National forest owner survey and resource inventory of alternative species

Stage 2b: Mapping alternative species using remote sensing

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Executive Summary

This study provides a proof of concept of using remote sensing to classify species of small-scale plantation at a regional level and achieved high classification accuracies for most species. Douglas-fir and eucalyptus were the two most accurately classified alternative species, with over 90% of producer’s accuracy. The most important input variable selected for the classification was DEM (Digital Elevation Model), suggesting that elevation plays an important role in differentiating plantation species. The accuracy of species classification highly depends on the availability of truthing data.

In total, 2151 ha of alternative species were classified for Hawke’s Bay and a majority of them are eucalyptus, cypress and poplar. The transferability of classification derived from one region to another region is low due to regional variations in the topography, climate and species composition. In order to map the national cover of alternative species, truthing data that cover a range of species and ages classes from all regions are required. One limitation with the study is that pre-defining the geographic boundaries of alternative species is required to define the extent of classification, as the current small-scale plantation map developed by the School of Forestry may not pick up all the alternative species. Without the pre-defined boundaries, the classification approach tends to map other land covers as alternative species plantations due to a similar spectral signature.

Introduction

The Stage 1 objective of this project was to identify a suitable methodology for a NZ-wide survey and inventory of alternative species forests and their owners by undertaking a pilot study in Hawke's Bay Region. This objective was achieved, mapping the alternative species resource down to 0.1ha in the Hawke's Bay Region, and identifying a significant proportion of the forest owners via application of the LINZ cadastral layer. The work confirmed that there are significant differences between National Exotic Forest Description (NEFD) data for alternative species in Hawke's Bay and the actual forest resource on the ground.

Stage 2a objectives were to validate and extend the small-scale owners' data gathered in Stage 1 and generate information about the Hawke's Bay alternative species resource. A survey on small-scale alternative species was delivered to small-scale owners identified from Stage 1, however the response rate was very poor and the survey did not provide much information on the alternative species resource.

Stage 2b objective is for the School of Forestry to develop an automated mapping approach to classify alternative species based on input data received from small-scale owners (Stage 2a) and corporate owners. This is a potentially highly valuable approach for an accurate national inventory of NZ's alternative species resource. The work, which we believe is a 'first' in New Zealand, has merit both as novel research as well as its potential for immediate application once developed.

Stage 3 objective: the classification method developed in stage 2b on the Hawke's Bay resource will be applied nationally.

Stage 2b: Introduction

Stage 2b of this project aims to identify the spatial distribution of alternative species in Hawke's Bay using automated classification of remote sensing data such as satellite imagery. As it is impractical to describe the alternative species through surveys and ground measurements, a remote sensing approach which obtains information on resources without physically visiting the forests becomes a viable approach for resource description. Although studies using satellite imagery to perform automated forest species classification have proven to work worldwide (Fassnacht et al., 2016), this approach has not been applied in New Zealand plantation species classification mainly due to a lack of truthing data.

Truthing data with known location and species are required to perform species classification, and the data should be representative and cover a wide range of age classes and site conditions, so that the classification algorithm can learn what a forest species looks like spectrally and texturally from satellite imagery, and then classify pixels with similar features as this species accordingly. Truthing data plays an important role in the classification process. Therefore, the first step of the project is to investigate the availability of truthing data, followed by automated species classification.

Methods

Truthing data

Truthing data were intended to be collected from both small-scale owners and large-scale owners. The survey on alternative species was sent to small-scale owners identified in Stage 1. There were only three valid surveys but none was used as the location of the resources mentioned in the surveys was not identifiable. Therefore, the truthing data consists of data collected from the large-scale owners who tend to have a spatial representation of their resources.

During Stage 1 of the project in 2020, the large-scale owners in Hawke's Bay provided spatial information that covered 914 ha of alternative species (Table 1), of which 65% (598 ha) were eucalyptus species. Cypress, redwood, pine (non-radiata), poplar, larch and other species, together made up the remaining 35% (316 ha). On average, there were 52 ha represented for each species group except eucalyptus. In addition, over one-third of the resource is aged five or below (Table 2). That means they are less likely to be detected from satellite imagery as young trees are less visible spectrally.

Table 1: Species breakdown of large-scale owners' forests in Hawke's Bay

Species group	**Area (ha)**
Eucalypts	598
Poplars	47
Cypresses	74
Redwoods	57
Pines	26
Larch	23
Others	85
Total	**914**

Table 2: Age class distribution of large-scale owners' forests in Hawke's Bay

Age Class	**Area (ha)**
0-5	321
6-10	163
11-15	144
16-20	69
21-25	48
26-30	56
31-35	68
35-40	0
40+	45
Total	**914**

Given the information received from large-owners in Hawke's Bay, it is not sufficient to extract enough training data that are representative of each species group. As a result, we needed to acquire more truthing data. Further species information with accurate geospatial location and establishment year was obtained from large-scale owners throughout New Zealand.

