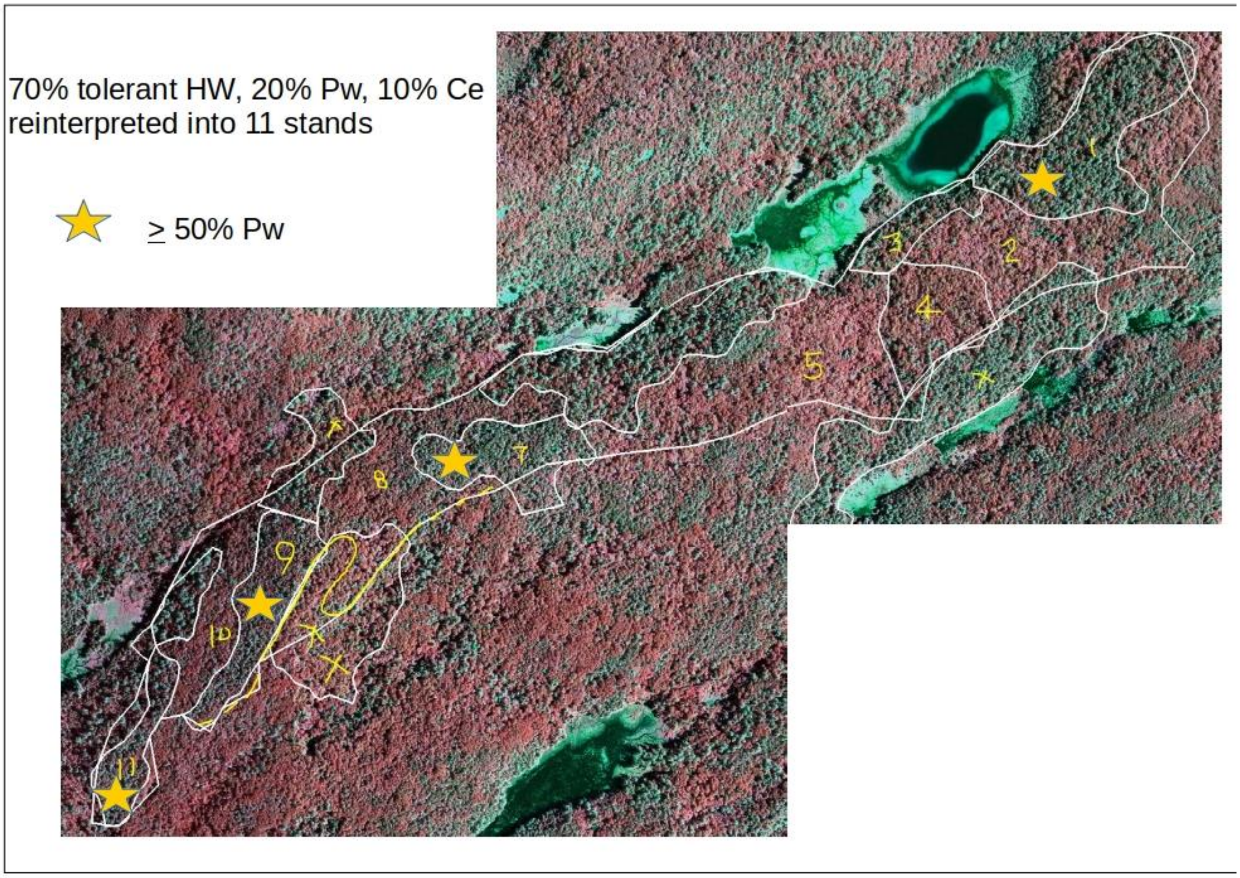


Figure 7 Reinterpreted stands displayed on 2011 eFRI imagery

Additional reinterpretation examples are provided in Appendix 2.

To summarize the issues presented by these samples.

FIRST:
Many of the '98 FRI stands in the Griffith test area are large and diverse.
Using streamlined photo interpretation (on 2011 eFRI imagery) these can readily be broken into smaller stands, on the basis of species composition and other attributes.

The above sample ('98 FRI stand 82110 shows how a large (68 ha), largely hardwood stand with 20% pine could be broken into more homogeneous stands, including several with $\geq$ 60% concentrations of Pine, one of the primary commercial species in the area.

Appendix 2 includes:

'98 FRI 24060: a 131 ha, pure hardwood stand, reinterpreted into 22 stands with:

- approx. 20% of the area (5 stands) is made up of >50% cedar stands (not represented in the '98FRI stand description)
- another 20% of the area (4 stands) is dominated by poplar (represented as only 10% of the '98FRI stand description)
- 60% of the area (13 stands) is dominated by hard maple or red oak, more or less in agreement with the '98FRI

'98 FRI 86040: a 78 ha, 70% pine stand
reinterpreted into 16 stands, indicating overall a 40% pine component

It will be problematic if the '98 FRI is used as the basis for tree species for the T2 eFRI.

SECOND
Areas set aside for deer management may be an OVF management issue. We don't know the related processes but believe that cedar and hemlock areas, identified on the '98 FRI products, may be used to identify deer management areas. With the large, diverse '98 FRI stands, areas of Cedar are not well located. These could be readily located with a reinterpretation process.

In Appendix 2, '98 FRI stands 67100 and 74100: 30 ha and 16 ha, respectively, with 30% and 40% cedar as the primary species were reinterpreted to isolate smaller, higher concentration of cedar areas

Also, there may be a problem with the '98 FRI misidentifying Red Pine as Hemlock. In reviewing a 20ha '98FRI stand with leading species of He (50%) and no Pr, the interpreter interpreted considerable Pr and no He. Management decisions based on the He component from the '98 FRI may be suspect.

2.1.4 Reinterpretation of planned harvest areas

After providing initial reinterpretation results to OVF for review, we considered how best to fit such products into OVF's FMP process. It was decided to undertake a similar exercise using the 10-yr plan harvest areas scheduled for the test area.

Additional summer 2022 field work was undertaken to address initial interpretation challenges in particular difficulties in separating red oak from hard maple.

Figure 8 displays approx. 2,800 ha of OVF planned harvest areas, contained in approx. 30, '98 FRI stands which were reinterpreted. Figure 9 displays the results of the reinterpretation.

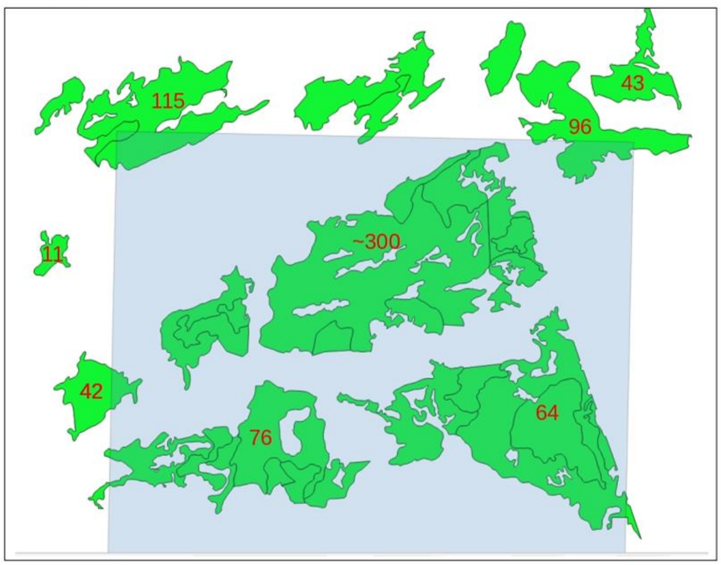


Figure 8 OVF Planned harvest blocks in test area, based on '98 FRI stands. Related areas (ha) in red.

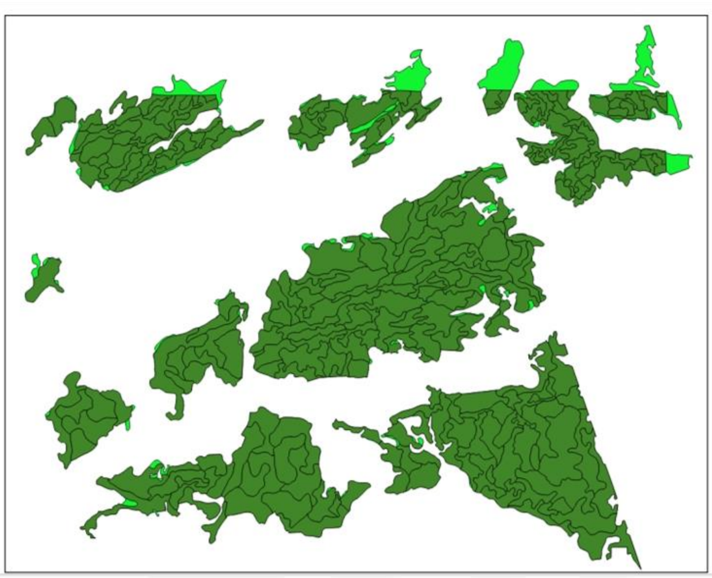


Figure 9 Reinterpreted stands within harvest blocks

The results of the reinterpretation of the harvest areas were provided to OVF – see initial comments under 2.1.8.

2.1.5 Inventory Update

Since the '98 FRI information is at least 30 years old, and the T1 eFRI imagery is 10-15 years old, updating the inventory information is an issue for OVF. While updating typically refers to growth as well as disturbance, this project assessed disturbance updating only. One alternative explored during this project is the use of readily available, 2019, DRAPE imagery.

Description: from the Ontario Geohub portal:

- Orthorectified Tiles - 1km x 1km, Pansharpened, 16cm resolution, 8-bit, RGBNiR in .TIF format (150MB/tile) and a compressed tiled .TIF format (approx. 10MB/tile)
- Stereo data - Vexcel UltraCam X and Vexcel UltraCamEagle frame based - 12 cm resolution, 16 bit, RGBNiR (sizes vary, please see index)

The biggest issue with this imagery for forest inventory is that the imagery was flown in leaf-off conditions, making interpretation in deciduous areas a challenge, if not an impossibility.

Sample stereo and orthophoto products were purchased and assessed.
Technical difficulties related to JWRL's stereo viewing software (PurView) prevented stereo viewing.

Image quality is such that the 2019 DRAPE would be very useful during any reinterpretation process, for disturbance update as well as for ancillary information during the interpretation. The following graphic displays the quality of the imagery.

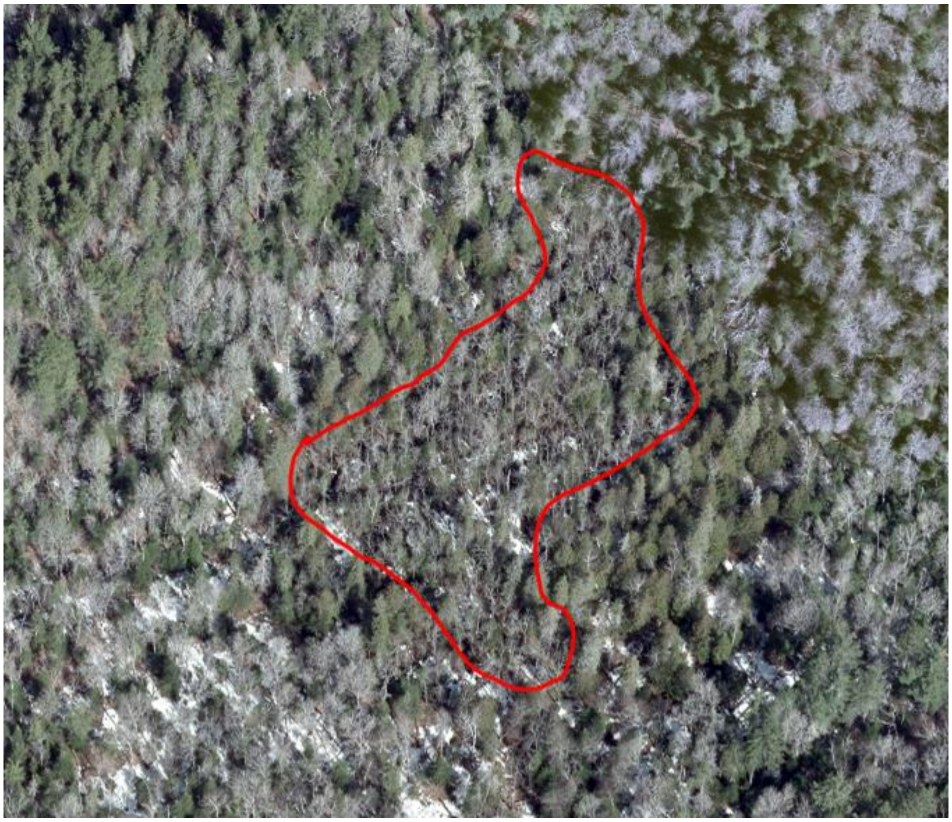


Figure 10 DRAPE orthophoto image quality

While no disturbances were detected in the test area, these (wind, fire, harvest) should be readily detected on the DRAPE products (OVF is using them currently). The stereo product and related viewing techniques are recommended but a good job is possible using the ortho product only.

