



# Application of Sentinel-2 Satellite Data in Forestry

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Sentinel satellite series

## Background

Uses of Sentinel

Measuring and understanding forest health

## Study site

## Methods

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## Discussion

## Questions





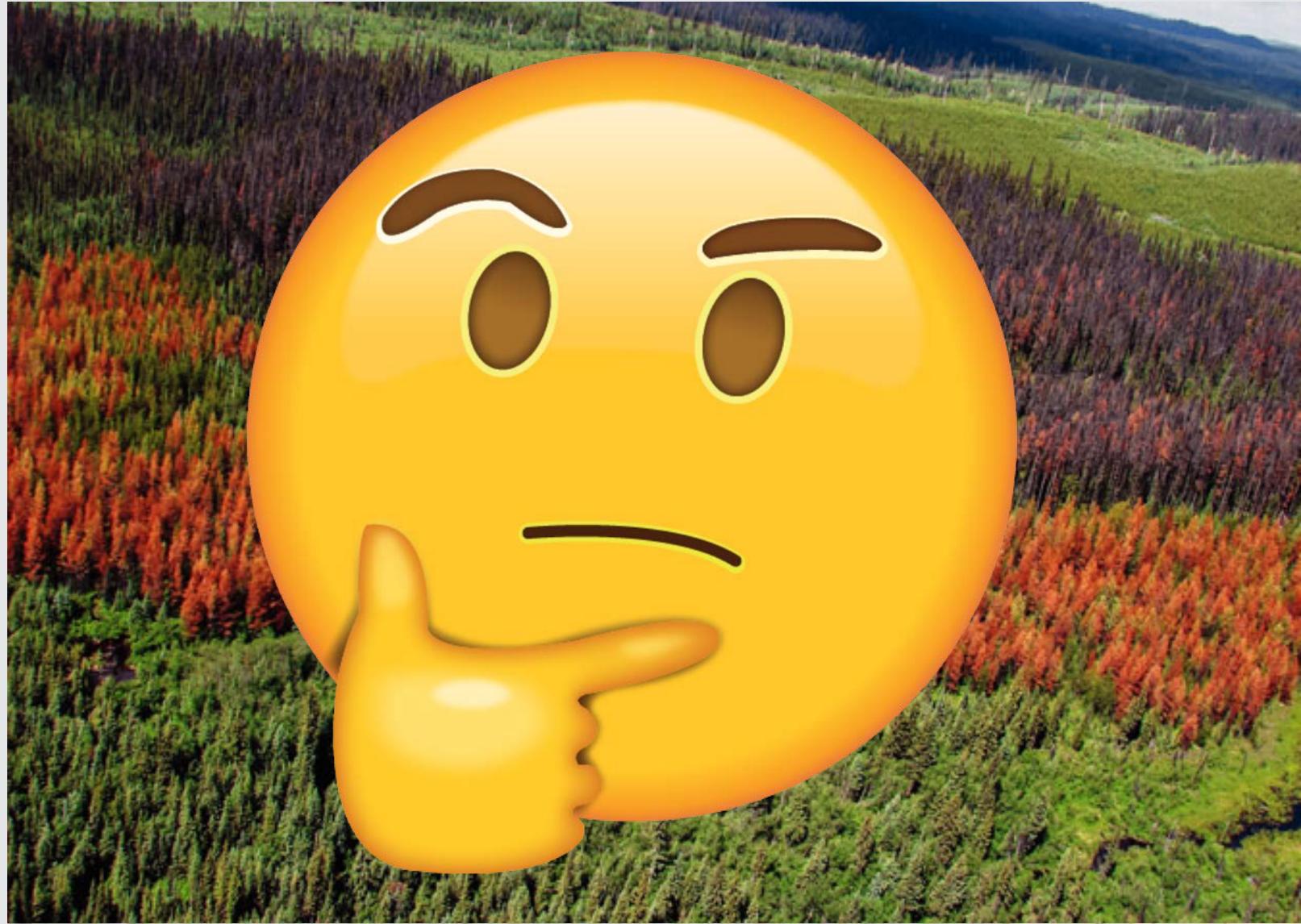
# Introduction

# Sentinel overview

- Part of Copernicus (European Space Agency)
- 5 missions so far, Sentinel-1 to Sentinel-5
- Sentinel-2 provides RGB bands at 10m resolution, other spectral bands at 20-60m
  - Sentinel-2A > 23 June 2015
  - Sentinel-2B > 07 March 2017
  - Land observation, land use and detection maps, disaster relief support
  - Orbit height: 786km
  - Swath: 290km
  - Repeat cycle: 10 days with 1 satellite and 5 days with 2 satellites
- FREE!



# Uses of Sentinel in Forestry





# Background

# Forest health

Numerous definitions!

Understanding the relationships between drivers, stress, and ecosystems spatially and over time to allow better forest management decisions

**Help the trees be the best they can be!**



# Leaf area index (LAI)

- Ratio of leaf area per unit ground surface area
- A healthier tree with more foliage will have a higher LAI, while a less-healthy tree with minimal foliage will have a lower LAI
- Field = slow
- Remote sensing = faster?



# Leaf area index (LAI)

- Provide an understanding of changes in productivity (Zheng and Moskal, 2009)
- LAI can give an overall picture of the forest to assist tree management decisions (fertilization)



# Leaf area index (LAI)

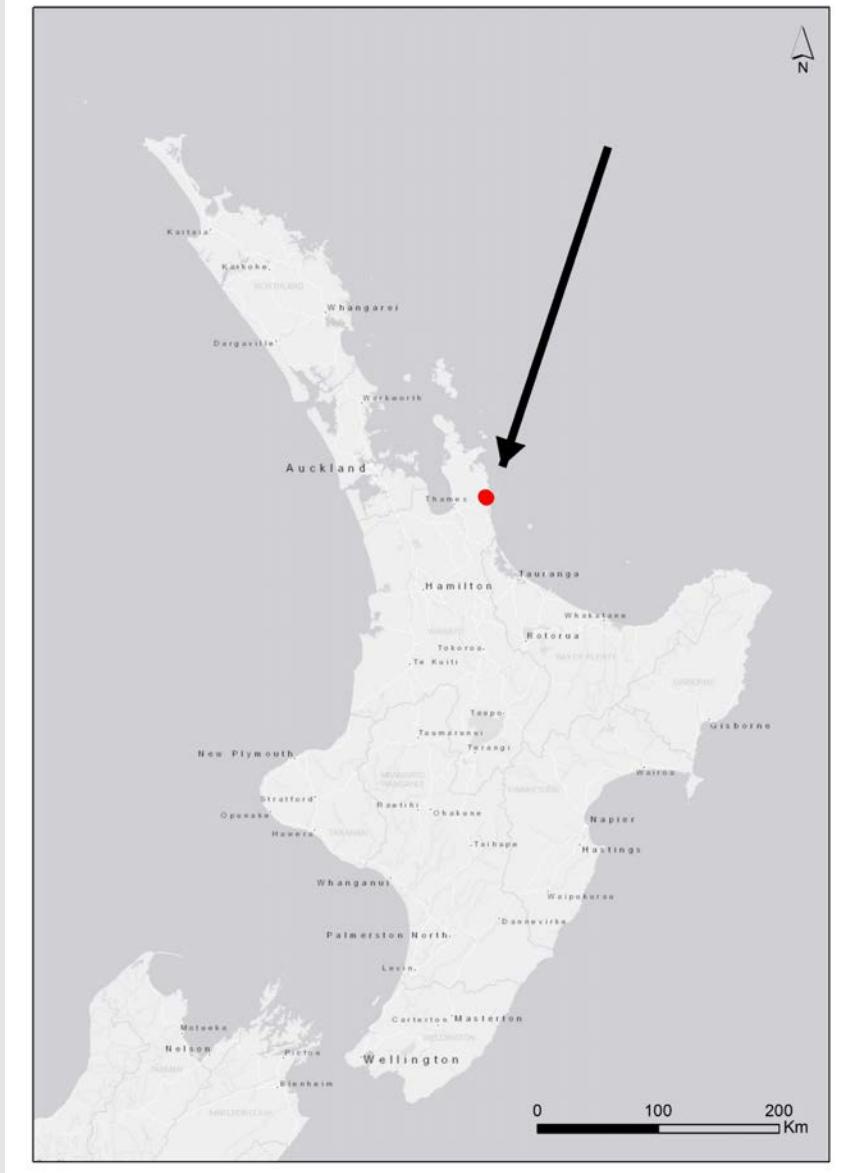




# Study Site

# Study site

- Tairua Forest
- Eastern Bay of Plenty
- Operational aerial fertilizer trial (2016)
- Multiple sets of field/lab data:
  - Foliage samples (chemistry)
  - Soil samples (chemistry)
  - Growth measurements
  - LiDAR surveys



# Study site

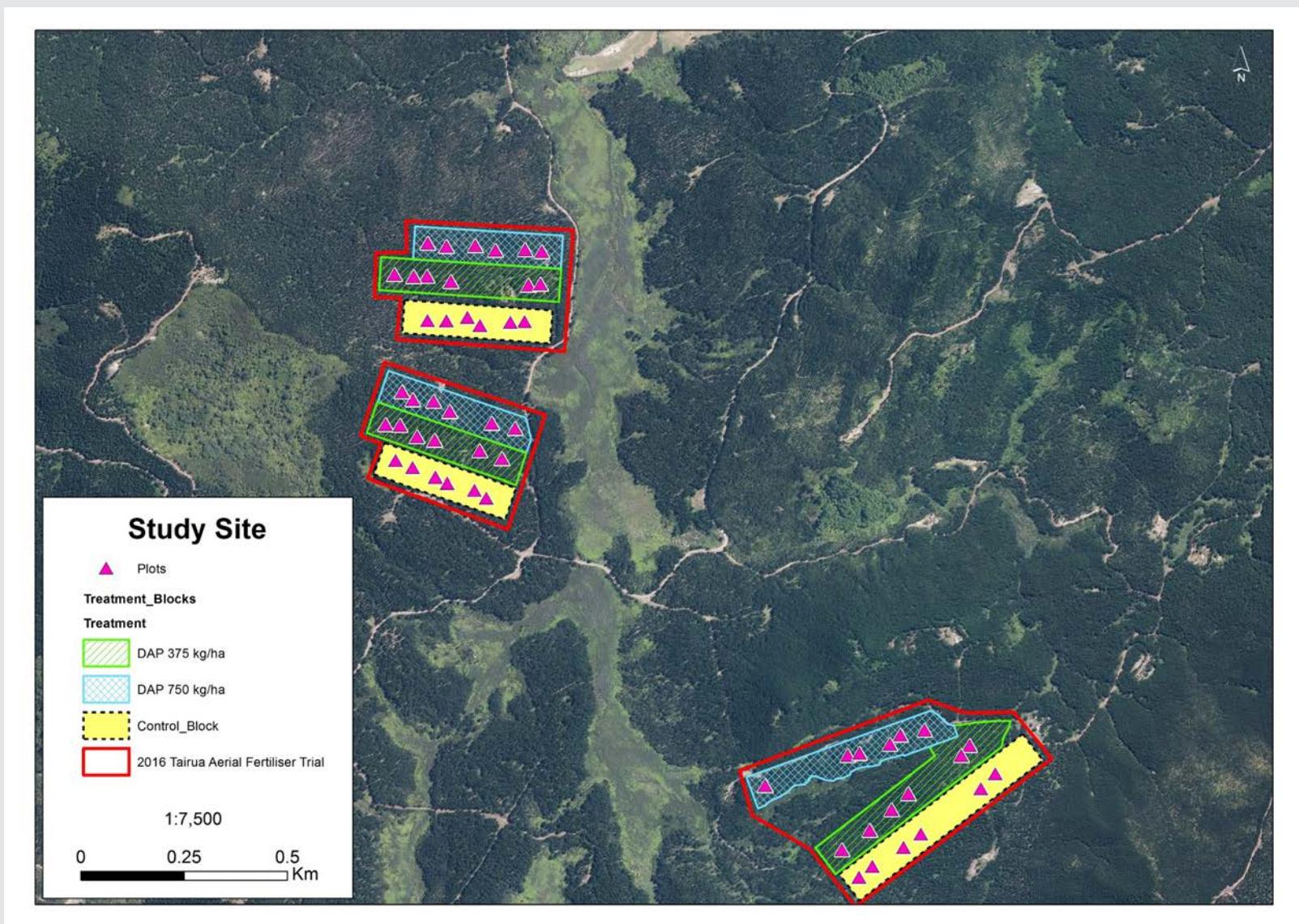
- Phosphorus deficient
  - Short needles
  - Narrow crowns