The School of Forestry sent out requests for spatial information on alternative species to 11 large-scale owners in June/July 2021. All of them responded positively and provided GIS layers (in the form of ESRI shapefile or geodatabase) with species and establishment year. In total we received data on 32,120 ha (Table 3), over 120 individual species (belonging to 10 species groups) across NZ (Table 4). Not all data received was used in the mapping process, overlapped areas were checked and corrected, polygons that were less than 0.01 ha were removed. Some 266 ha of native species (13 different species including manuka) were excluded as they were not planted for timber use.

Table 3: Alternative species received from large-scale owners for each region

Wood Supply Region	Area (ha)
Northland	296
Central North Island	17,879
East Coast	771
Hawke's Bay	501
Southern North Island	1,020
Nelson and Marlborough	899
Canterbury	2,109
Otago and Southland	8,645
Total	**32,120**

*Table 4: Species breakdown of large-scale owners' forests received. *Native included 13 species.*

Species Group	Area (ha)
Acacia	229
Cypress	2,504
Douglas-fir	18,626
Eucalyptus	3,441
Larch	433
Pine	3,027
Redwood	2,622
Others	1,143
Native*	96
Total	**32,120**

It is challenging to develop a mapping approach for Hawke's Bay region due to limited truthing data. Central North Island (CNI) contained the most truthing data (17,879 ha) and covers a wide range of species. Therefore, the truthing data from CNI and Hawke's Bay were combined. It was then transformed to sample data for classification in the form of smaller polygons within the provided GIS stand boundaries in order to reduce classification time. The data was then randomly split into 70% training and 30% validation dataset. A summary of the size of truthing data for each target classification class is described in Table 5.

Table 5: Description of training and validation data for each species class. Each pixel represents a 10x10 m grid. Mixed species are plantation with more than one alternative species. Other exotic species include other alternative species that are not listed in the table such as cedar and willow. Radiata pine samples were manually added as place holders in the classification. Pines are pine species other than radiata pine.

Species Group	No. of Training pixels	No. of Validation pixels	Total No. of Truthing pixels
Acacia	1,770	758	2,528
Cypress	9,264	3,970	13,234
Douglas-fir	40,432	17,328	57,760
Eucalyptus	14,376	6,160	20,536
Larch	1,465	627	2,092
Mixed species	5,013	2,148	7,161
Other exotics	1,822	780	2,602
Pine	4,813	2,062	6,875
Poplar	1,356	580	1,936
Radiata	27,399	11,742	39,141
Redwood	4,792	2,053	6,845
Total	**112,502**	**48,208**	**160,710**

Remote sensing data

The classification used Sentinel-2 2020 mosaic which was processed by Manaaki Whenua - Landcare Research and distributed by the Ministry for the Environment (MfE). The image product is a 10m, ten-band multispectral, cloud-minimised mosaic of multiple Sentinel 2A and 2B satellite images over New Zealand and were captured late-2019 and early-2022 (Table 6). The mosaic went through pan-sharpening, atmospheric and bidirectional reflectance distribution function (BRDF) correction, cloud clearing and minimising process.

Table 6: Bands included in Sentinel-2 image mosaic

Sentinel-2 Bands	Wavelength (nm)
Band 1 - Blue	490
Band 2 - Green	560
Band 3 - Red	665
Band 4 - Red Edge	705
Band 5 - Red Edge	740
Band 6 - Red Edge	783
Band 7 - Near Infrared (NIR)	842
Band 8 - Narrow NIR	865
Band 9 - Short Wave Infrared (SWIR)	1610
Band 10 - SWIR	2190

The input features derived from the Sentinel-2 imagery included the ten spectral bands, 33 vegetation indices which are spectral transformation of two or more spectral bands, three phenological features derived from analysing the temporal variation of Enhanced Vegetation Index-2(EVI2) from 01/01/2019 to 31/12/2020, eight textural features which are Gray-Level Co-Occurrence Matrix (GLCM) statistics calculated using a 3 × 3 window size for the first principle band after Principle Component Analysis (PCA). In addition, a Digital Elevation Model (DEM) was retrieved to provide elevation as an input as species distribution tends to be related to elevation. All the features were extracted using remote sensing software ENVI version 5.6 (ENVI, 2021). The details of all 55 input features are shown in Appendix 1.