Softwood species can be identified quite well on the ortho DRAPE while the stereo imagery would improve results.

Poplar and birch were easier to identify than other hardwoods (oak, maple, beech, basswood, ash) on the leaf-off imagery. Stereo imagery is unlikely to significantly improve results.

Because of the leaf-off condition, deciduous and coniferous species are better distinguishable from each other than under full leaf conditions. This might lead to improved species composition attributes in areas where conifer cover is partially obscured by deciduous. This may also have applicability for other applications such as conifer understories.

2.1.6 Cost

Based on this initial work JWRL estimates a price of just under $2.00/ha to undertake just the interpretation component. For the 2,800 ha interpreted in the harvest blocks, approx. $5,000.00.

This covers overhead and profit on the interpretation component of the work.
It does not cover such things as:

- field calibration work (1-2 days field work),
- imagery cost,
- GIS management costs.

It is expected that as the interpreter became even more familiar with the area (for example separating hard maple from red oak) the price could be reduced, but probably not significantly.

2.1.7 Canopy Height Model (CHM)

In the near future, Canopy Height Models (CHM) derived from Lidar data are expected to play a major role in the eFRI and FMP processes.

They may also be useful for any future photo interpretation undertaken since canopy height is a key determinant of stand delineation and attribution and as such, having related products available during interpretation could improve products/process.

Even without any photo interpretation being undertaken these products could be of help during operational planning, in particular if large, diverse stands such as those in OVF's ‘98 FRI are being utilized. Species information may remain problematic.

Lidar derived CHM were not available for this project so a photogrammetrically derived CHM was created for the project by Aeroquest Mapcon utilizing stereo DRAPE imagery. Overall, the leaf-off nature of the DRAPE imagery resulted in a CHM which considerably underestimated canopy heights of deciduous components of the stands.

One observation of the interpreter when viewing the leaf-off CHM with the T1 eFRI stereo imagery: Stands which have a pure hardwood component and those with a mixed HW/SW component appear differently on the leaf-off CHM. The pure HW areas show up with much lower heights while the mixed areas have more reasonable heights calculated.

From field observations, under full leaf-on conditions, there were lots of stands in the test area where, from above, the hardwood leaf cover often partially masked the conifer component in the stand. It is unknown (by us) whether a Lidar-based leaf-on CHM in such areas would also underestimate any 'masked' softwood component.

Such issues of species composition as well as softwood understorey might be supported by a leaf-off CHM, with or without photo interpretation, although without photo interpretation detailed species identification, especially among hardwood species would remain problematic.

Further R&D and/or operational trials would be required to assess the utility of a leaf-off CHM.

2.1.8 FRI Revision Summary

In a 2022 email, Margaret Penner kindly provided this with respect to tree species composition in the T2 eFRI:
"The polygon boundaries as well as species composition and age will be taken from the T1 inventory. Heights, volumes, basal area and most other quantitative tree attributes for T2 will be predicted from LiDAR (and field calibration plots). These LiDAR-derived attributes will be provided at the raster scale (20 x 20m) as well as rolled up to the T1 polygons."

Polygon boundaries and species composition will remain problematic for OVF if Lidar results are merged with the '98 FRI stands – they are too large & diverse. If these stands could be reduced in size with more reliable species information this would:

- provide a much more reliable T2 eFRI,
- better locate tree species of commercial importance,
- provide better data for planning with respect to harvest methods (e.g., selection vs shelterwood),
- better locate suitable deer yard areas which affect 40% or more of OVFs allocations.

Probably the preferred approach (for OVF) would be to create a brand new eFRI for the OVF, with new aerial imagery providing up-to-date stand boundaries and species composition. Alternatively, the reinterpretation approach undertaken during this project could be utilized. Since the T2 eFRI lidar data should provide all the height related metrics, the reinterpretation process (based on 2011 T1 eFRI imagery and 2019 DRAPE for update) can be focused primarily on stand delineation and tree species and composition, making the process faster and more cost effective. Interpreted crown closure estimates could also be readily provided if Lidar derived crown closure estimates are still unproven.

The process could be further streamlined:

- applied only to areas likely to be of interest in the short-medium term,
- restricted to species of most interest,
- restricted to stands > 4ha.

It is possible that specifications could vary within OVF:

- by ecological characteristics,
- by SFL Client to be accessing the area.

Related Notes:

- The Lidar derived CHM should support the reinterpretation especially with respect to stand delineation.
- The stereo 2019 DRAPE data is recommended to be used for both disturbance updating and for reinterpretation support.
- No heights or height related metrics would be collected during the reinterpretation, unless spot checking of Lidar heights was felt to be useful (the provision of height data is not a time-consuming process photogrammetrically)
- **AGE:** age cannot be seen on the imagery. It is better left to be derived from Growth and Yield processes based on species, heights and related information.

Finally, with training and a program of Quality Control, OVF staff would be ideal candidates to undertake this work internally.

After an initial review of the reinterpretation of the harvest blocks in the test area, but before any field visits, the following comments were provided by OVF:

- an overall positive impression re the improvement in species composition and stand delineation vs the '98 FRI,
- for cost effectiveness, additional reinterpretation costs would have to provide matching cost savings (or greater) in Field Operational Planning (FOP) work (e.g., FOP pre-walking planning, mapping of treatment areas). This has yet to be determined.
- It would take time to get a comfort level with the photo interpretation work based on site visits, but assuming everything matches well, possible upsides could be to provide a better focus on where to plan field time, leaving the known and straight forward stands, and spending more time on the complicated or other prioritized forest types.

2.2 Sentinel-2 (S2) Satellite Imagery Demonstration

Accurately Identifying tree species remains one of the biggest challenges for FRI, especially with what seems to be a desire to do away with photo interpretation. There have been many efforts over the years to do this, and JWRL has been involved with a number of these. The bottom line so far is that ecological variability on the ground makes automated FRI-level species identification and composition a challenge.

One bright light: Sentinel-2 (S2) optical satellite imagery.
The S2 imagery provides freely available, 10 m (and 20 m) spatial resolution, optical imagery, every 5 days, with historical sets dating back to 2015. While the spatial resolution appears to be relatively coarse, it is in line with the possible 10m T1 eFRI raster product. The cost (free) and frequency (every 5 days) perhaps provides for a new model of image analysis to address the FRI species identification issue. That is, over time, a multi-temporal analysis of known conditions on the ground may help solve the FRI species identification problem.

It is important to note this this will unlikely provide a quick fix for the species identification issue. Considerable site-specific R&D will be required.

2.2.1 An overview of the S-2 Demo

An approach presented by Grabska et al (reference follows) was used as a starting point, i.e:. Forest Stand Species Mapping Using the Sentinel-2 Time Series; Ewa Grabska et al, 2019; Remote Sens. 2019, 11, 1197; https://www.mdpi.com/2072-4292/11/10/1197

A key to any image analysis exercise is reliable ground truth information.
For OVF, the species composition of 10 m areas on the ground is impossible to predict on the large, species-diverse stands of the 1998 FRI. The reinterpretation of the '98 FRI using the 2011 T1 FRI provided a number of stands which are much more suitable for this purpose.

As an initial assessment we considered reinterpreted stands in the OVF which were made up of 60% or more of a certain tree species or group of tree species, of interest to OVF.
To simplify this initial analysis, we arbitrarily picked 4 species groups:

- Pine, made up of 60% or more of red or white pine,
- Oak-Maple, made up of 60% or more of these species,
- Cedar, made up of 60% or more of this species (for deer management purposes),
- Other Hardwoods, including poplar and other intolerant deciduous species.

Then, with the help of some image analysis friends, we gathered all of the available (85) S2 images for 2019, 2020 and 2021 and with the help of Google Earth Engine created Normalized Differential Vegetation Indices (NDVI) for each (58) of the selected reinterpreted stands.

Graphs showing means and standard deviations for each of the species groups, over multiple dates on each of the selected years were created (the raw data is available to interested groups) and are displayed in the next sub-section.

The intent was not to be rigorous with this project but rather exploratory only to see if any potential exists for exploring this further.
Questions on the graphs (shown below) are more plentiful than answers.

- What is the effect of snow cover on the NDVI.
- What is the effect of cloud cover on the NDVI.
- What is the effect of conifer understorey in hardwood stands, especially under leaf-off conditions.

We made no attempt to address these.

What is apparent is that there are a number of dates where the average NDVIs and the related standard deviations indicate that species classification (among the 4 selected groups) may be possible. We're not taking this any further here but welcome discussion with interested groups and are quite prepared to make our data available to groups interested in pursuing this further.

A carefully planned and executed photo interpretation exercise could be part of this process, in particular in areas where there may be low confidence in species information within the 10m S2 pixels.

Should further work be undertaken, the species groups should be further expanded to match operational requirements, for example distinguishing white from red pine since they are assigned different harvest systems.

2.2.2 Details

Ground Truth

From JWRL reinterpreted stands 58 were selected:

- 12 stands with Ce as the leading species,
- 15 stands with the combined species composition of Mh and Or leading,
- 20 stands with the combined species composition of Pr and Pw leading,
- 11 with Pt leading,

where ‘leading’ was defined as 60 to 100% species composition.

The polygons containing each of these species characteristics were assessed on S2 images.

To do this NDVIs for all available S2 images over a 3-year period, 2019 – 2021, without discriminating for image quality (e.g. cloud cover) were analysed for

Sentinel 2 Images

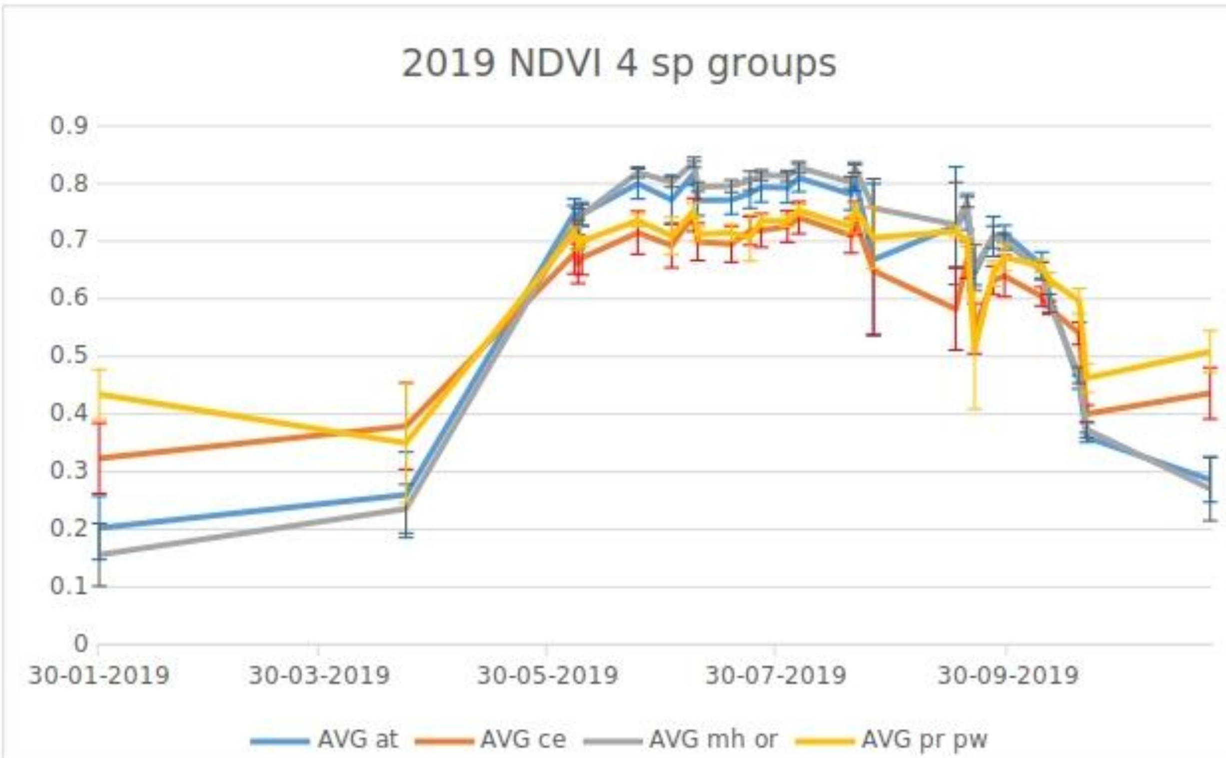
JWRL accessed and prepared a time series of S2 images covering the OVF test area, for each of 2019, 2020 and 2021 as displayed in Figure 11.