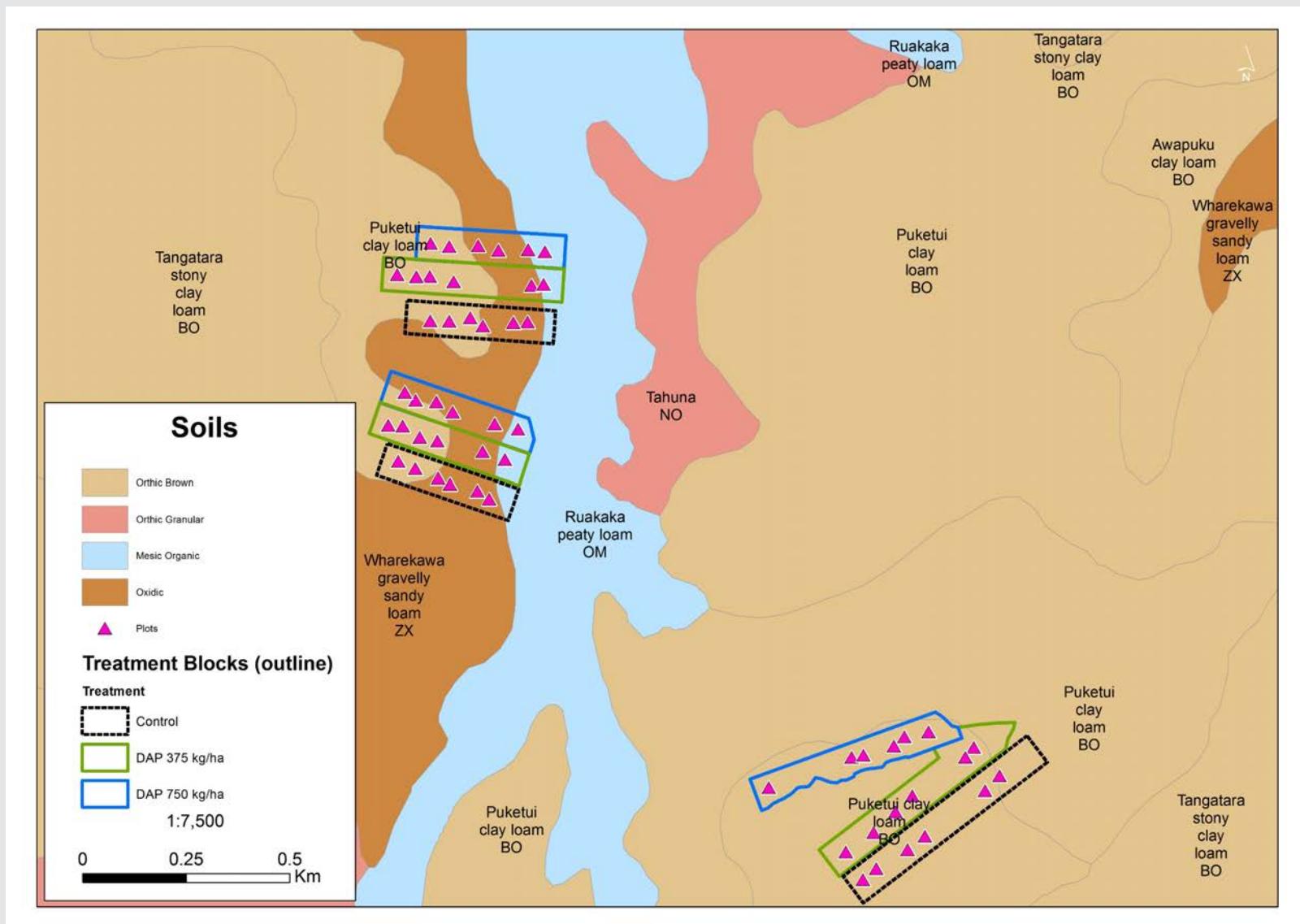
Davis et al. 2010

# Study Site

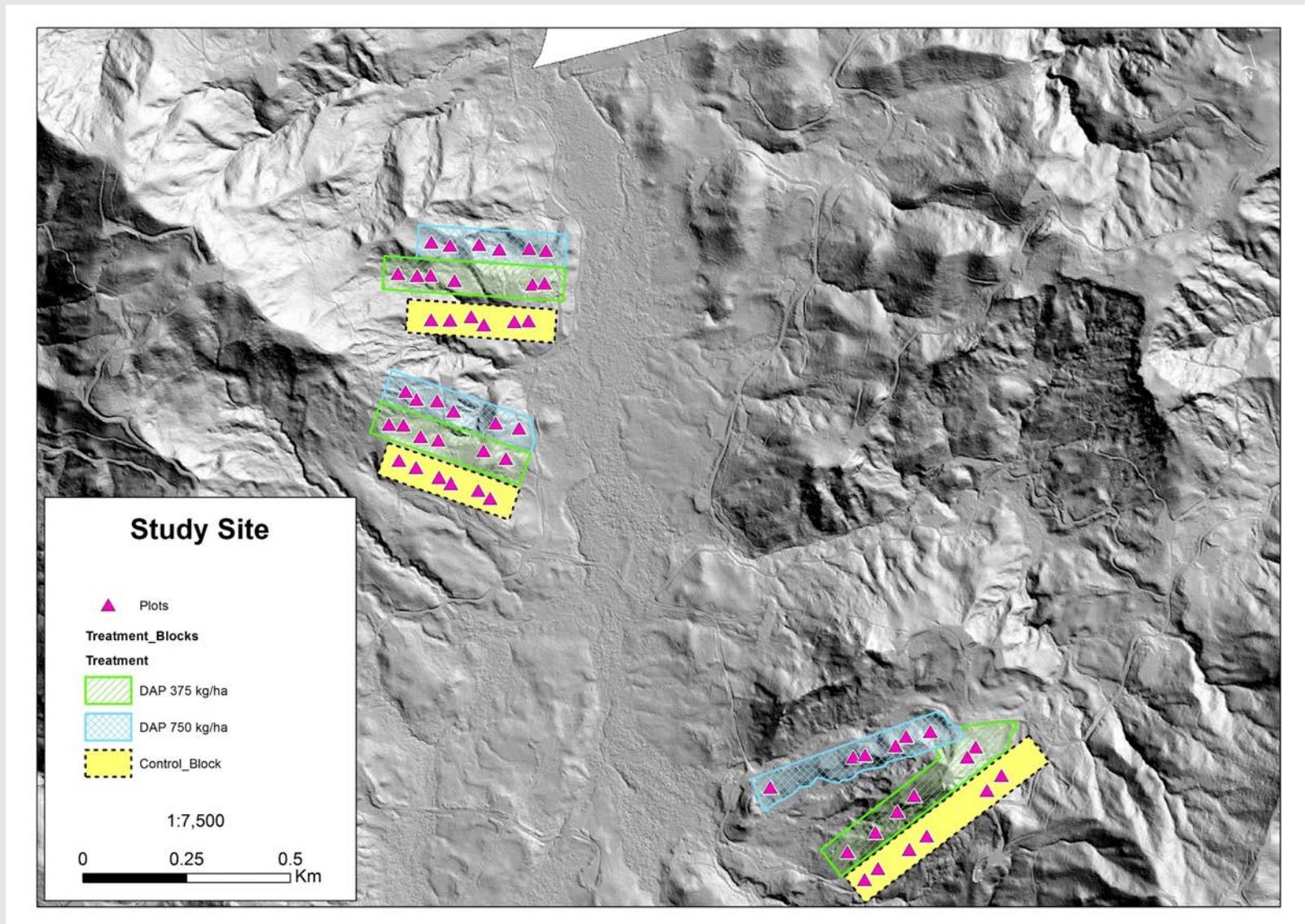
## Aerial Fertiliser Trial - DAP



# Study Site Soils



# Study Site Terrain





# Methods Sentinel Processing

# Sentinel Processing



# Sentinel Processing

Secure | https://scihub.copernicus.eu/dhus/#/home

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S2\*

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Request Done: S2\* AND ( footprint:"Intersects(POLYGON((175.42715877027766 -37.24351886105658,176.02058291483237 -37.24351886105658,176.02058291483237 -36.87499798386935,175.42715877027766 -36.87499798386935,175.42715877027766 -37.24351886105658,176.02058291483237 -37.24351886105658))" )