Species classification

Pixel-based classification with the random forest classifier was applied using the R statistical package (R Core Team, 2013). Random forest is a machine learning algorithm that has been applied widely in image classification because of its high prediction accuracy and the ability of handling high dimensional data. The classifier is an ensemble of independent individual decision trees, each tree votes on the class assigned to the given sample, and the most frequently selected class wins the vote (Breiman, 2001). Random forest classification was implemented with the training dataset using the “randomForest” package (Liaw & Wiener, 2002). Due to high dimensional input features and target species classes, a feature selection process was applied using the “VSURF” package (Genuer et al., 2015) to eliminate redundant variables and reduce computation time for classification.

The accuracy of classification was assessed by using the most common approach - confusion matrix (Congalton, 2001), which compares the classified and truth species classes based on the validation dataset. Measures such as the overall accuracy, the producer’s and user’s accuracies for individual classes were calculated. The overall accuracy indicates the proportion of pixels that were correctly classified out of all the truth pixels. The producer’s accuracy, which is related to omission error, reflects the probability of a species class being correctly classified. The user’s accuracy relates to the commission error, which represents the probability that a pixel classified into a given species actually represents that species on the ground.

Area comparison

The output classified image was clipped to the extent of the small-scale alternative species in Hawke’s Bay which was mapped at Stage 1, so that the area of each species class can be calculated within the mapped extent. The areas were then aggregated with the summary of the large-scale alternative species to provide a full area description of the alternative species in Hawke’s Bay.

Results and Discussion

Different land covers absorb, emit and reflect different wavelengths of the electromagnetic spectrum. The spectral profile which shows reflectance of each species (Figure 1) suggests generally all tree species have a similar pattern and there are more variations in the reflectance for some species than others. This indicates the differentiation of some species can be challenging for species with a similar spectral profile.