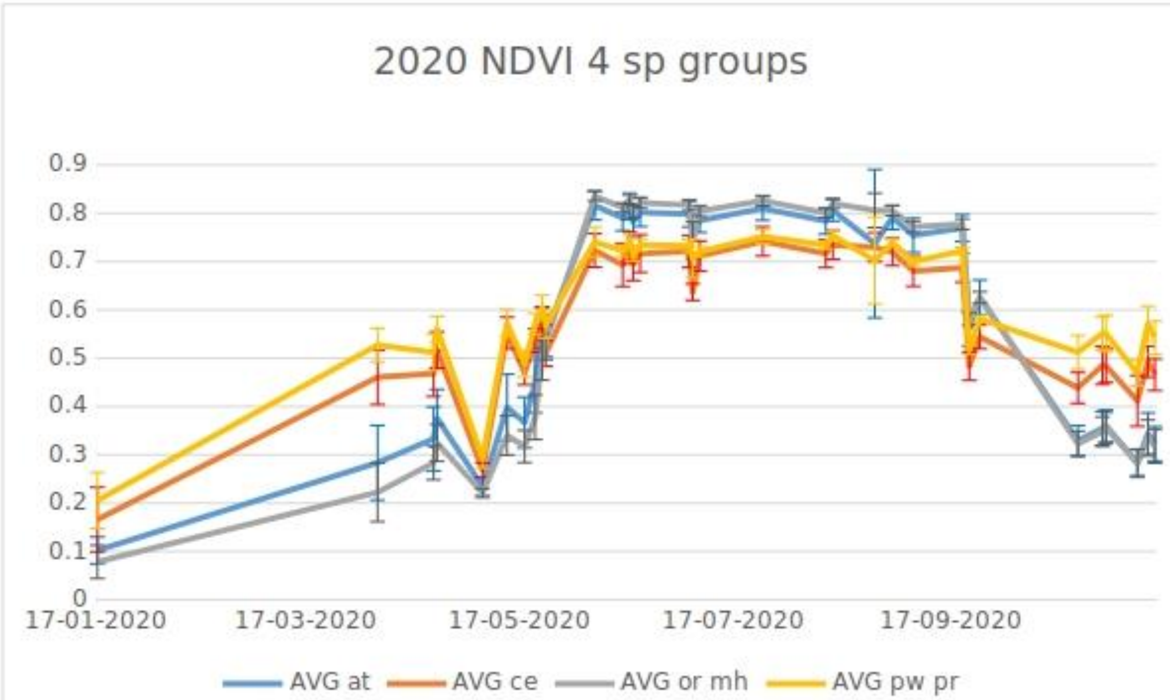
Dates of S2 imagery			
2019	2020	2021	Total
27 images	33 images	25 images	85 images
30-01-2019	17-01-2020	04-02-2021	
22-04-2019	06-04-2020	29-03-2021	
06-06-2019	22-04-2020	02-04-2021	
07-06-2019	23-04-2020	08-04-2021	
08-06-2019	06-05-2020	23-04-2021	
23-06-2019	13-05-2020	13-05-2021	
02-07-2019	18-05-2020	27-05-2021	
08-07-2019	21-05-2020	31-05-2021	
09-07-2019	23-05-2020	10-06-2021	
18-07-2019	24-05-2020	12-06-2021	
23-07-2019	07-06-2020	15-06-2021	
26-07-2019	15-06-2020	17-06-2021	
02-08-2019	17-06-2020	20-06-2021	
05-08-2019	18-06-2020	22-07-2021	
19-08-2019	20-06-2020	04-08-2021	
20-08-2019	04-07-2020	24-08-2021	
25-08-2019	05-07-2020	31-08-2021	
16-09-2019	07-07-2020	16-09-2021	
19-09-2019	25-07-2020	20-09-2021	
21-09-2019	12-08-2020	28-09-2021	
26-09-2019	14-08-2020	23-10-2021	
29-09-2019	26-08-2020	27-10-2021	
09-10-2019	31-08-2020	28-10-2021	
11-10-2019	06-09-2020	04-11-2021	
19-10-2019	20-09-2020	24-11-2021	
21-10-2019	22-09-2020		
23-11-2019	25-09-2020		
	23-10-2020		
	30-10-2020		
	31-10-2020		
	09-11-2020		
	12-11-2020		
	14-11-2020		

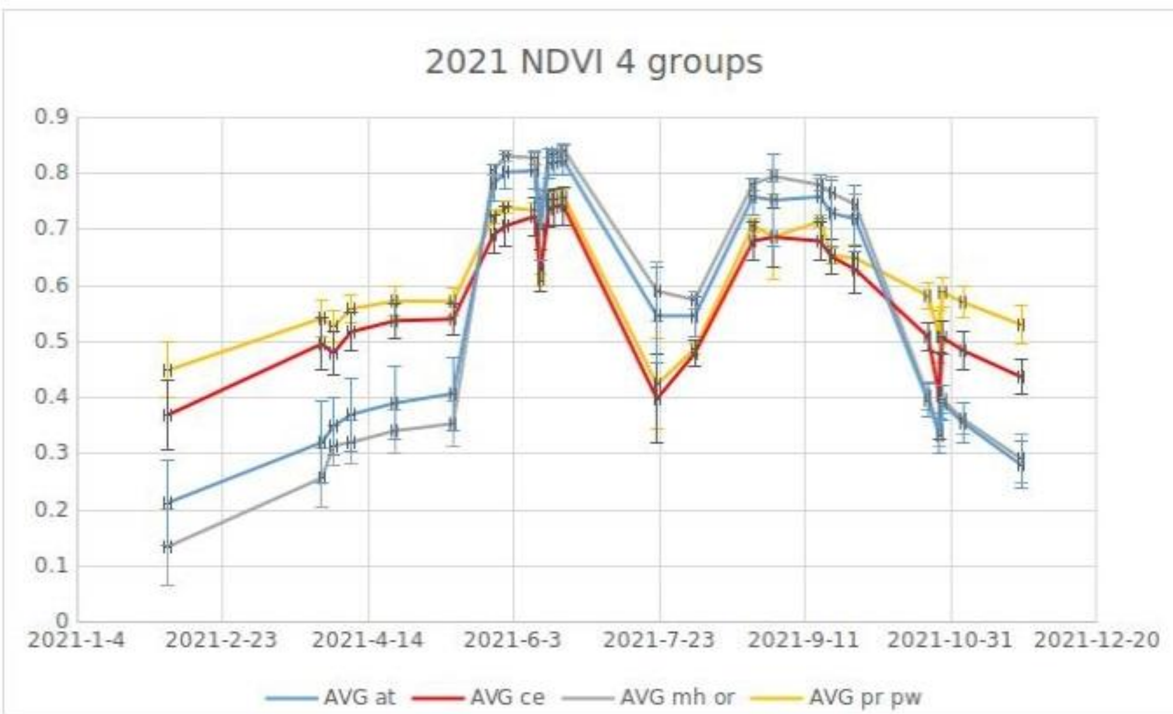
Figure 11 Dates of Selected S2 images

NDVI Assessment

Using Google Earth Engine, NDVI averages and standard deviations were calculated for each stand of species groups, on each S2 image. The following graphs show results.




2020 NDVI 4 sp groups
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
17-01-2020
17-03-2020
17-05-2020
17-07-2020
17-09-2020
AVG at
AVG ce
AVG or mh
AVG pw pr


2021 NDVI 4 groups
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2021-1-4
2021-2-23
2021-4-14
2021-6-3
2021-7-23
2021-9-11
2021-10-31
2021-12-20
AVG at
AVG ce
AVG mh or
AVG pr pw

Related Observations:

The NDVI seasonal curves are different for the four tree groups. The consistency of relative levels of NDVI curves for the 4 groups in the three years means that they can be classified, although the error bars show classification will produce confusion among groups. This is a very encouraging sign. During early (before April) and late (after October) of a year, all 4 groups can be classified, but during mid-year, possibly only deciduous and conifers can be differentiated although there may be potential for separating tolerant from intolerant hardwoods.

Only NDVI curves were extracted for simplicity. Better classification might result if original band reflectance data were used. We need to pay attention to a reality that in early and late days on a year, presence of snow might have some effects.

2.3 Volume Sampling Test

Volume from Aerial Photos

In the 1980's, JWRL staff, as employees of Dendron Resource Surveys, were involved with evolving and implementing Large-scale Aerial Sampling Photography (LSP). Volumes derived from tree species, heights and crown areas as determined off the aerial photos correlated well with field data. The process became operational and large areas across several provinces were subject to production LSP volume determinations, using stratified random sampling processes.

At that time FRI photos were typically between 1:10,000 - 1:20,000 scales, too small for the required individual tree measurements, so specialized flights with specialized camera equipment were used. Also, processing algorithms were based on now obsolete computing and photogrammetric equipment.

JWRL has felt for a while that the high resolution FRI imagery used for the T1 eFRI might be suitable for a similar process, eliminating the need for a separate LSP flight.

During this project the only observation made was by viewing the 2011 eFRI calibration plots on the 2011 eFRI imagery. Species of individual trees could be identified and heights and crown diameters measured on the imagery and subsequently used for volume measurements.
No further explorations were made, however, as the T2 eFRI Lidar data makes the LSP process obsolete.

APPENDIX 1 Field Planning and Pics

Field plot planning and site pics.

The site pics indicate:

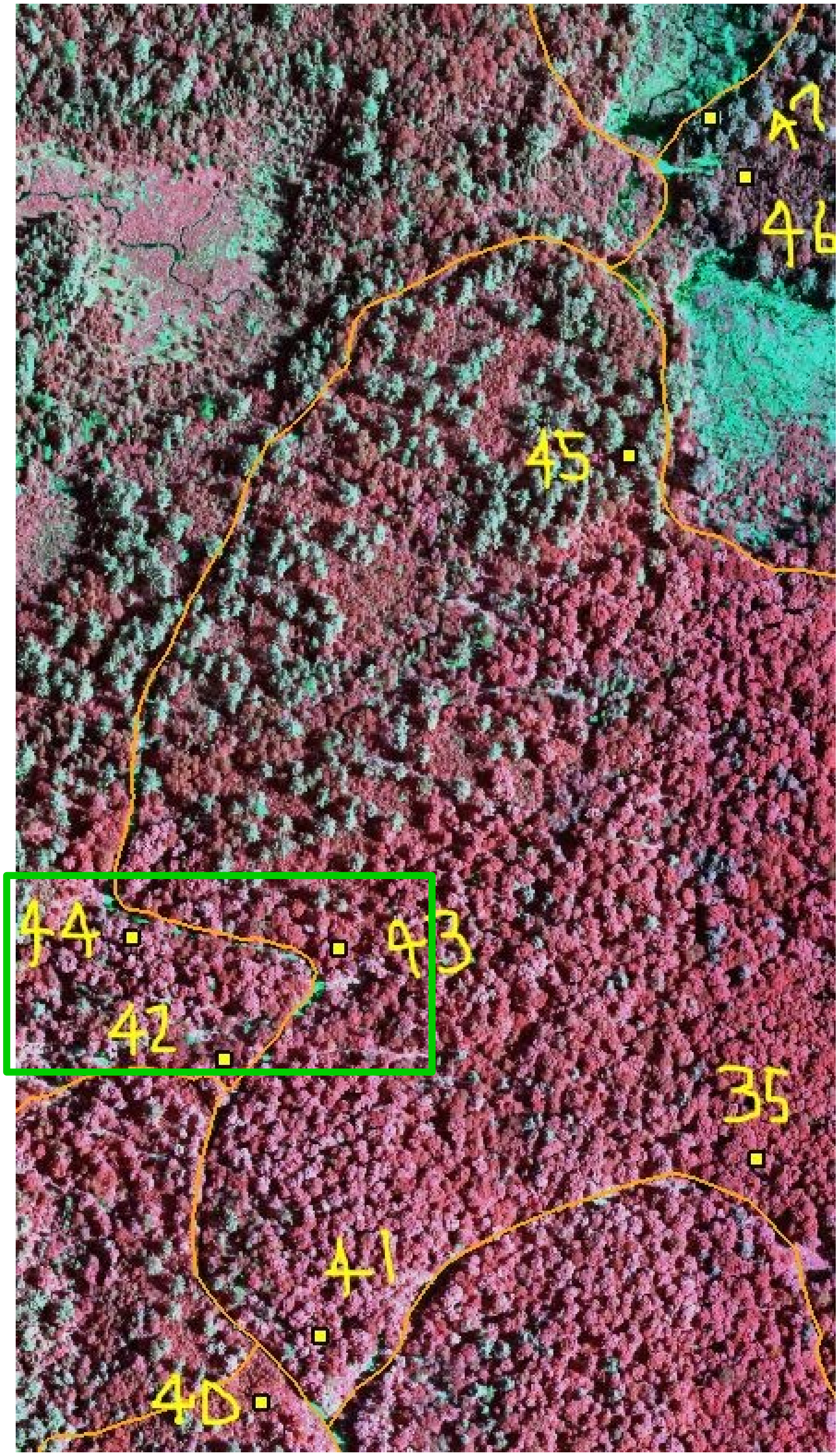
- the excellent road access around the perimeter of the test area, with interior access provided by ATV trails – the area is well used recreationally
- the mature nature of the overall area
- the dominant white pine trees observed throughout the area