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Pan Box Polygon Clear

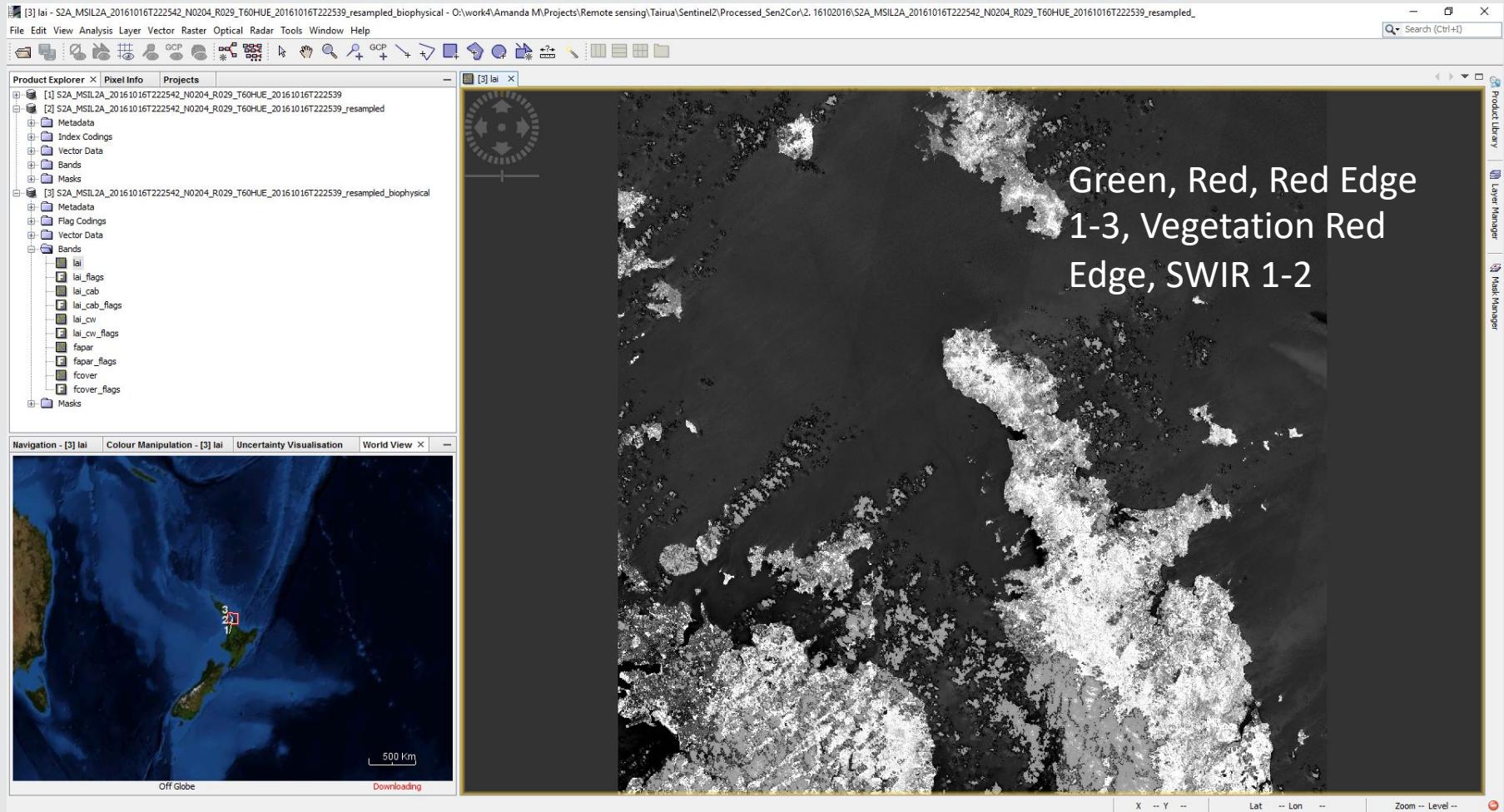
19

# Sentinel Processing

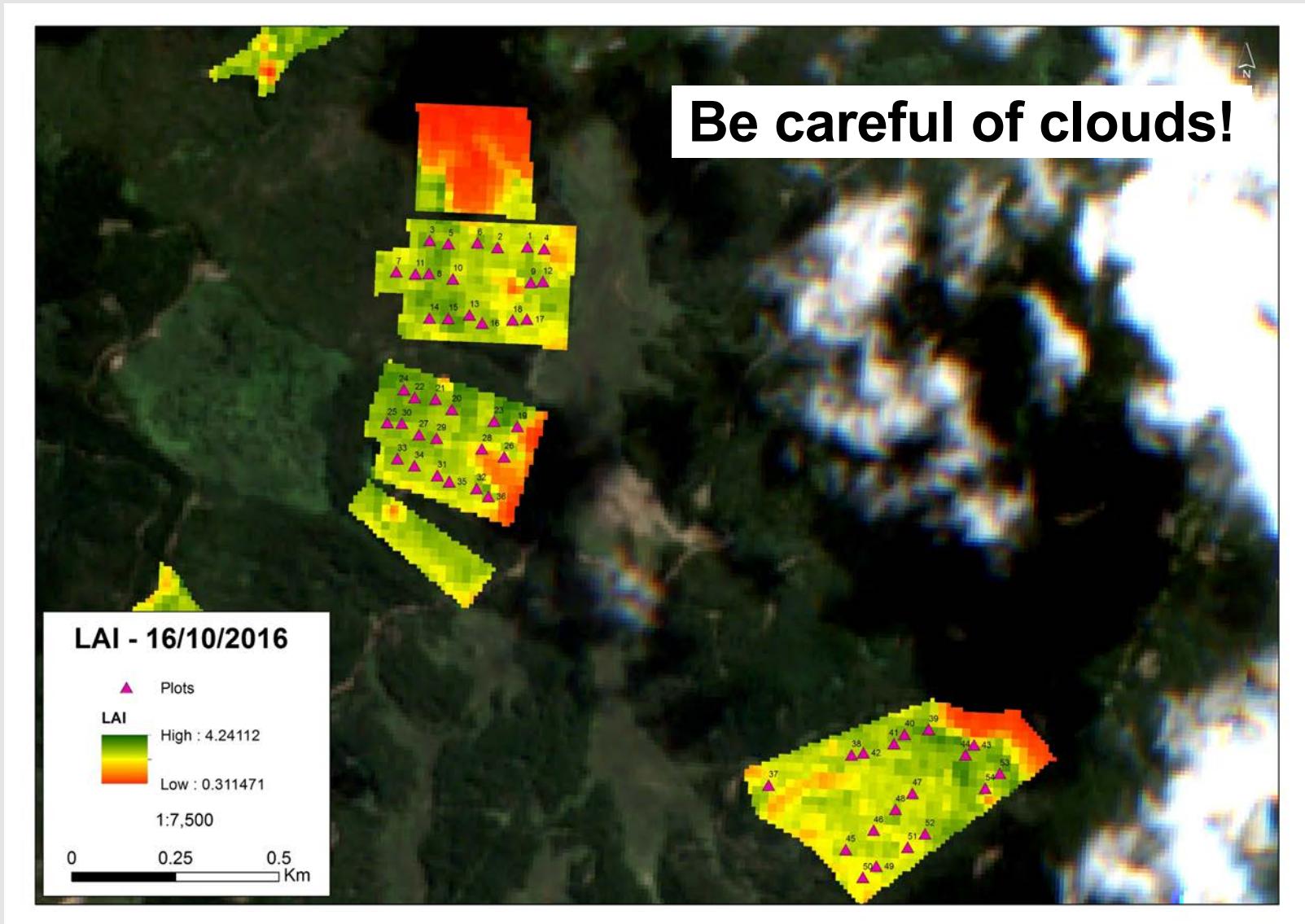
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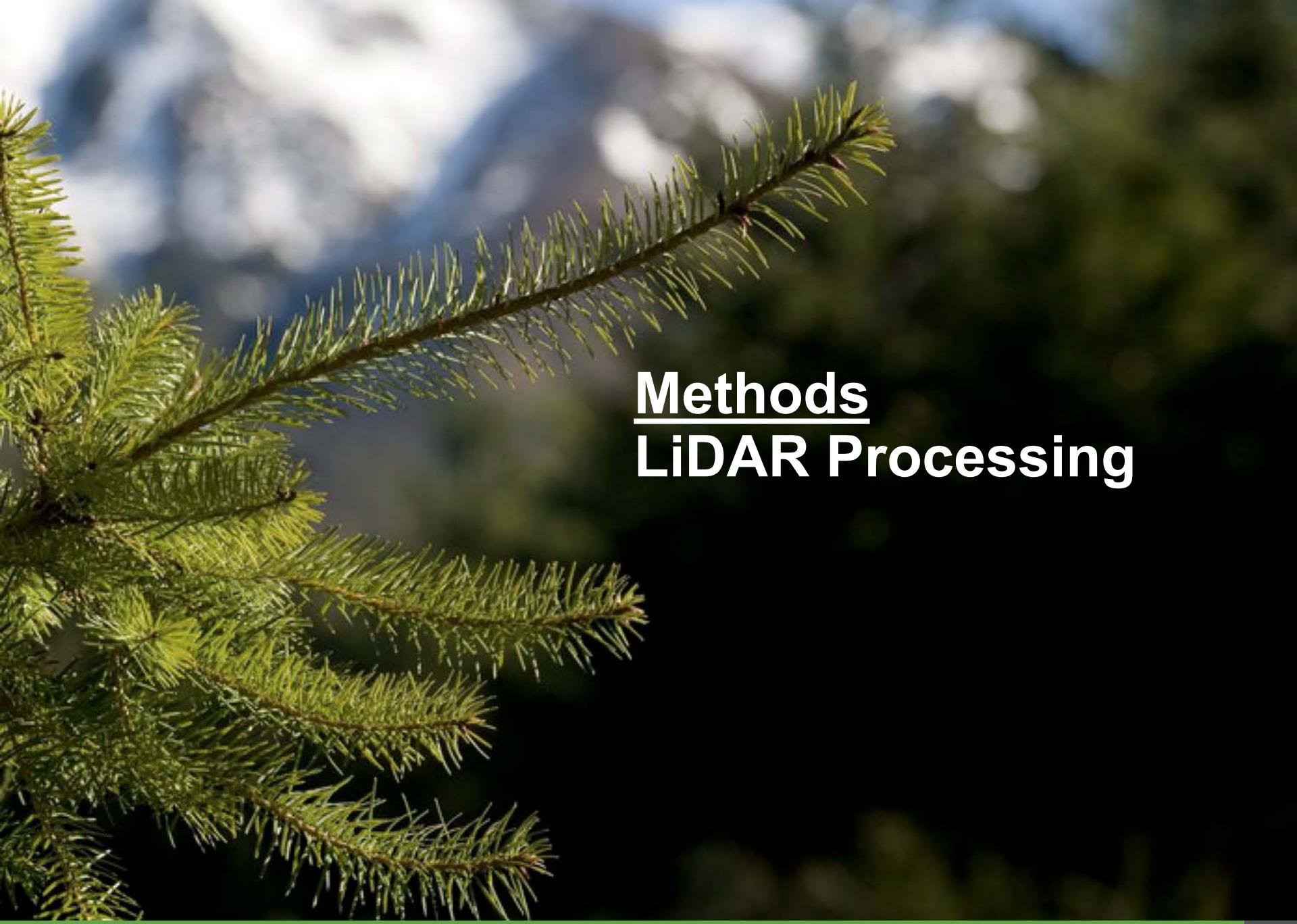
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```

# Sentinel Processing



# Sentinel Processing





# Methods LiDAR Processing

# LiDAR Processing

Light Detection And Ranging (LiDAR) refers to an active laser-scanning technology that allows accurate 3-D measurement of forest vegetation and the ground surface based on laser pulse return times.

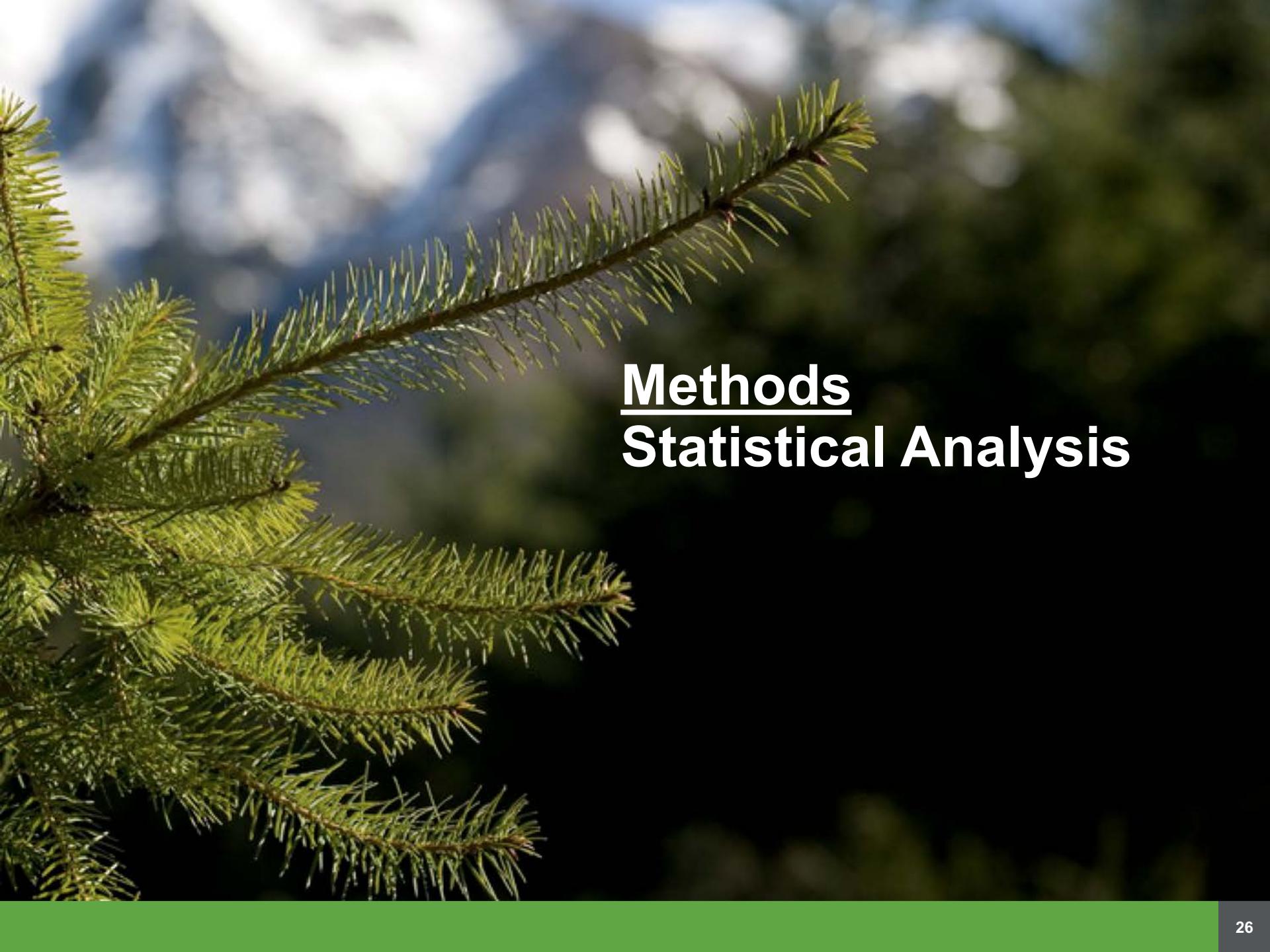


- P50fp: height above ground corresponding with the 50th percentile of the point cloud above a base height (0.5m)
- %veg: percentage of first returns above a base height – it is an estimate of canopy cover