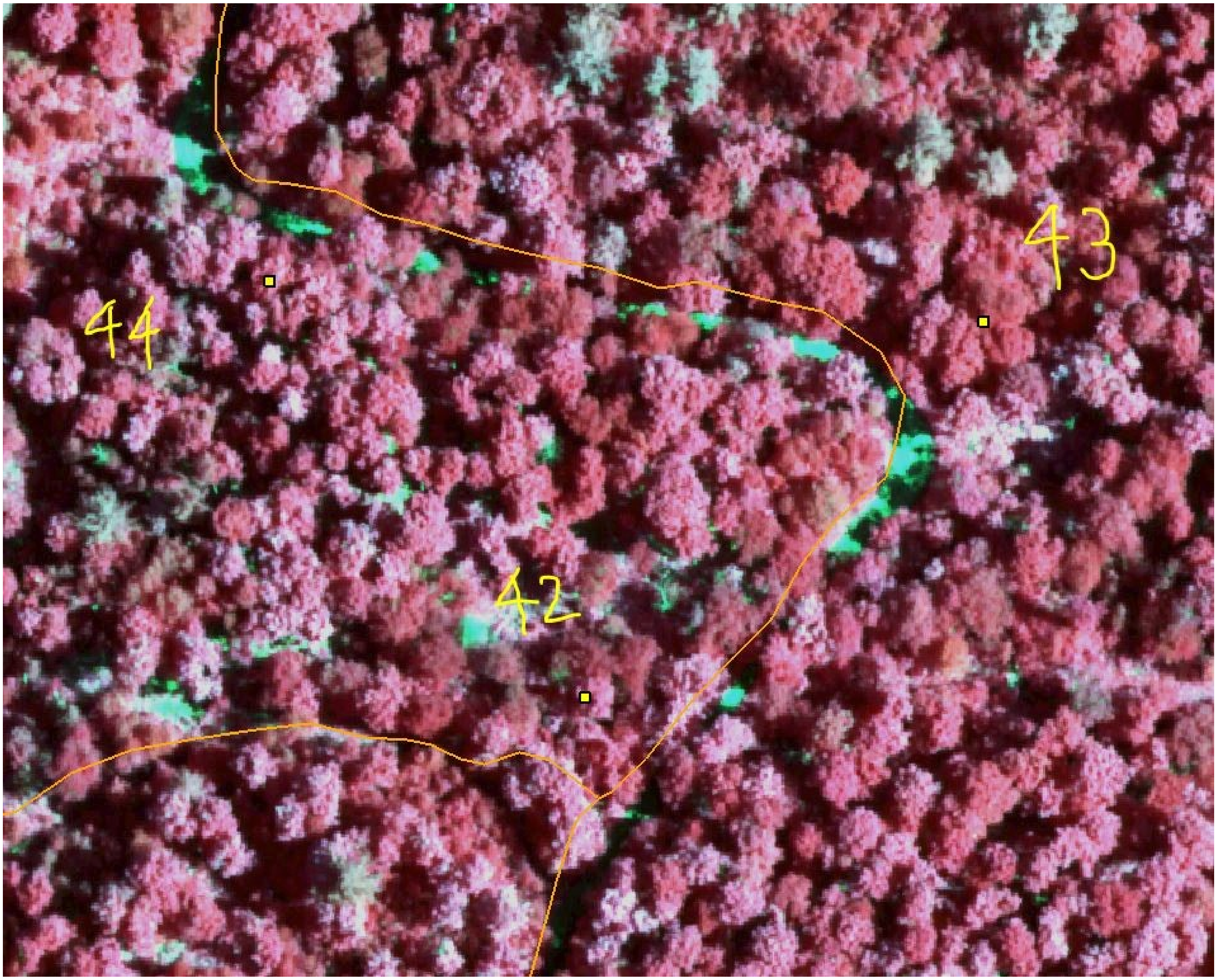
Field Trip 1
early fall 2021
scouting access
excellent access going around the test area via 2-Island Lake Road
access 4 wheel drive accessible
Internal trail network:: ATV only
reasonable access to entire area

Field Trip 2
Fall 2021
Prelocated plot locations using 2011 stereo eFRI imagery
occular plots only, no formal sampling technique (eFRI calibration plots)
Focus on species ID
Considered species types throughout test area but selected locations based on good vehicle access

Field Trip 3
early Fall, 2022
occular plots based on prelocated plot locations determined by viewing planned harvest blocks
ATV access

plots pre-located on imagery by interpreter
area in green box zoomed into on next pic




43
44
42

Interpreter in red circle

APPENDIX 2 Reinterpretation of '98 FRI stands on 2011 eFRI imagery

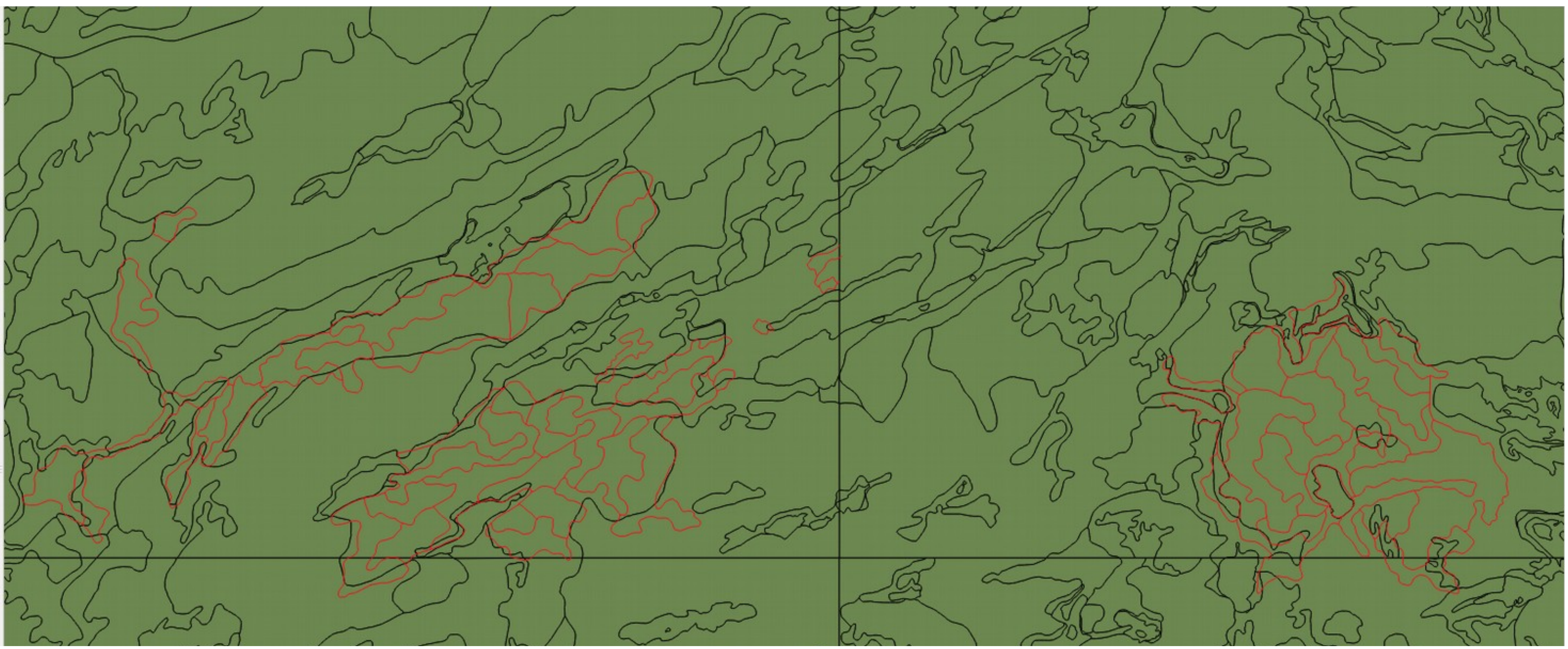
These include:

'98 FRI 24060: a 131 ha, pure hardwood stand
reinterpreted into 22 stands, including 5, cedar dominated

'98 FRI 86040: a 78 ha, 70% pine stand
reinterpreted into 16 stands, indicating overall a 40% pine component

'98 FRI stands 67100 and 74100: 30 ha and 16 ha, respectively, with 30% and 40% cedar as the primary species
reinterpreted to isolate smaller, higher concentration of cedar areas

The interpreter selected several 1998 FRI stands (black lines, below) within the test area
for reinterpretation (red lines, below) using the 2011 eFRI imagery

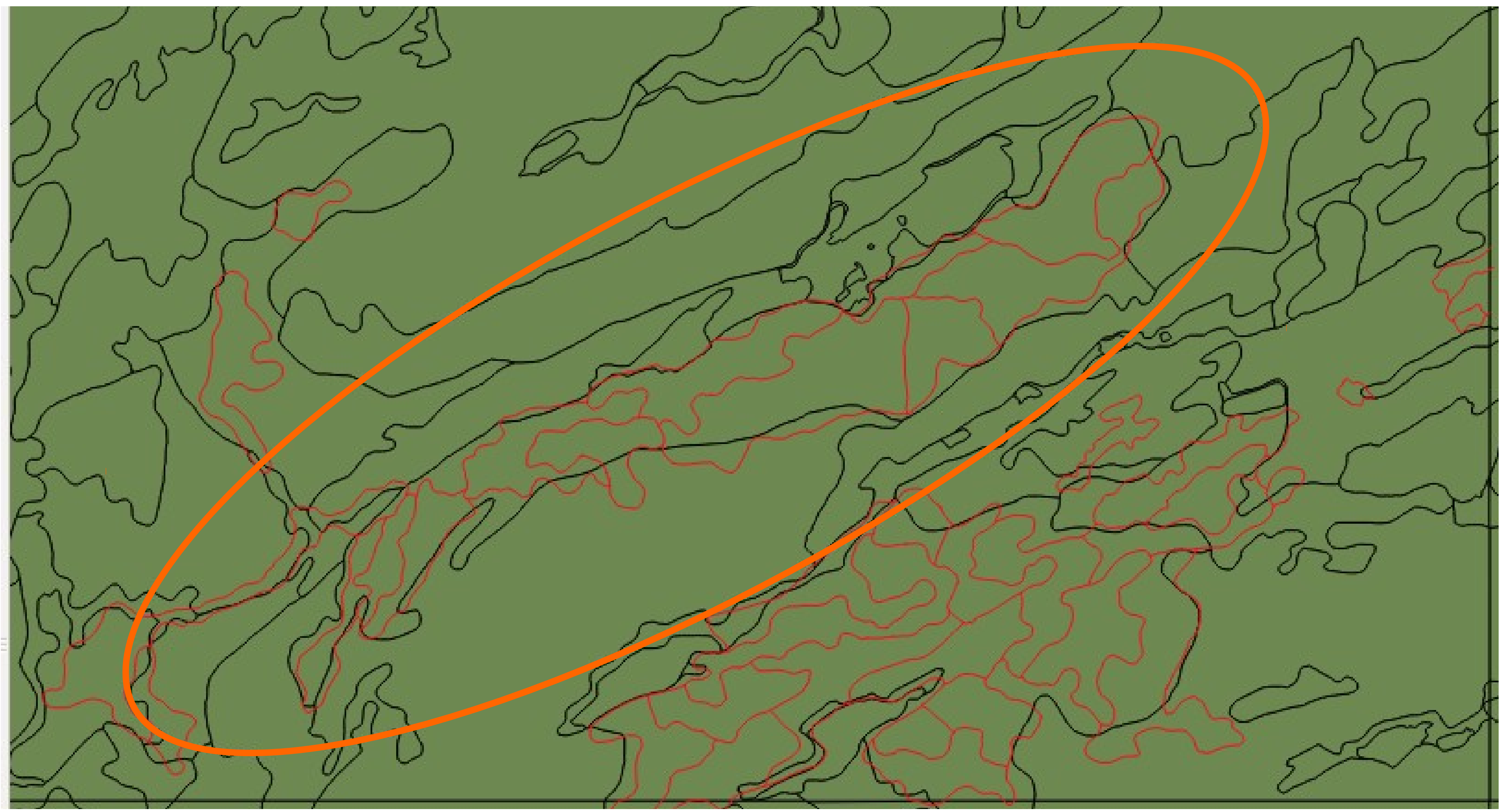


'98 FRI stand **82110**
68ha, 19m

Or3 Mh2 Pw2 Be1 By1 Ce1

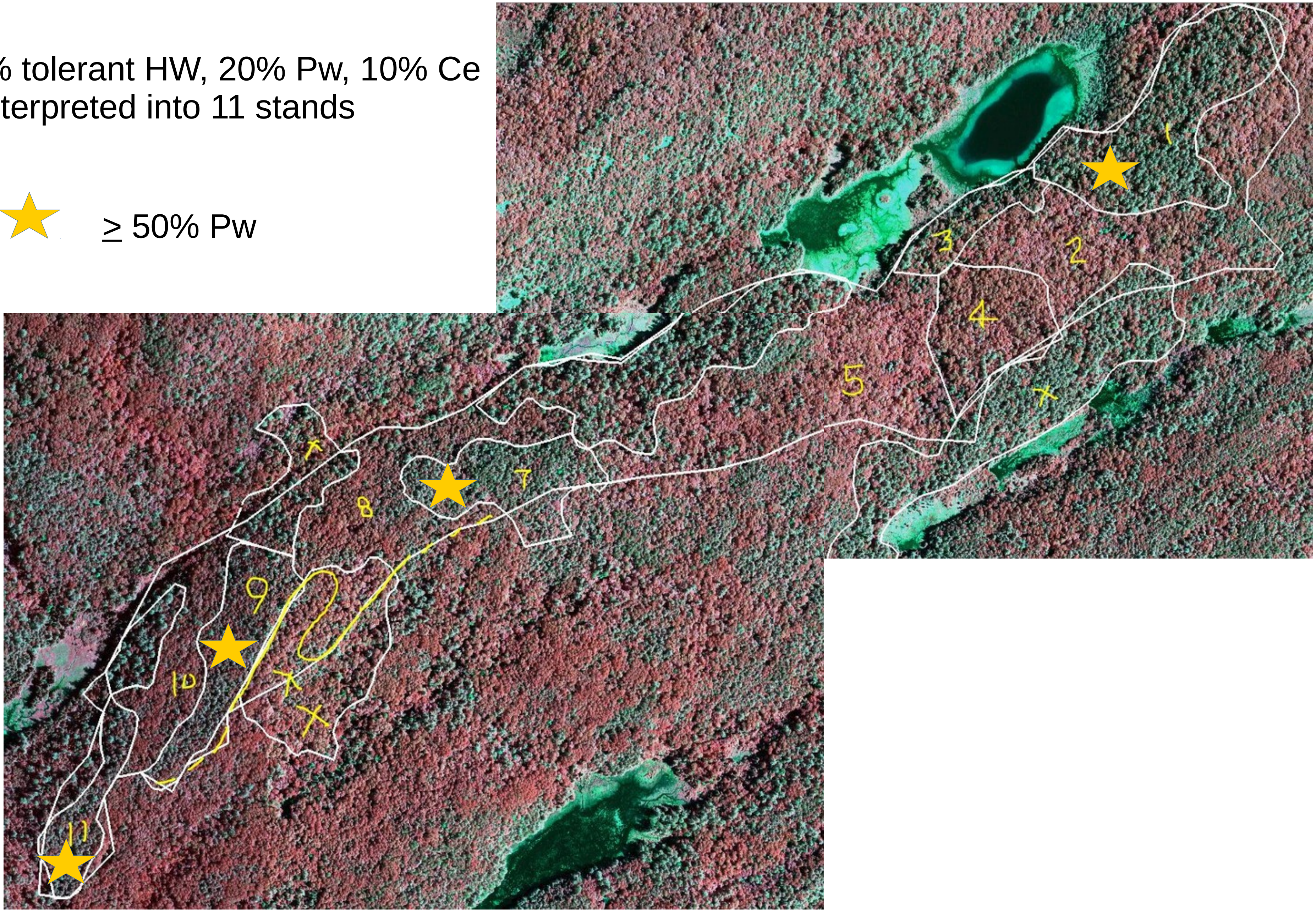
70% tolerant HW, 20% Pw, 10% Ce

Reinterp (using 2009 imagery) into 11 stands



70% tolerant HW, 20% Pw, 10% Ce
reinterpreted into 11 stands

★ ≥ 50% Pw

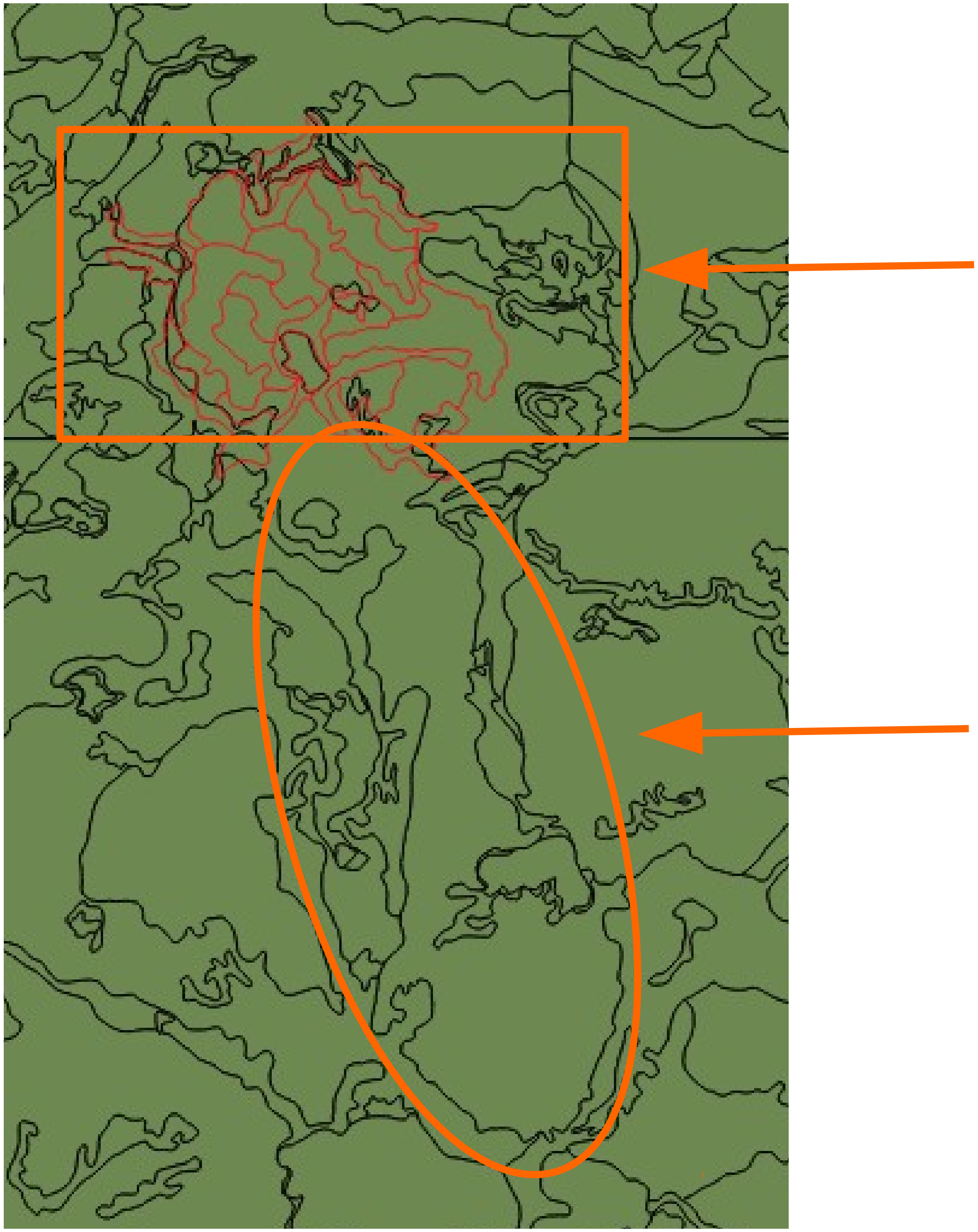


SAMPLE 2:
1998 FRI: stand 82110: OR3 MH2 PW2 BE1 BY1 CE1 – 68 ha - 19m
i.e.: OrMh stand, 70% hw

Reinterp (using 2009 imagery)
to 11 stands avg area ~6 ha

poly 1 - Pw6 Pt2 Or 1 Mh1, 26m	Pw60
poly 2 - Mh4 Or2 Pw2 Pt1 Ce1, 17m	MhOr60
poly 3 - Ce4 Pw2 Pt2 He1 Fb1, 14m	sw80 with CeHe50
poly 4 - Pt6 Mh2 Pw1 Sw1, 20m	Pt60
poly 5 - Mh4 Or2 Pw2 Sw1 Pt1 – 17m	MhOr60
poly 6 - Pw5 Pt2 Mh2 Or1 - 24m	mixed Pw50 MhOr30
poly 7 - Pw7 Mh1 Pt1 Or1 -18m	Pw70
poly 8 - Or2 Pw2 Pt2 Mh2 Sw1 Fb1 – 22m	mixed OrMh40 Pw20
poly 9 - Pw6 Pt2 Sw1 Or1 – 14m	Pw60
poly 10 - Pt4 Pw3 Mh1 Sw1 By1 – 17m	mixed Pw30 MhBy20
poly 11 - Pw6 Pt1 Or1 Fb1 – 22m	Pw60

Summary with hts (m):
4 Pw stands, 26, 18, 14, 22
2 MhOr stands, 17, 17
3 mixed Pw MhOr, 24, 22, 17
1 sw (with 50% Ce & HE), 14
1 hw stand, 20



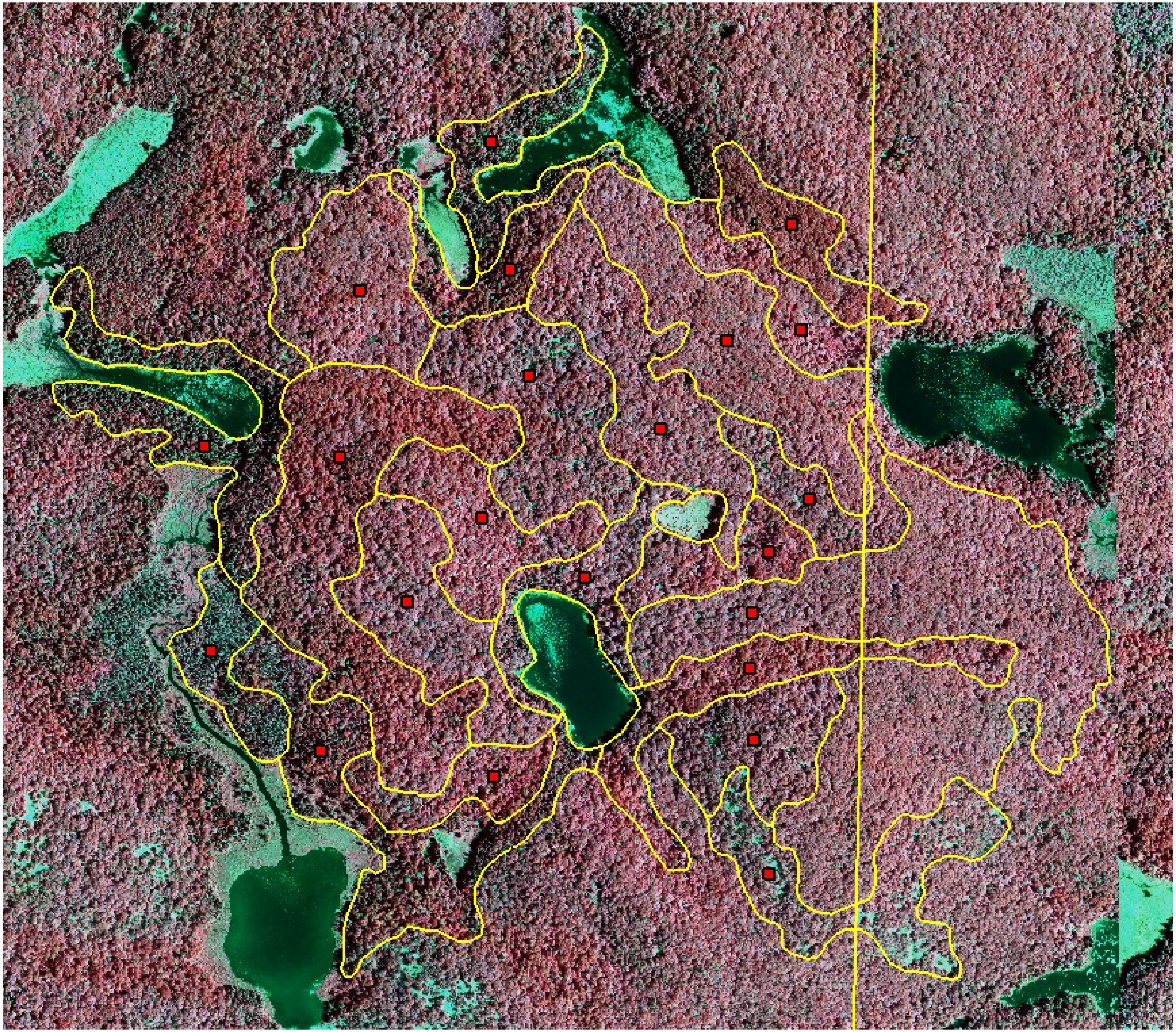
98FRI 24060 - 131 ha
Or5 Mh2 Bw1 By1 PO1
19.0 m - 91yrs