# LiDAR Processing

## LiDAR processing (LasTools)

- Remove low and high outliers (lasnoise)
- Classify ground and non-ground points (lasground)
- Create a normalized point cloud (lasheight)
- Create forest metrics (lascanopy)



# Methods Statistical Analysis

# Statistical Analysis

- ArcMap
  - Zonal statistics (mean) from plot 5m buffer
  - Extract values from rasters (Sentinel LAI, LiDAR p50fp, %veg, elevation, slope and aspect)



# Statistical Analysis

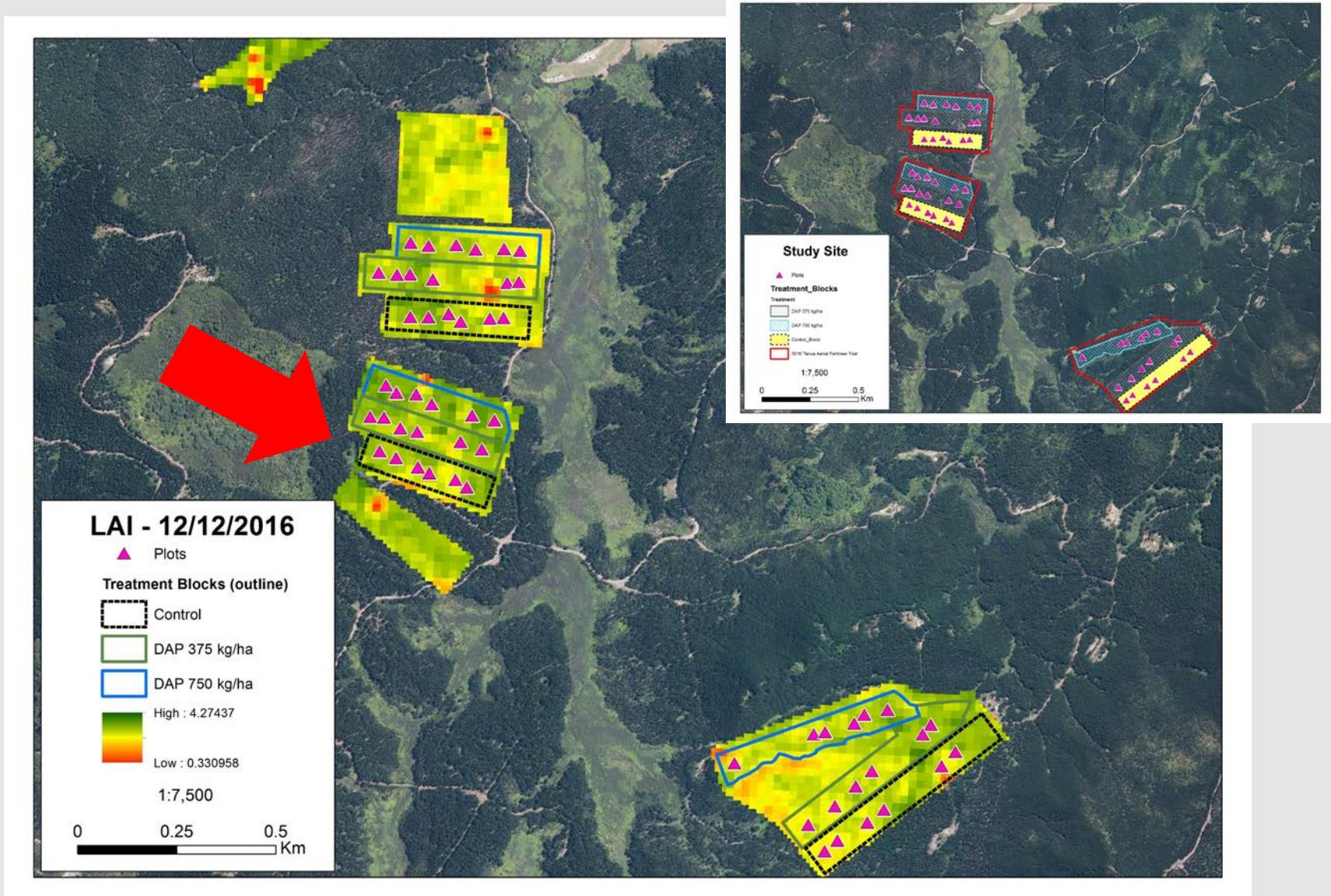
- Multivariate analysis using stepwise regression (Minitab)
  - 54 plots
  - 37 variables
    - Growth measurements (DBH, BA, Total Height, Crown Height, Crown Length)
    - Foliage (C, N, B, Ca, Cu, Fe, K, K-Mg ratio, Mg, Mn, P, Zn, Fasicle weight)
    - Soils (pH, C, N, P, B, Al, Na, Mg, P, K, Ca, Mn, Fe, Cu, Zn)
    - Terrain (Elevation, Aspect, Slope)