which effectively extended south but was divided on a map sheet boundary

98FRI 29840 - 159 ha
Or5 Mh2 Bw1 By1 PO1
19.0 m - 91yrs

Together:
a 290 ha hardwood stand
50% Or

reinterpreted into 22 sub stands



98FRI 24060 - 131.2 ha
Or5 Mh2 Bw1 By1 PO1 – 19.0 m

reinterpreted into 22 sub stands
using 2011 eFRI imagery (stereo)

sub-stand #	area ha	ht m	cc %	Sp 1	%	Sp 2	%	Sp 3	%	Sp 4	%	Sp 5	%	Sp 6	%
40	3.4	13	65	Ce	50	Fb	40	Pt	10						
43	5.4	14	95	Ce	70	Fb	20	Pt	10						
53	3.2	12	70	Ce	50	Mh	20	By	10	Or	10	Sw	10		
55	2.4	10	50	Ce	90	La	10								
56	7.8	11	65	Ce	60	Fb	10	Pt	10	Ab	10	By	10		
	22.2														
45	4.2	14	80	Mh	50	Or	20	Pt	20	Bw	10				
47	6.4	14	85	Mh	70	Or	20	Pt	10						
50	3	19	70	Mh	70	Pt	10	Or	10	Bw	10				
51	3	12	65	Mh	60	Or	40								
52	2.6	16	80	Mh	40	Pt	30	Or	20	Bw	10				
54	2.8	14	70	Mh	60	Or	20	Bw	10	Be	10				
58	2.5	13	85	Mh	30	Ce	20	Bw	20	Pt	20	By	10		
59	21	14	90	Mh	60	Or	40								
61	6	12	45	Mh	60	Or	30	Be	10						
	51.5														
42	5.5	17	95	Or	60	Mh	30	Pt	10						
46	6.3	12	70	Or	40	Mh	30	Ce	10	Bw	10	Pt	10		
48	7.7	15	95	Or	50	Mh	50								
60	3.7	13	65	Or	50	Mh	40	Pw	10						
	23.2														
41	2.7	18	70	Pt	30	Ce	20	Bw	20	Or	10	Mh	10	Fb	10
44	11.6	19	75	Pt	60	Or	10	Mh	10	Ce	10	Bw	10		
49	2.7	14	75	Pt	80	Mh	10	Pr	10						
57	4.4	19	70	Pt	60	Mh	20	Or	10	Ce	10				
	21.4														
	118.3	ha total													

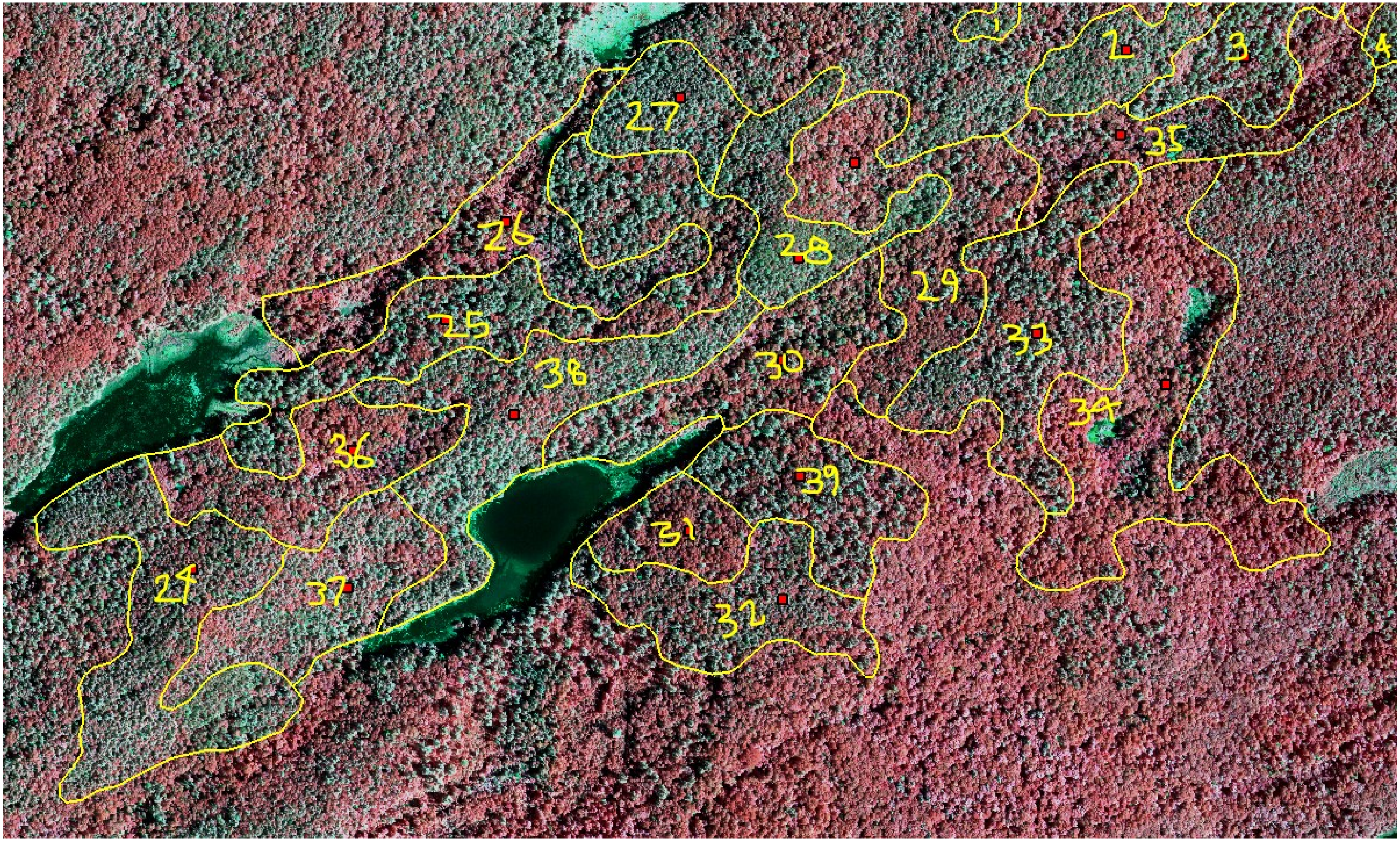
Highlit species not in 1998 typing

Comments:
Avg stand area: 5.4ha: several possibly too small to be picked up.
Small concentrations of Ce might have deer management implications?

'98FRI stand **86040**: PW7 BW2 PO1 - 78.0 ha – 22.7 m

(extends into southern map sheet for another 20ha)

reinterpreted into 16 stands



'98FRI stand 86040: PW7 BW2 PO1 - 78.0 ha – 22.7 m

reinterpreted into 16 stands
area of reinterpreted stands weighted by SP% yields:

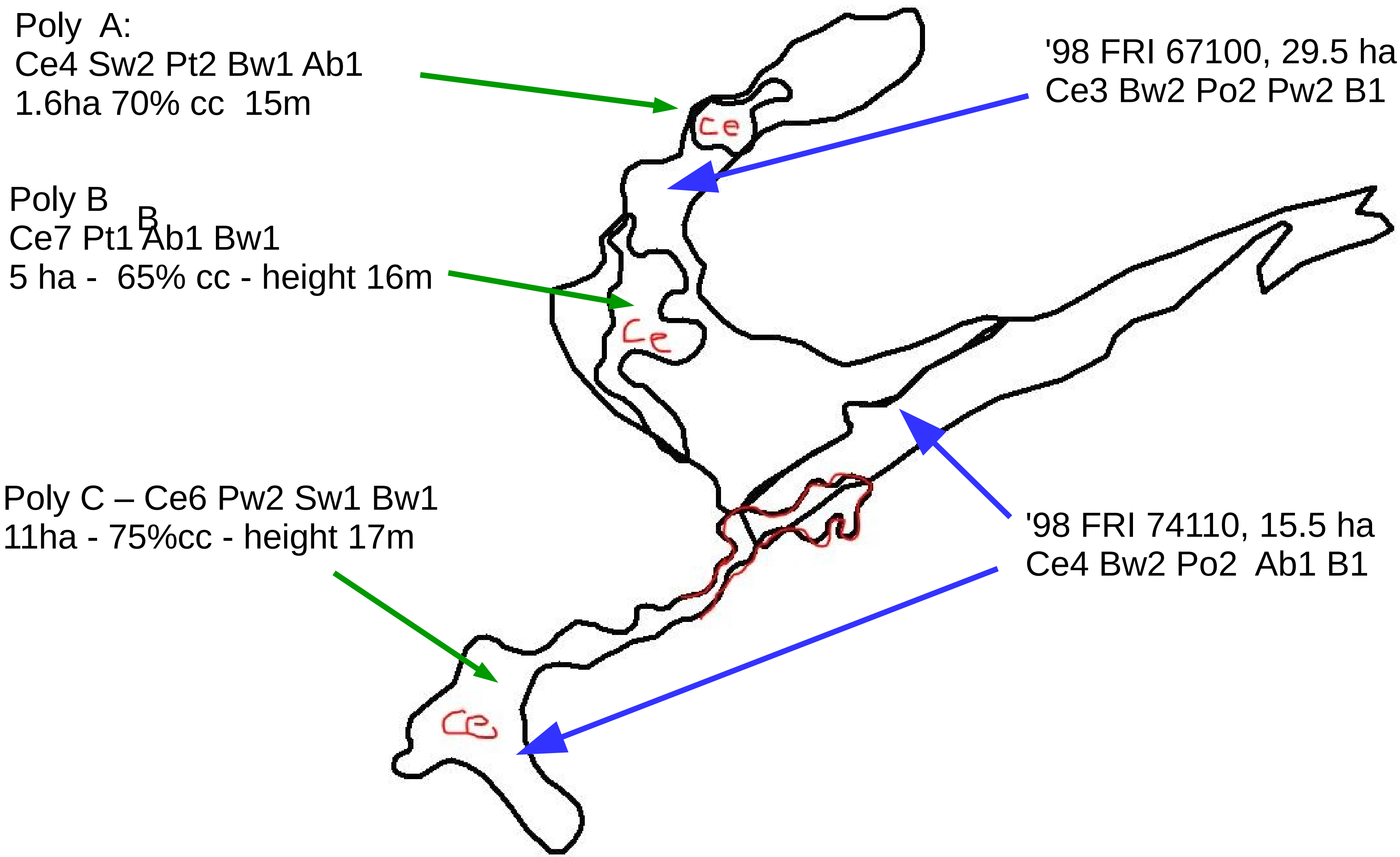
Pw4 Pt2 Mh2 Bw1 Ce1

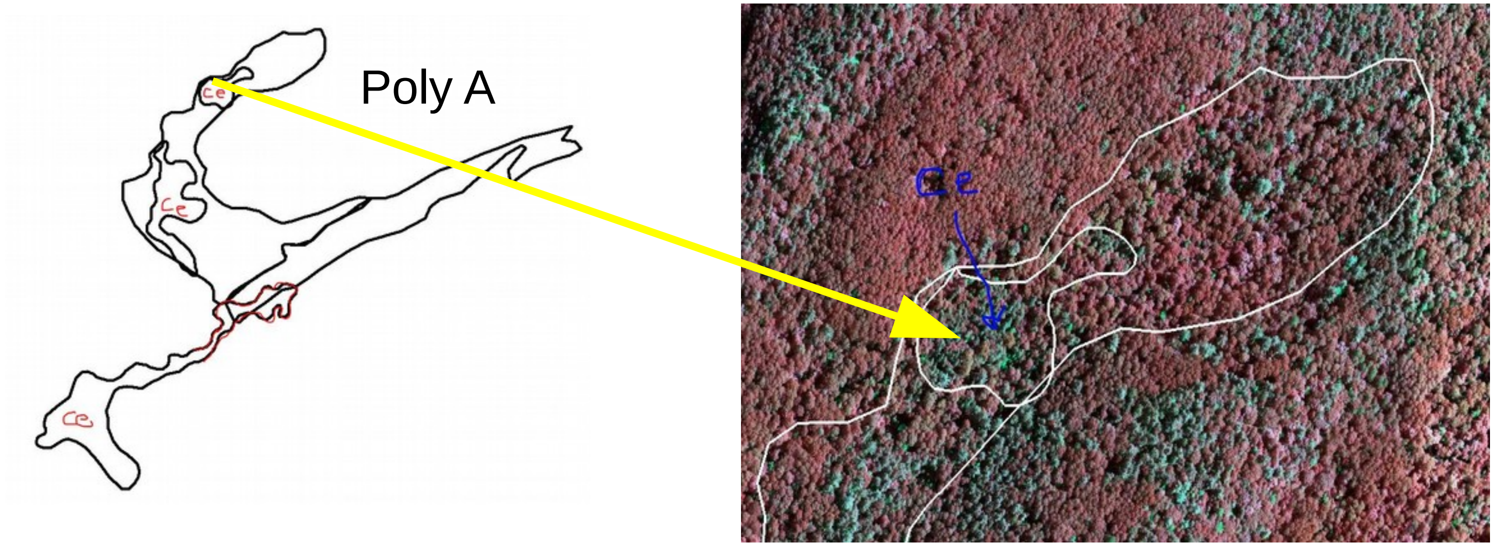
sub-stand #	area ha	ht m	cc %	Sp 1	%	Sp 2	%	Sp 3	%	Sp 4	%	Sp 5	%	Sp 6	%
24	7.7	17	95	Pw	60	Pr	20	Pt	10	Or	10				
25	8.2	25	90	Pw	50	Pt	20	Pr	10	Sw	10	Mh	10		
26	5.7	14	65	Ce	40	Ab	20	Fb	10	Pw	10	Bw	10	Mh	10
27	2.4	20	95	Pw	90	Mh	10								
28	3.4	19	90	Pw	40	Pr	40	Sw	10	Pt	10				
29	6	18	95	Pt	50	Pw	20	Mh	20	Or	10				
30	5	15	80	Ce	30	Pw	30	Pt	20	Mh	10	Bw	10		
31	2	17	95	Pt	60	Pw	20	Bw	20						
32	4	20	95	Pw	50	Pt	20	Mh	20	Sw	10				
33	6	22	90	Pw	50	Pt	20	Mh	10	Sw	10	Bw	10		
34	10	17	75	Pt	40	Mh	30	Pw	10	Ce	10	Bw	10		
35	4.3	15	65	Ce	30	Bw	20	Ab	20	Pw	10	Sw	10	Pt	10
36	4.3	17	85	Pt	40	Pw	20	Mh	20	Ce	10	Sw	10		
37	5	21	85	Pw	50	Mh	20	Bw	10	Or	10	He	10		
38	6.8	21	90	Pw	70	Sw	10	Or	10	Mh	10				
39	3.8	25	85	Pw	50	Pt	20	Mh	20	Or	10				

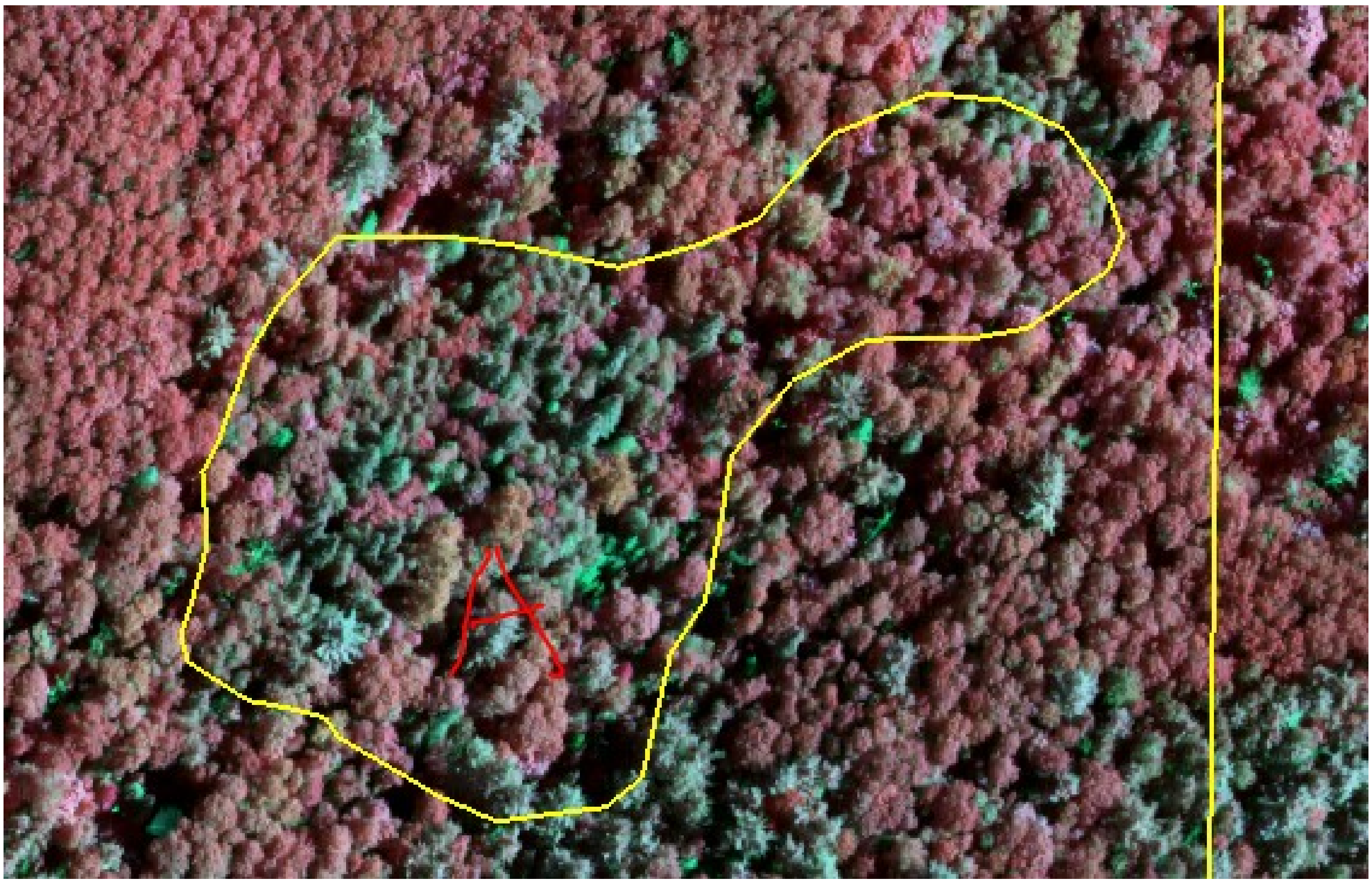
84.6 ha
5.3 ha avg

Identifying Ce stands

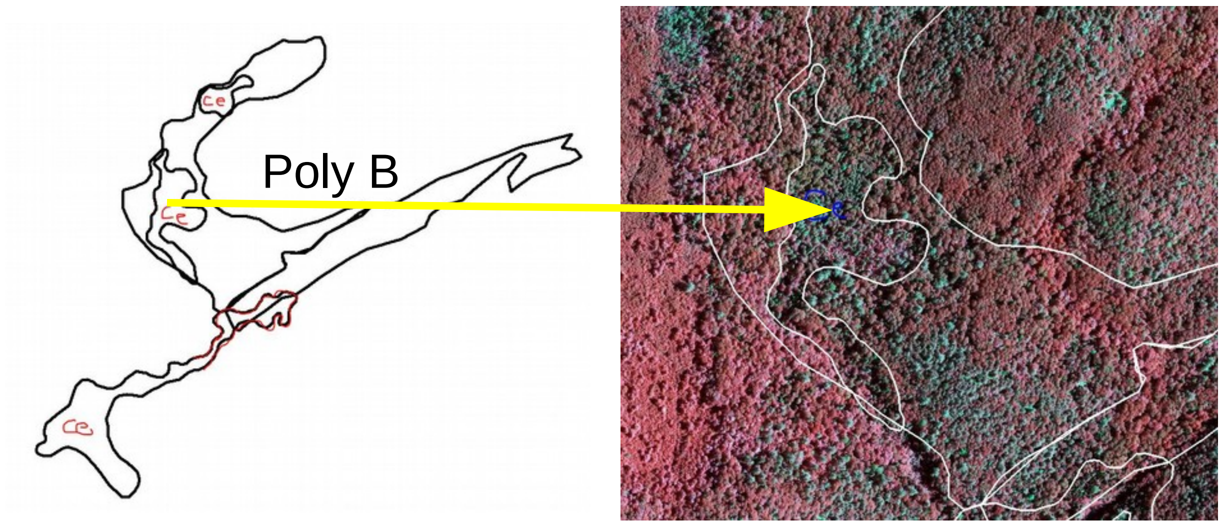
3, reinterp Ce stands (A, B, C) within 2 '98 FRI stands