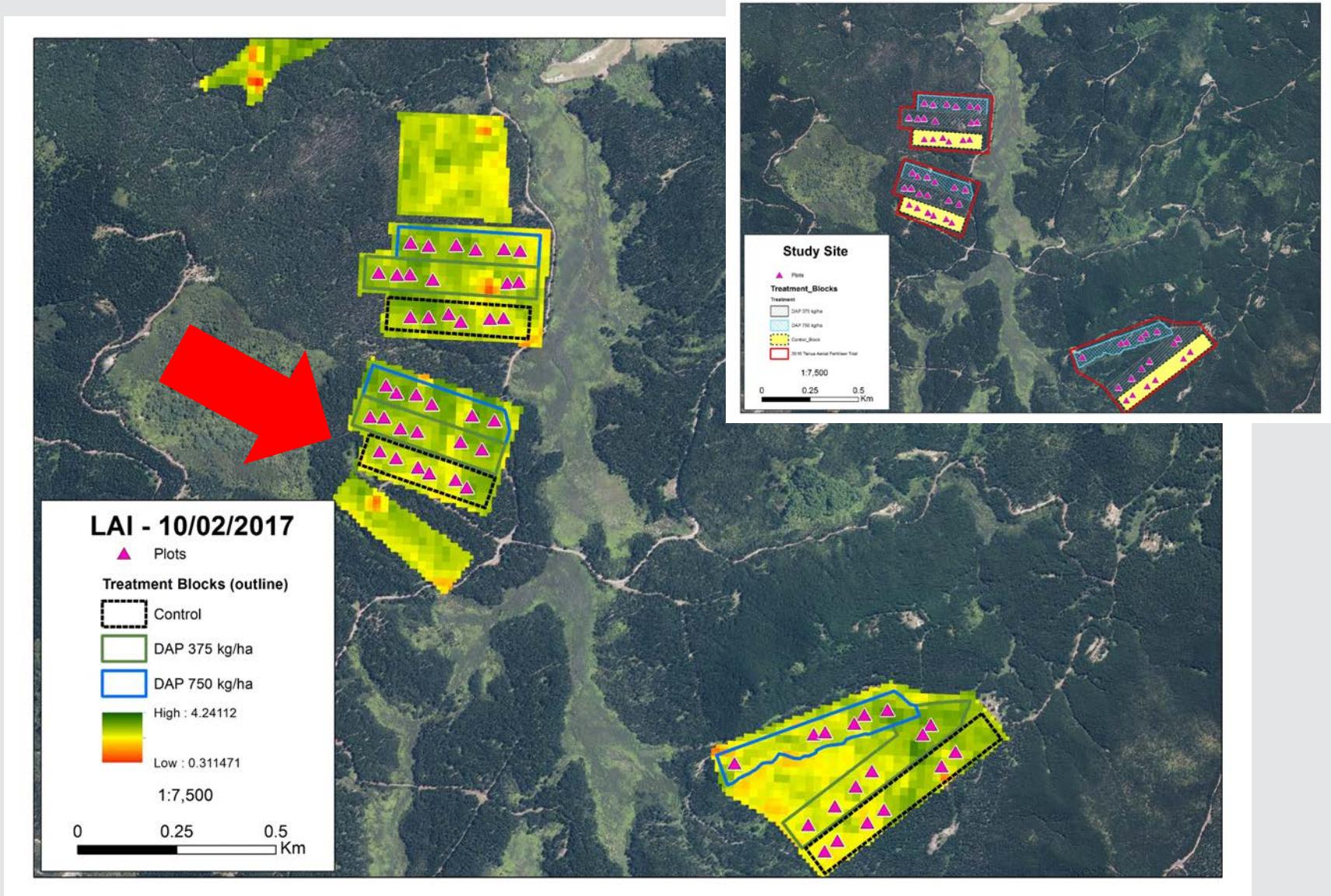


# Results Sentinel

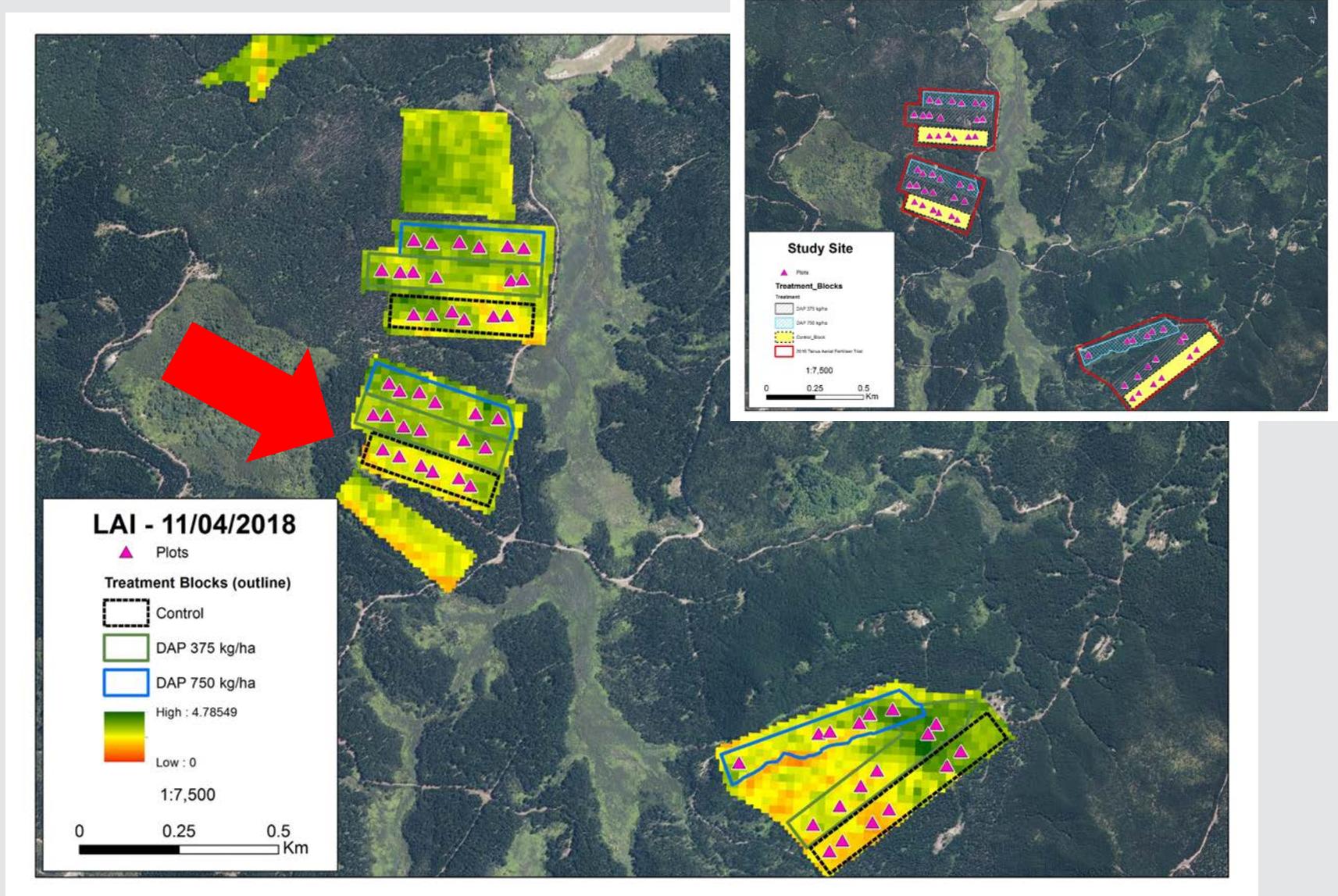
# Sentinel Results – 2016



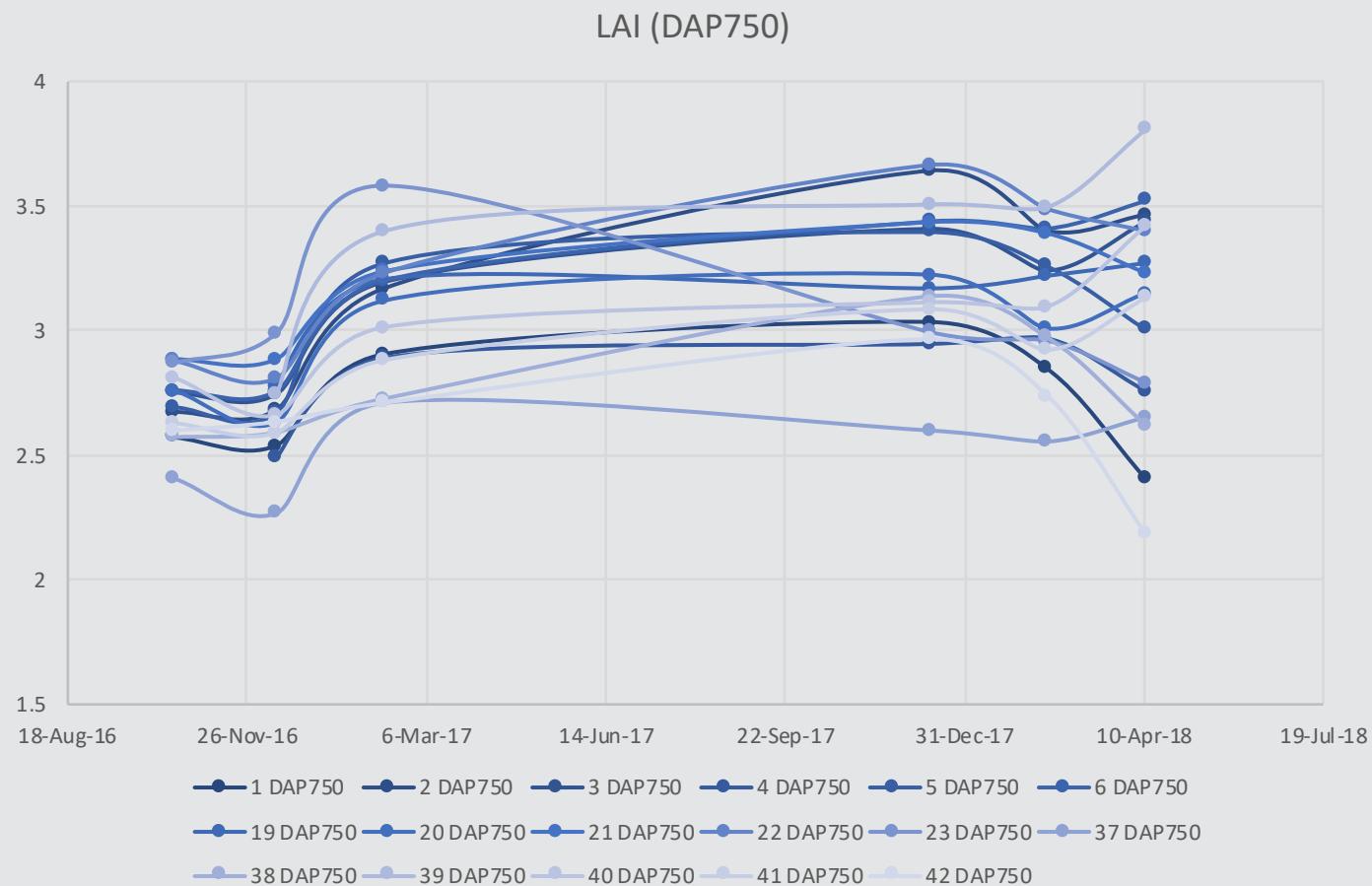
# Sentinel Results – 2017



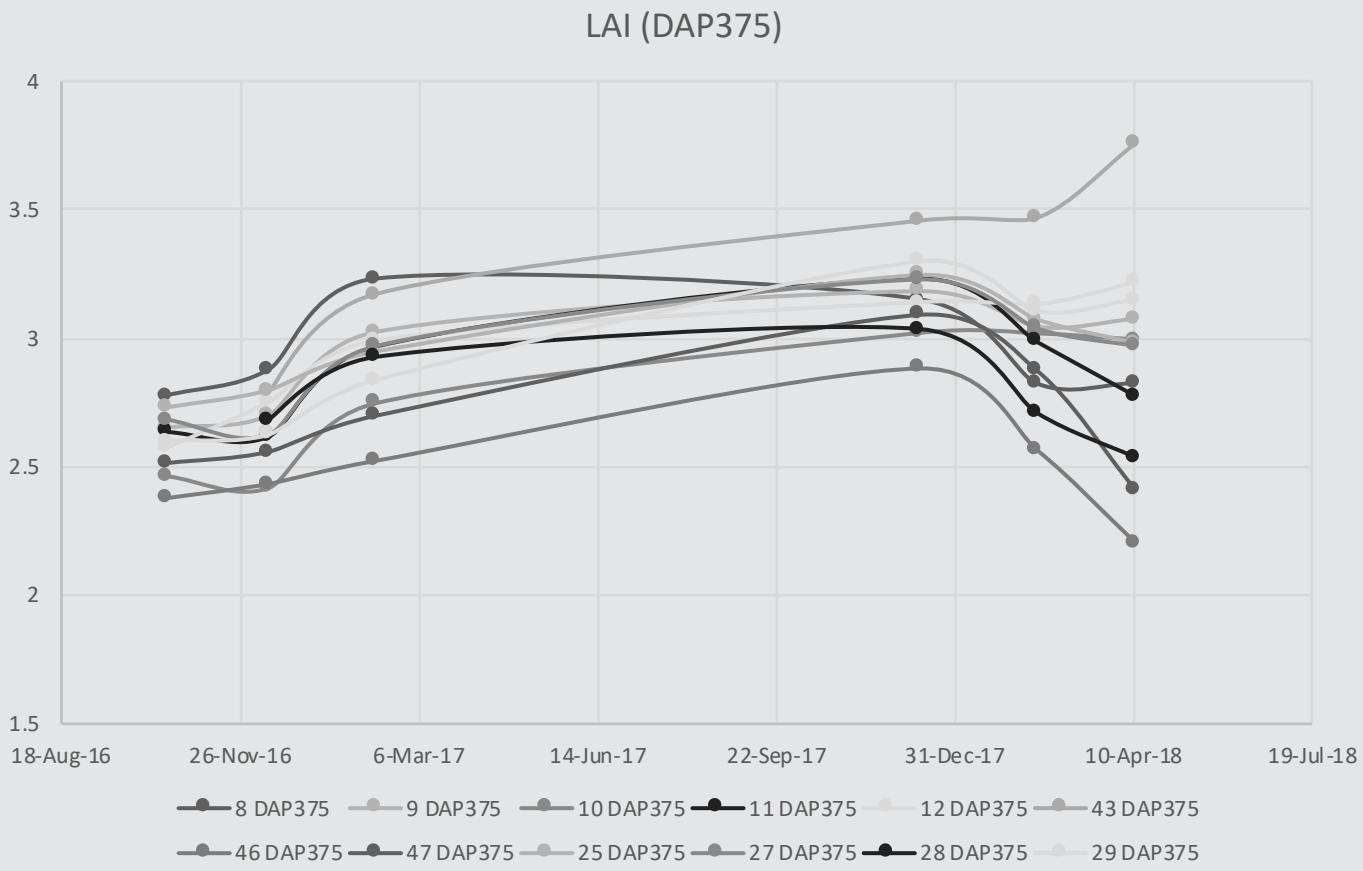
# Sentinel Results – 2018



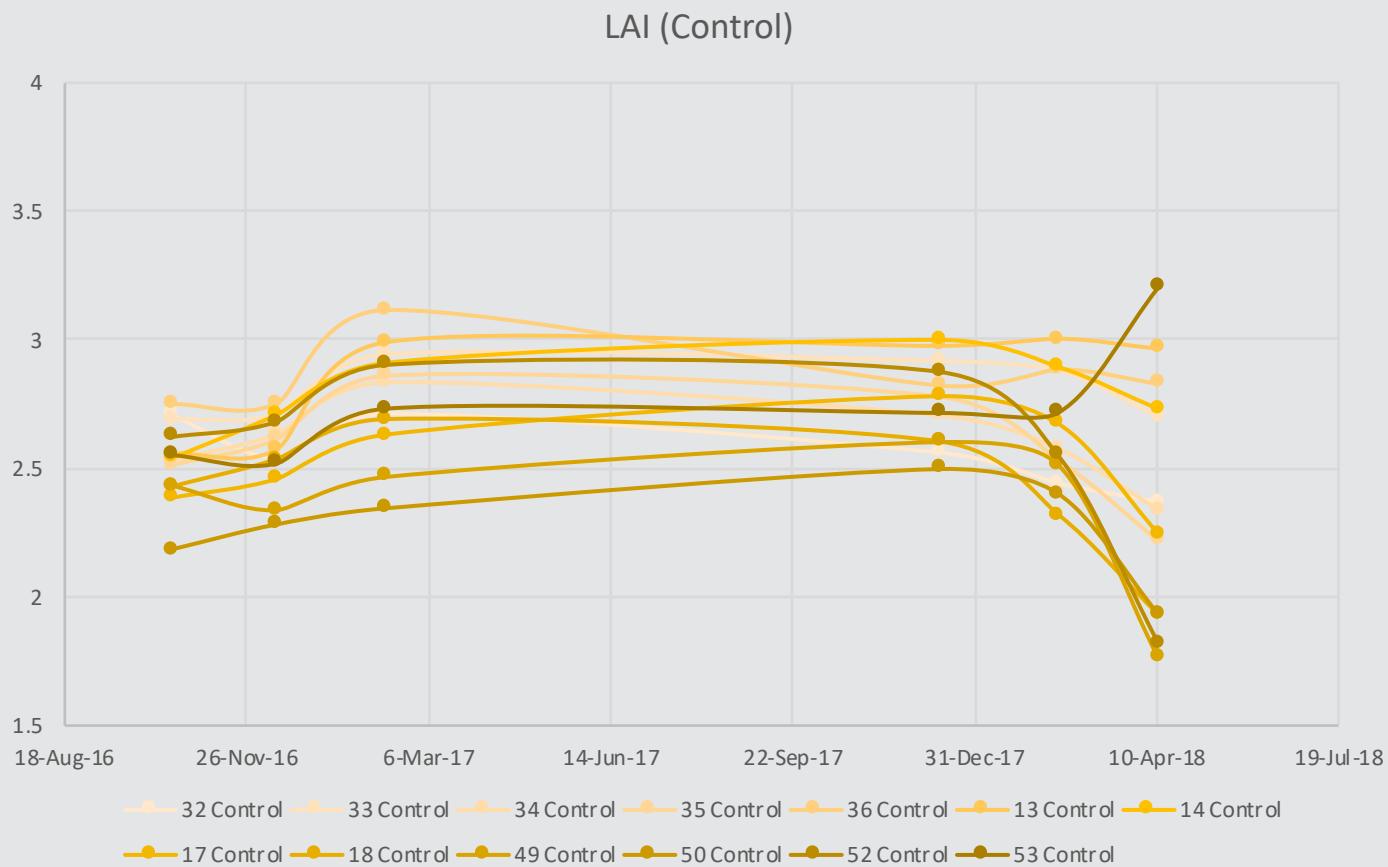