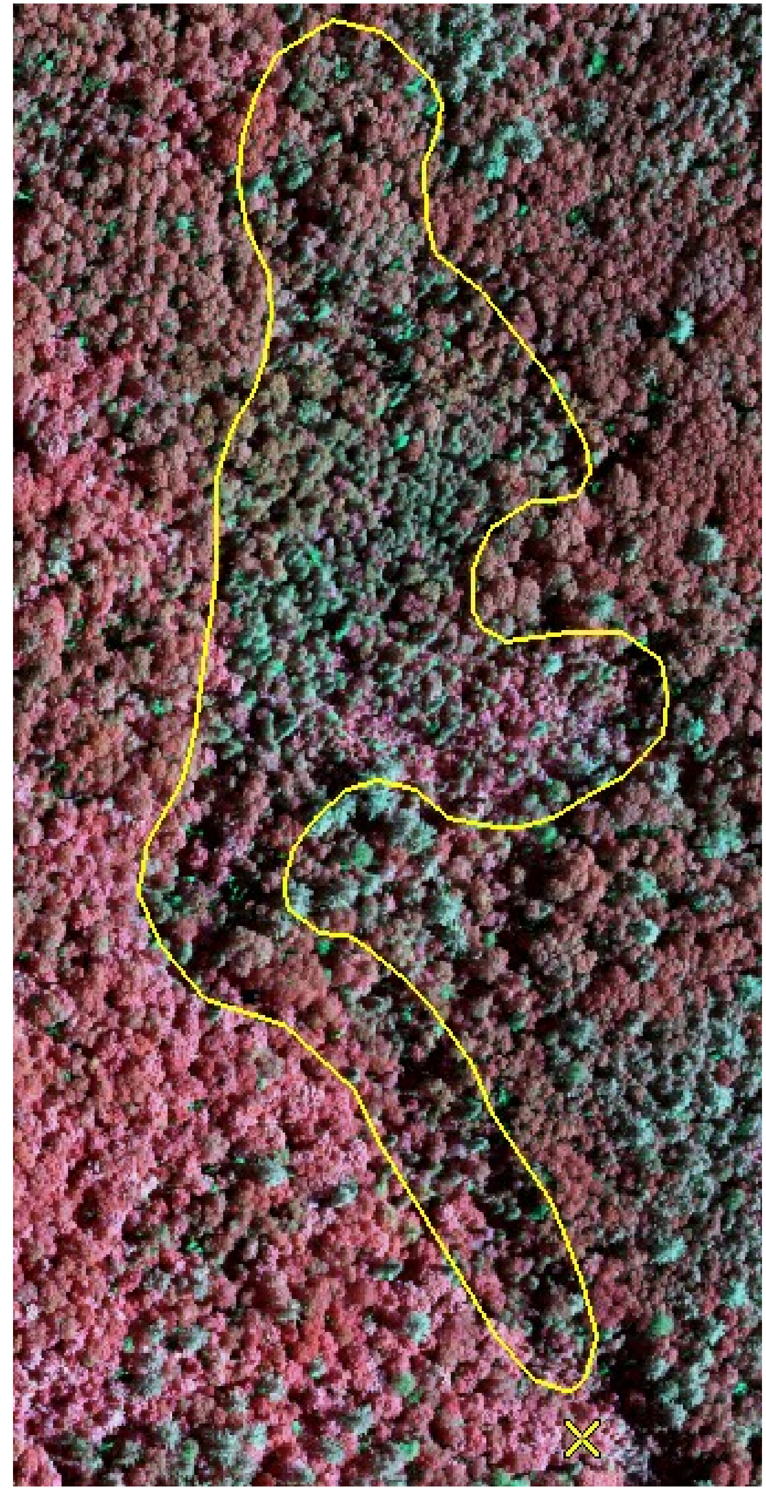




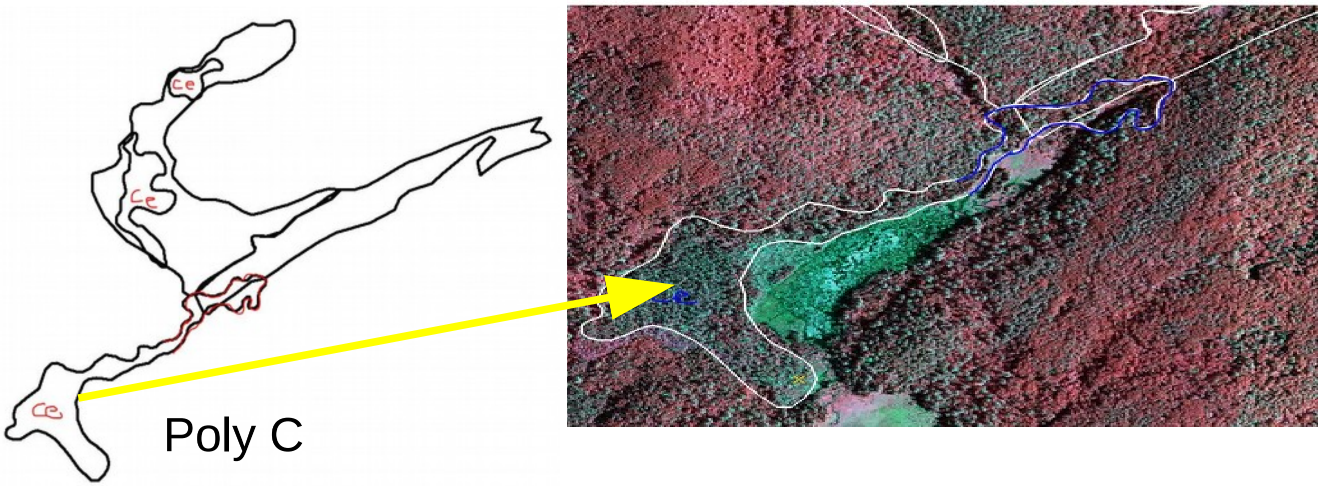


Poly A:
Ce4 Sw2 Pt2 Bw1 Ab1
1.6ha 70% cc 15m

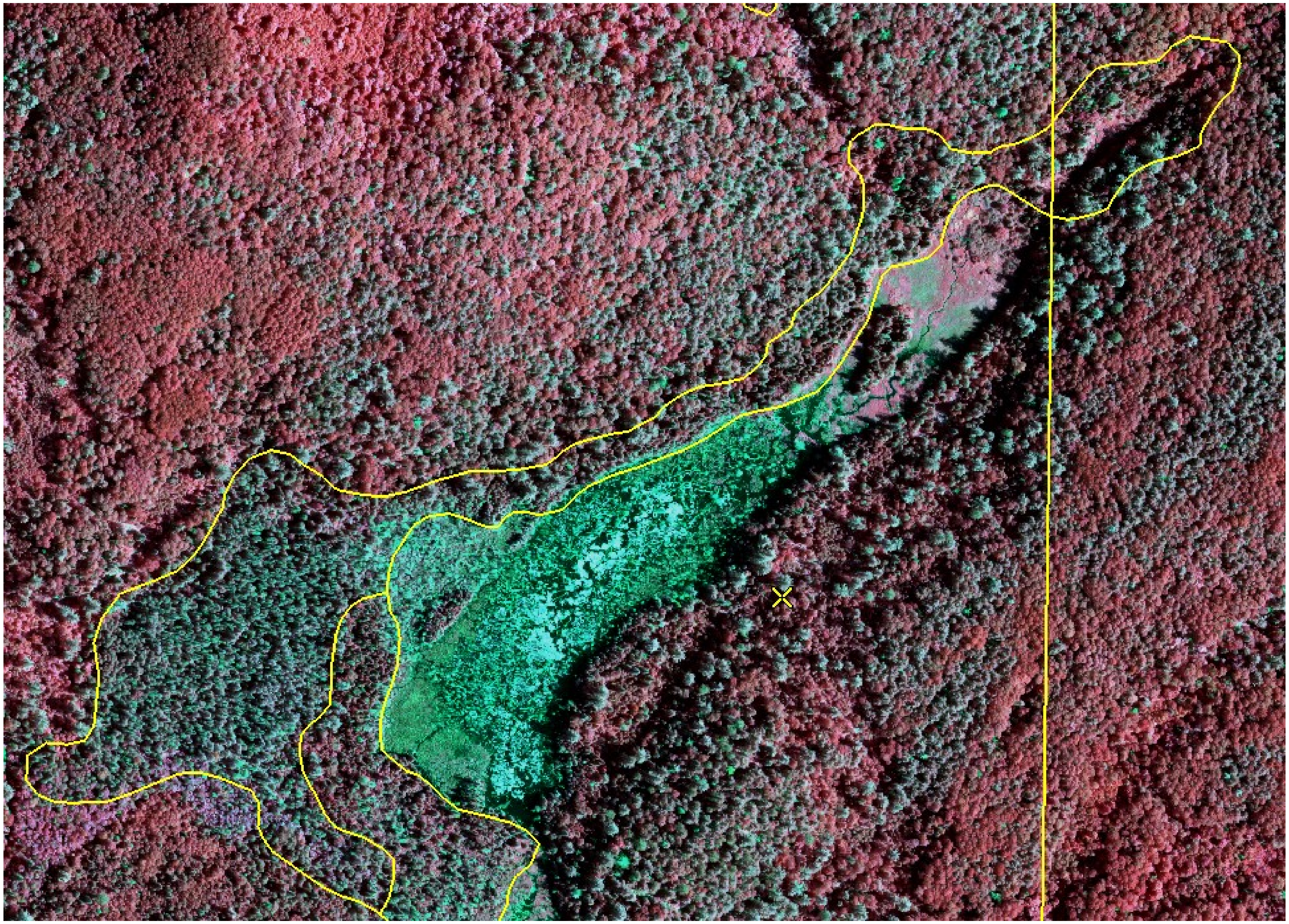




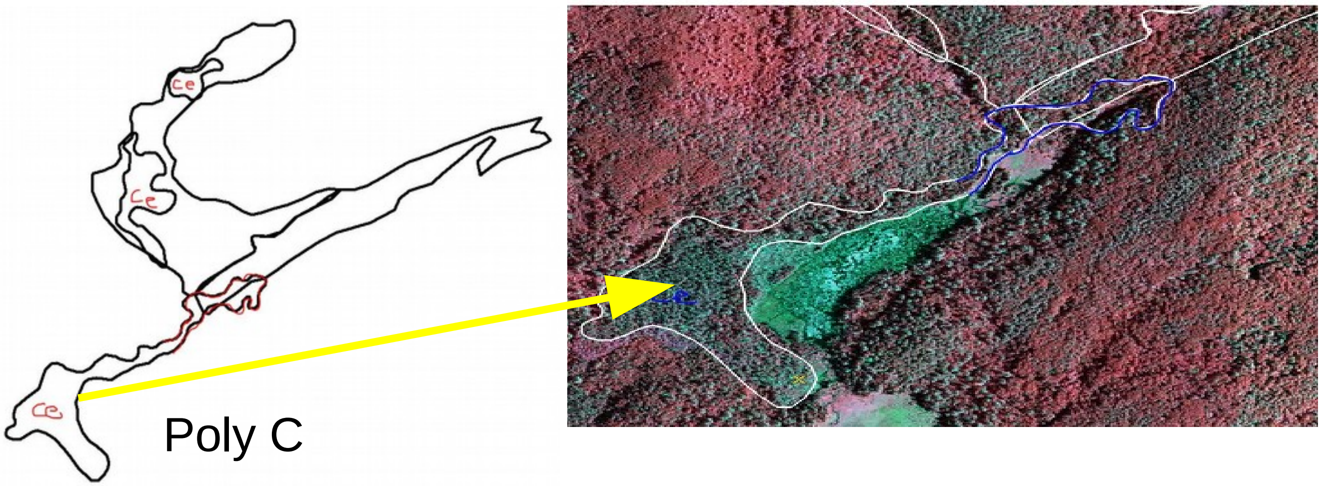
Poly B
Ce7 Pt1 Ab1 Bw1
5 ha - 65% cc - height 16m

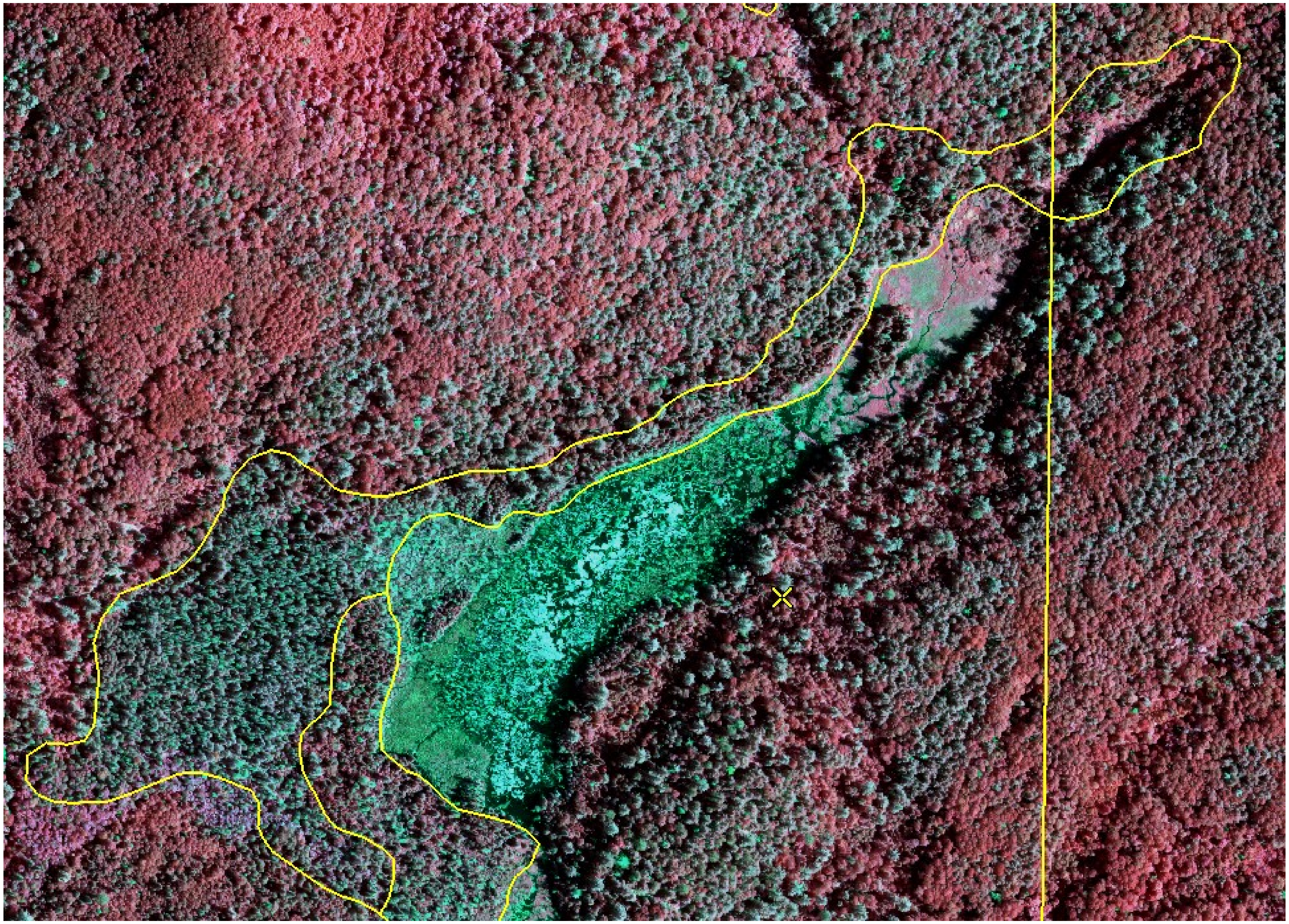


Poly C



Poly C
Ce6 Pw2 Sw1 Bw1
11ha - 75%cc - 17m





Poly C
Ce6 Pw2 Sw1 Bw1
11ha - 75%cc - 17m