# LAI over time



# LAI over time

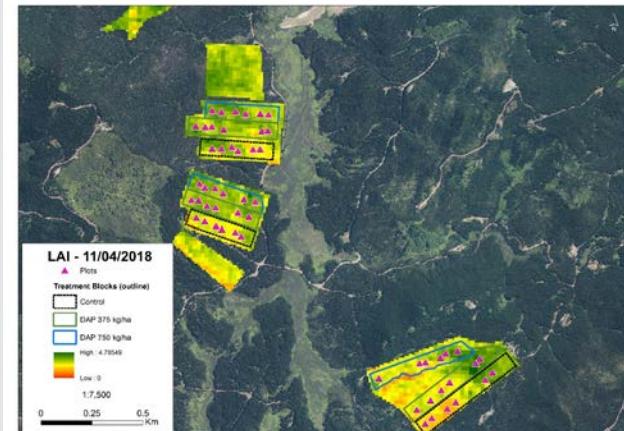
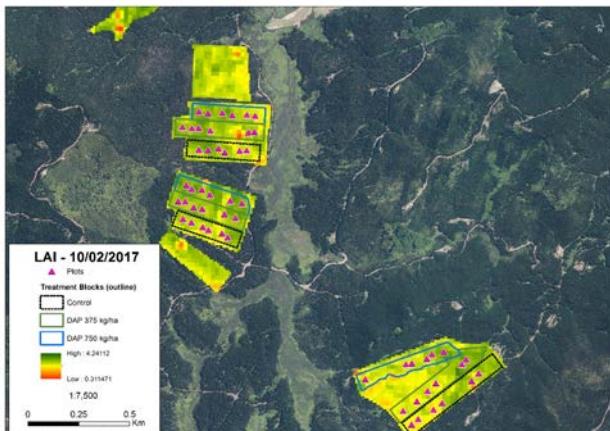
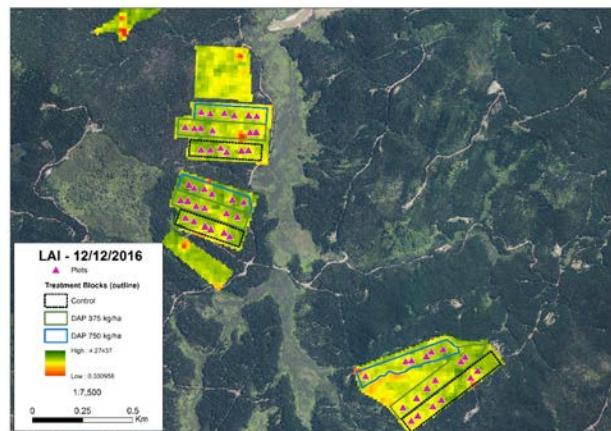
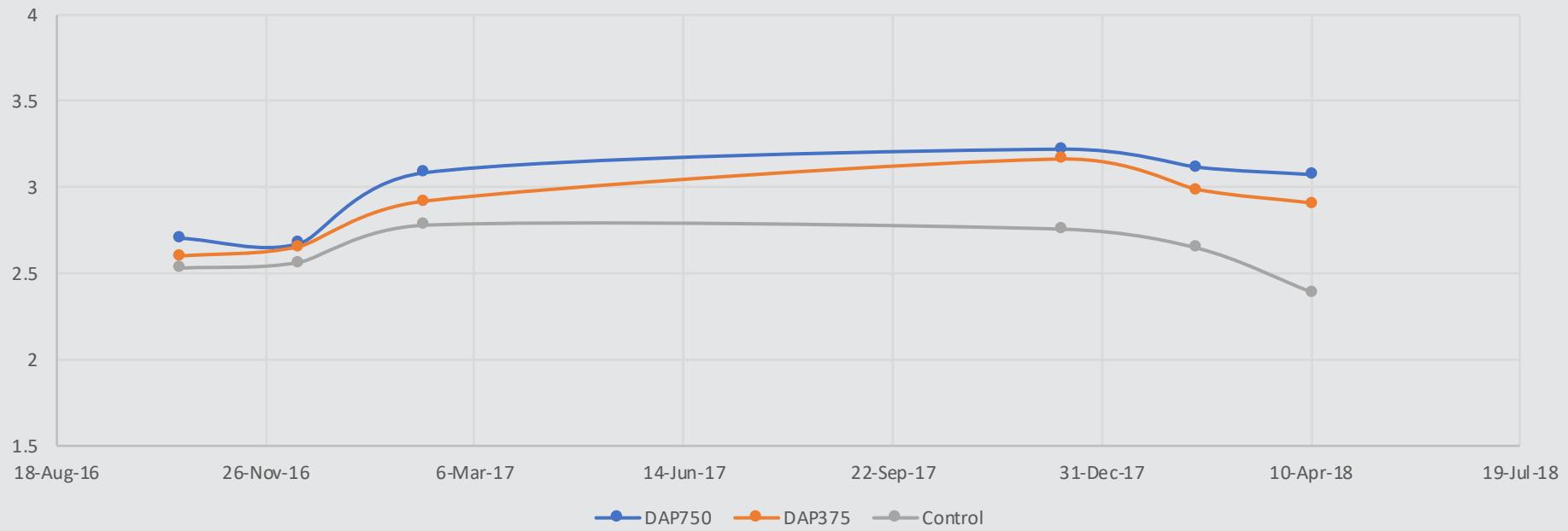


# LAI over time



# LAI over time

LAI (mean)

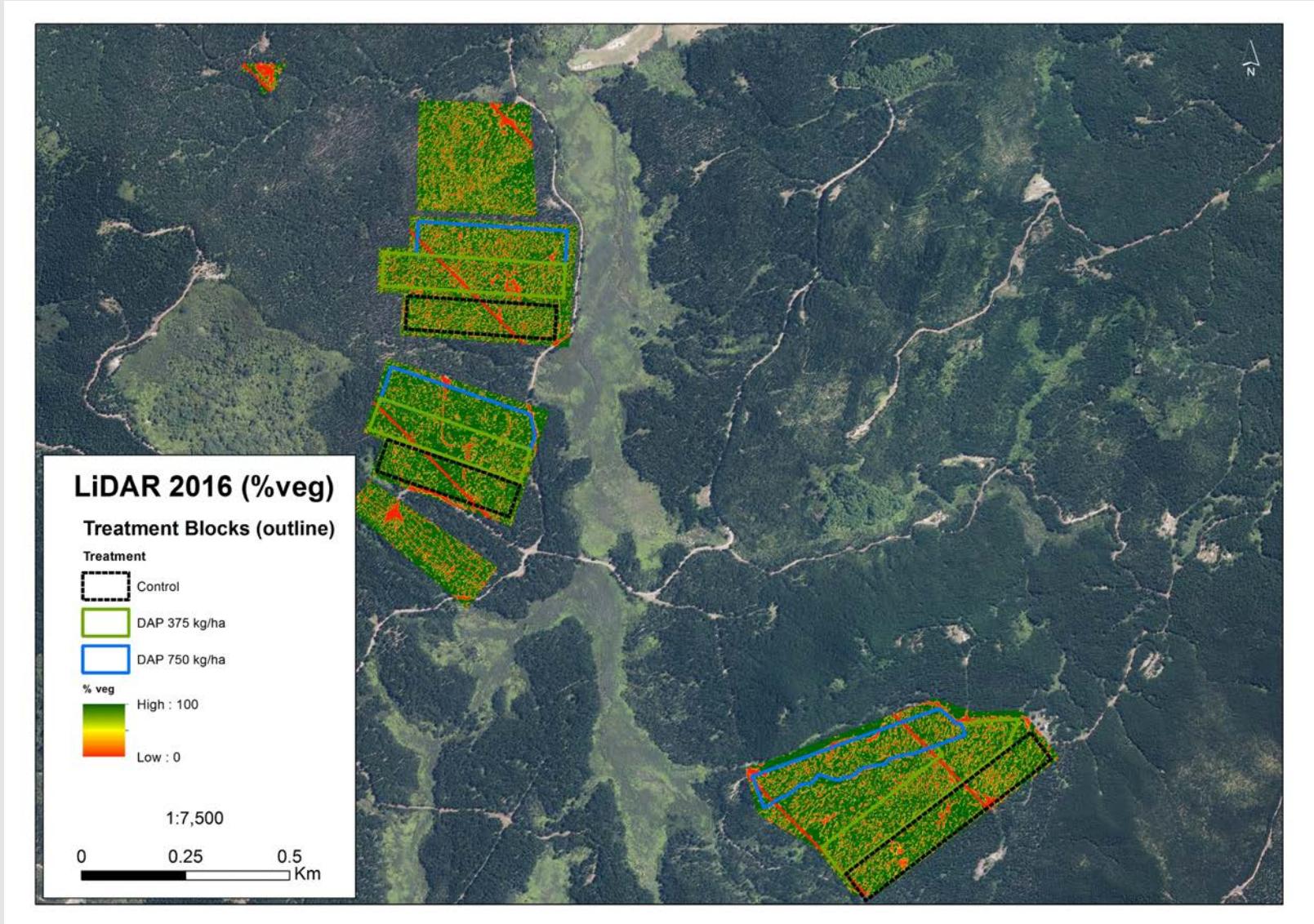




# Results LiDAR

# LiDAR Results – 2016

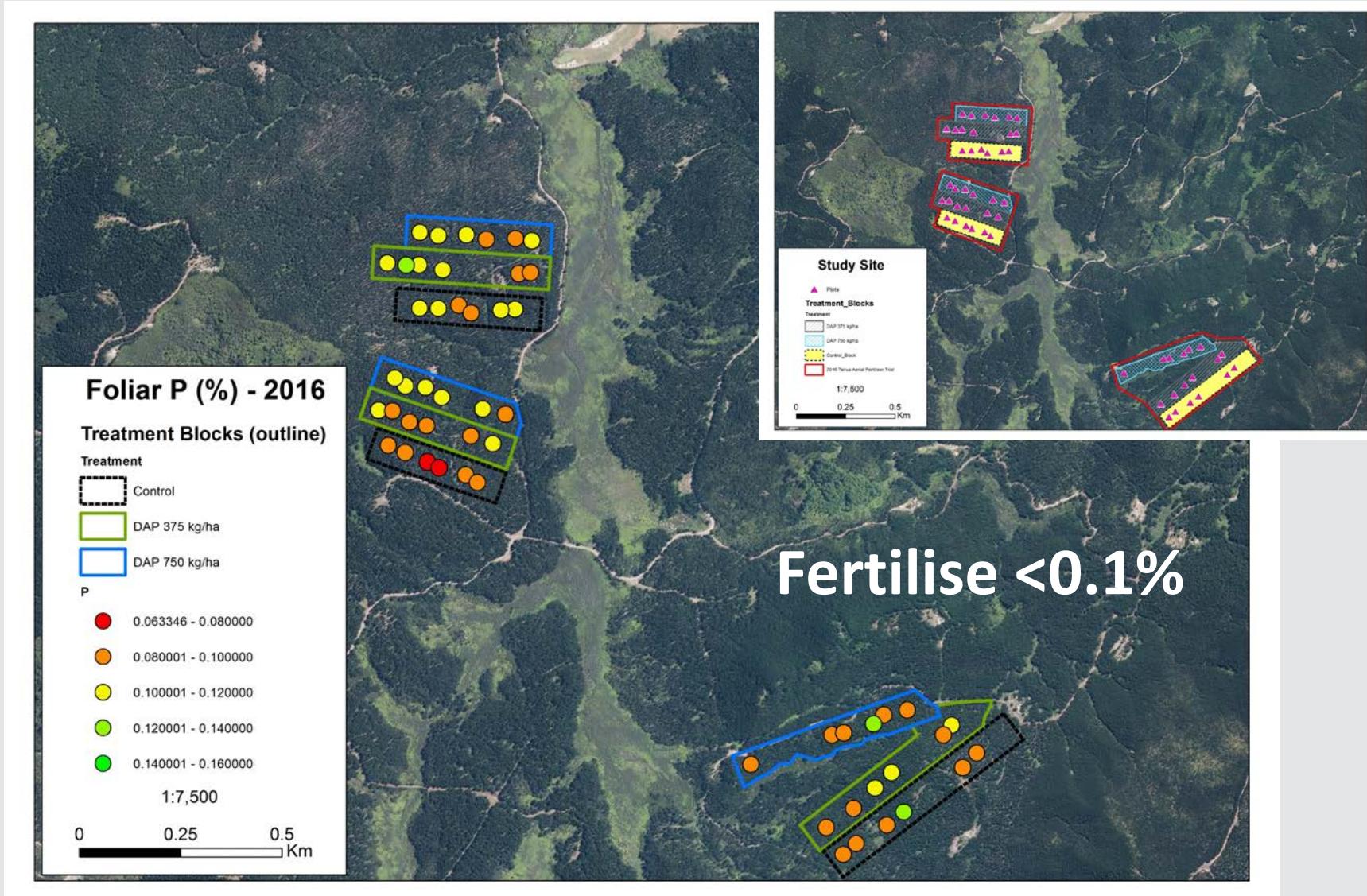
## Percentage of vegetation cover



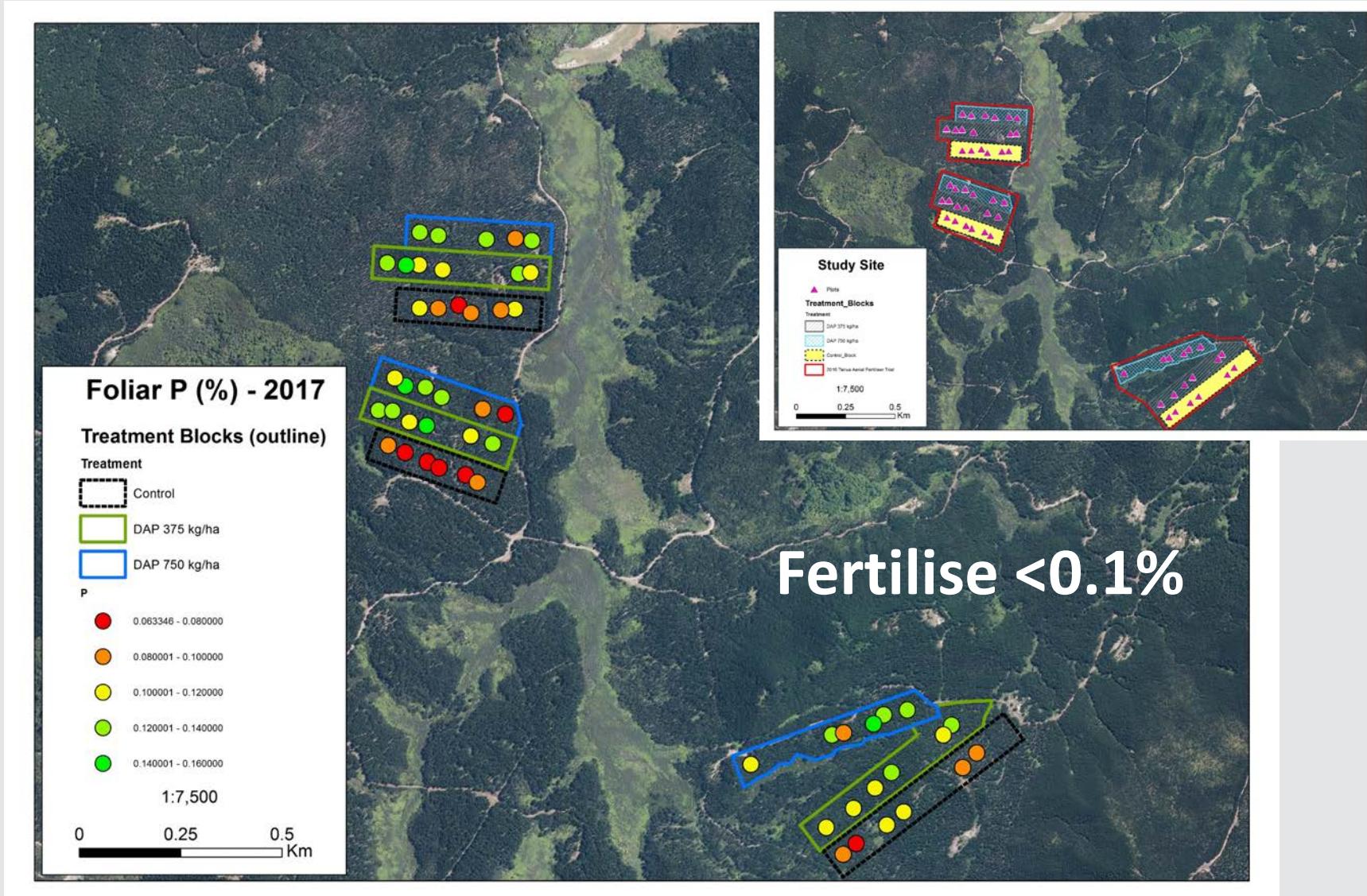


# Results Field and Lab

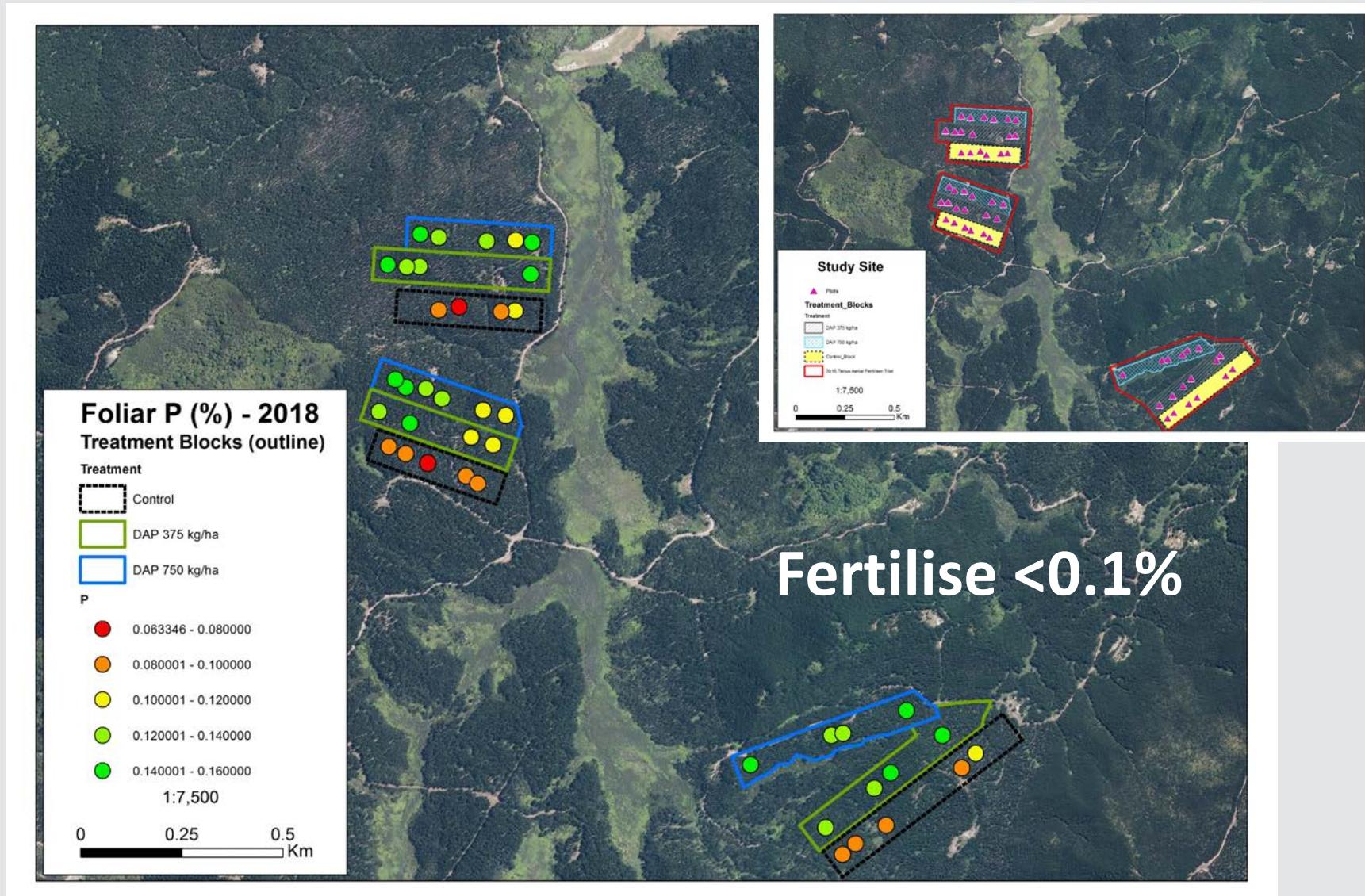
# Laboratory Results Foliar (P) - 2016



# Laboratory Results Foliar (P) - 2017



# Laboratory Results Foliar (P) - 2018



# Foliar (P) over time



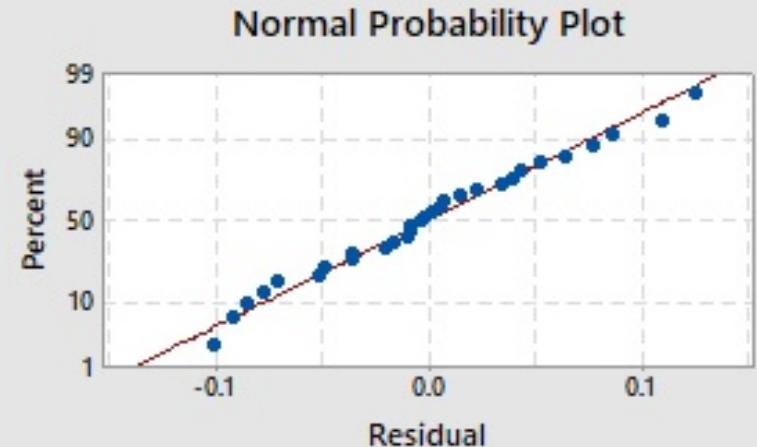


# Results Statistics

# Statistical Analysis

## LAI (Sentinel-2) vs other variables

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	10	0.45796	0.045796	8.78	0.000
DBH	1	0.08430	0.084301	16.15	0.001
C_foliage	1	0.03530	0.035303	6.76	0.018
B_foliage	1	0.01198	0.011979	2.30	0.146
K_foliage	1	0.01927	0.019269	3.69	0.070
Mg_foliage	1	0.05165	0.051651	9.90	0.005
Mn_foliage	1	0.10593	0.105926	20.30	0.000
Fasicle_Weight_foliage	1	0.03931	0.039315	7.53	0.013
Total P mg/kg_soil	1	0.02796	0.027964	5.36	0.032
Mg_soil	1	0.03804	0.038040	7.29	0.014
K_soil	1	0.17793	0.177931	34.09	0.000
Error	19	0.09916	0.005219		
Total	29	0.55712			



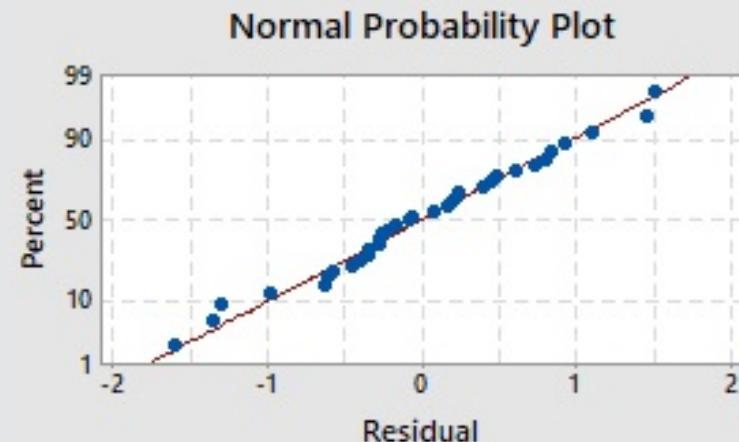
R-sq(adj)
72.83%

LAI	=	$6.20 + 0.002447 \text{ DBH} - 0.0898 \text{ C_foliage} + 0.01489 \text{ B_foliage} + 0.388 \text{ K_foliage}$ $+ 2.658 \text{ Mg_foliage} + 0.000317 \text{ Mn_foliage} - 0.0623 \text{ Fasicle_Weight_foliage}$ $- 0.001924 \text{ Total P mg/kg_soil} + 0.001818 \text{ Mg_soil} - 0.003189 \text{ K_soil}$
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# Statistical Analysis

## LiDAR (p50fp) vs other variables

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	10	109.738	10.9738	13.59	0.000
CrownHeight	1	12.514	12.5143	15.50	0.001
C_foliage	1	11.934	11.9339	14.78	0.001
N_foliage	1	12.118	12.1183	15.01	0.001
Cu_foliage	1	2.079	2.0787	2.57	0.122
Fe_foliage	1	10.830	10.8299	13.41	0.001
P_foliage	1	6.034	6.0337	7.47	0.012
Total C (%)_soil	1	19.278	19.2780	23.88	0.000
Al_soil	1	12.622	12.6223	15.63	0.001
Mg_soil	1	4.556	4.5564	5.64	0.026
P_soil	1	4.288	4.2883	5.31	0.031
Error	23	18.568	0.8073		
Total	33	128.306			



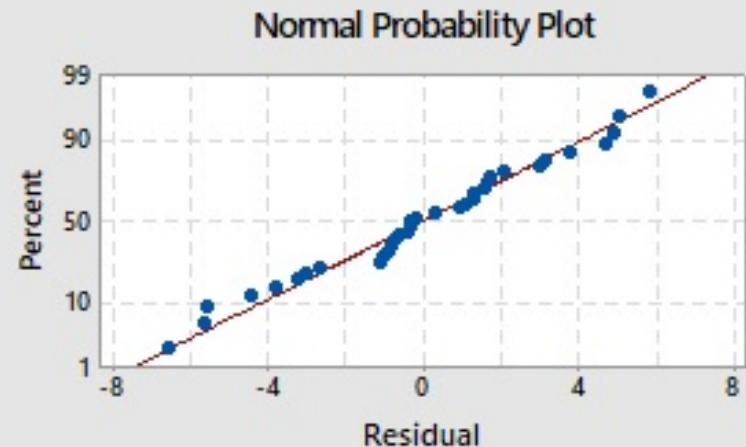
R-sq(adj)
79.24%

LiDAR (p50fp)	=	$81.6 + 0.800 \text{ CrownHeight} - 1.587 \text{ C_foliage} + 6.61 \text{ N_foliage} + 0.571 \text{ Cu_foliage} - 0.1649 \text{ Fe_foliage} - 50.9 \text{ P_foliage} - 1.374 \text{ Total C (%)_soil} + 0.002902 \text{ Al_soil} + 0.01035 \text{ Mg_soil} + 0.346 \text{ P_soil}$
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# Statistical Analysis

## LiDAR (% veg) vs other variables

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	10	2039.93	203.99	14.21	0.000
CrownHeight	1	528.14	528.14	36.78	0.000
Cu_foliage	1	292.81	292.81	20.39	0.000
Fe_foliage	1	211.15	211.15	14.71	0.001
K_foliage	1	164.18	164.18	11.43	0.003
Mn_foliage	1	134.36	134.36	9.36	0.006
Total C (%)_soil	1	47.82	47.82	3.33	0.081
Total N (%)_soil	1	102.88	102.88	7.17	0.013
Mg_soil	1	132.18	132.18	9.21	0.006
Ca_soil	1	81.82	81.82	5.70	0.026
Zn_soil	1	122.81	122.81	8.55	0.008
Error	23	330.23	14.36		
Total	33	2370.16			



R-sq(adj)
80.01%

LiDAR (% veg)	=	$105.0 - 3.665 \text{ CrownHeight} + 6.25 \text{ Cu_foliage} - 0.600 \text{ Fe_foliage} - 26.95 \text{ K_foliage} + 0.01288 \text{ Mn_foliage} - 5.77 \text{ Total C (%)_soil} + 161.5 \text{ Total N (%)_soil} + 0.1330 \text{ Mg_soil} - 0.0496 \text{ Ca_soil} - 7.54 \text{ Zn_soil}$
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# Discussion

## Discussion



- Statistical analysis shows a good relationship with LAI and field/lab data
- LAI trends over time show the potential to keep track of forest health using satellite data with some confidence
- On a broader scale, allows better forest management decisions to be made about fertilizer application type and areas where fertilizer need to be applied

# Issues

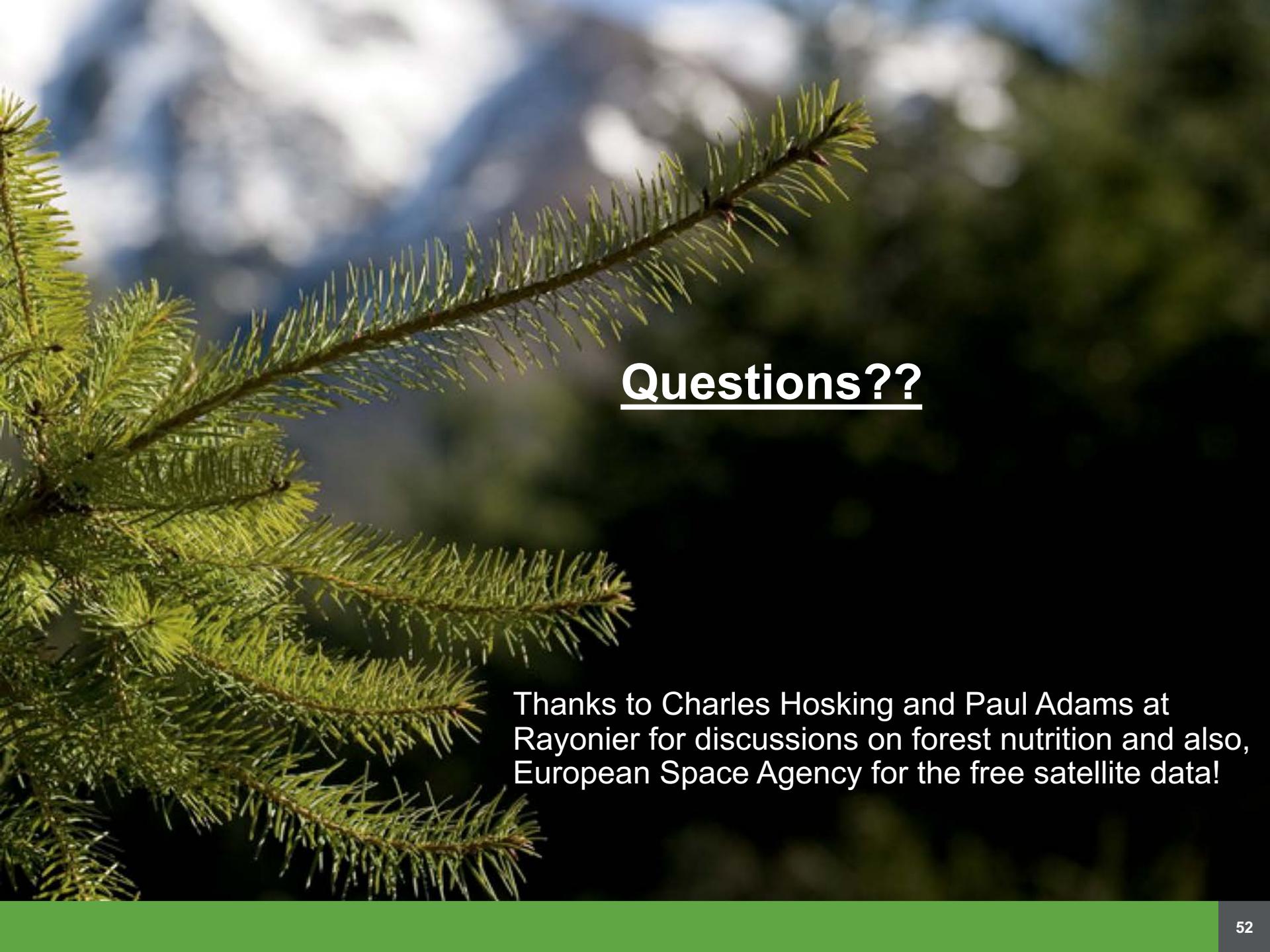


- Not a great correlation between LAI (Sentinel) vs LiDAR metrics
  - Dataset too small?
  - Too much noise in the Sentinel data.
  - Different algorithms?
- Regression analysis highlights the complexity of factors that affect forest health

# Conclusions/Further work



- Remote sensing using Sentinel-2 shows the potential to measure forest health objectively, accurately and cheaply
- Get monthly LAI from Sentinel and identify any seasonal variation
- Larger dataset



## Questions??

Thanks to Charles Hosking and Paul Adams at Rayonier for discussions on forest nutrition and also, European Space Agency for the free satellite data!