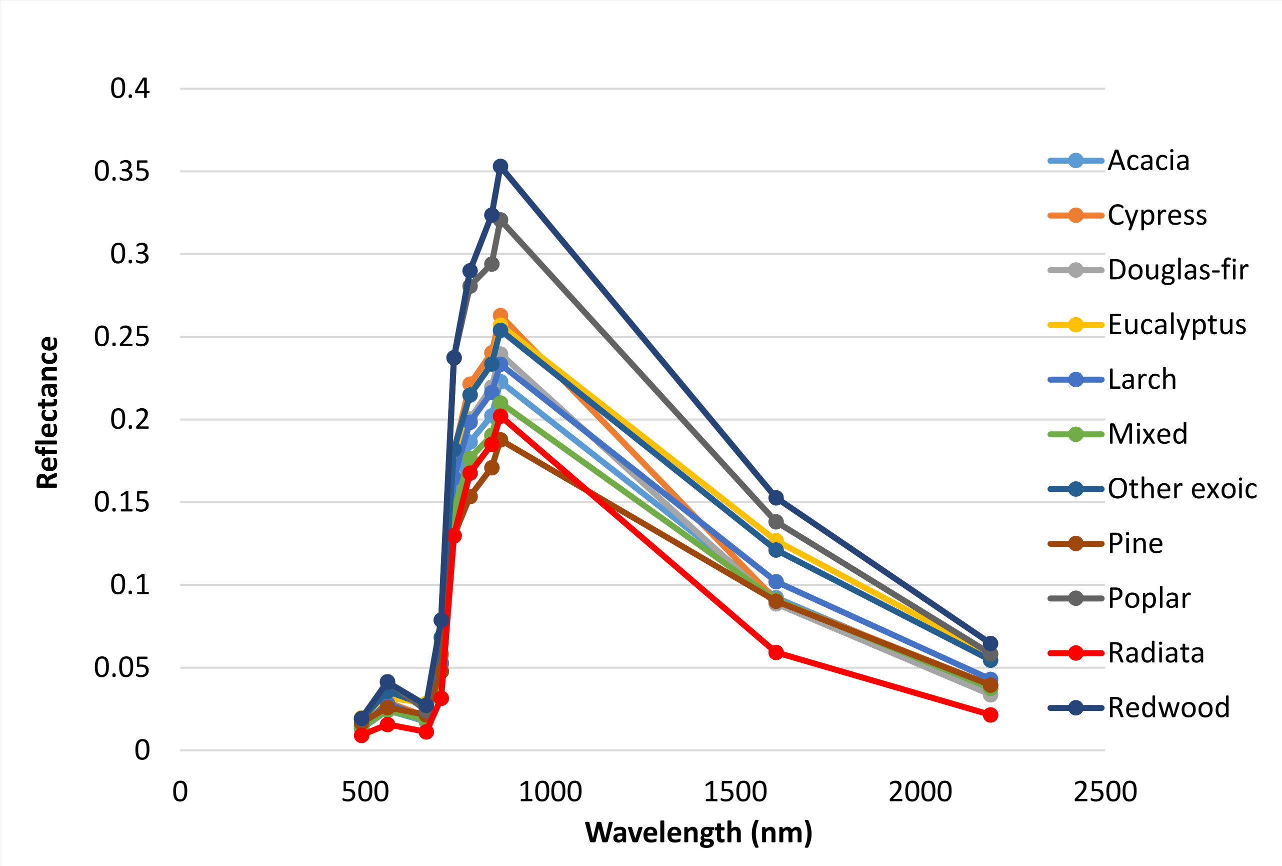

Figure 1: Spectral signature of different species on Sentinel-2 imagery

The species classification with all 55 input variables achieved an overall accuracy of 0.928 (Table 7), indicating 92.8% of the validation pixels were correctly classified. Douglas-fir and eucalyptus were the two most accurately classified alternative species, with over 90% of producer's accuracy. These two classes also contain more truthing data than other classes. On the other hand, acacia and other exotic species were the least accurately classified classes (less than 70% producer's accuracy).

All classes achieved high user's accuracies (over 85%), which means that over 85% of the pixels classified actually represent these species in the real world.

A variable selection process resulted in twelve important input variables selected for species classification (shown in Figure 2). The most important variable selected was DEM, suggesting that elevation plays an important role in differentiating plantation species. Four spectral bands mainly the Red Edge and SWIR bands were also identified as useful variables. Six out of the twelve variables were vegetation indices (NIR/RE705, TCARI, RENDVI, GI, Blue/RE705 and NIR/RE740). One phenology feature (Mean_EVI2) which is the mean value of EVI2 over two-year period was also selected. None of the textural features were selected.

The overall classification accuracy using the selected variables was the same as using all input variables (Table 8). The differences in the user's and producer's accuracies were also minimal. This indicates the redundancy of input variables when using all 55 variables. Therefore, the classification algorithm with selected variables was chosen to be applied of the whole study area, due to similar accuracy and reduced computation time.

Table 7: Confusion matrix of classification with all input features. It was produced based on 30% validation dataset. PA stands for producer's accuracy and UA stands for user's accuracy.

	Reference												
Prediction	Acacia	Cypress	Douglas-fir	Eucalyptus	Larch	Mixed species	Other exotics	Pine	Poplar	Radiata	Redwood	Total	**UA**
Acacia	438	18	11	7	1	7	7	1	0	1	1	492	**0.890**
Cypress	32	3517	32	14	34	19	26	17	1	22	51	3765	**0.934**
Douglas-fir	155	215	16892	142	69	350	105	160	29	107	161	18385	**0.919**
Eucalyptus	95	56	110	5762	16	71	33	63	18	43	54	6321	**0.912**
Larch	0	14	8	2	474	4	2	2	2	1	1	510	**0.929**
Mixed species	9	33	94	25	15	1565	31	16	16	16	15	1835	**0.853**
Other exotics	1	6	7	4	3	6	542	3	0	0	6	578	**0.938**
Pine	8	14	22	32	2	22	11	1786	1	5	11	1914	**0.933**
Poplar	0	1	1	4	4	20	1	0	506	0	2	539	**0.939**
Radiata	16	59	94	131	5	76	8	13	0	11542	32	11976	**0.964**
Redwood	4	37	57	37	4	8	14	1	7	5	1719	1893	**0.908**
Total	**758**	**3970**	**17328**	**6160**	**627**	**2148**	**780**	**2062**	**580**	**11742**	**2053**	**48208**	
PA	**0.578**	**0.886**	**0.975**	**0.935**	**0.756**	**0.729**	**0.695**	**0.866**	**0.872**	**0.983**	**0.837**		**0.928**

Table 8: Confusion matrix of classification with 12 selected variables. It was produced based on 30% validation dataset. PA stands for producer's accuracy and UA stands for user's accuracy.

	Reference												
Prediction	Acacia	Cypress	Douglas-fir	Eucalyptus	Larch	Mixed species	Other exotics	Pine	Poplar	Radiata	Redwood	Total	**UA**
Acacia	443	16	14	13	2	2	3	5	0	1	0	499	**0.888**
Cypress	22	3559	39	29	36	18	29	11	0	22	38	3803	**0.936**
Douglas-fir	176	165	16842	140	54	354	110	147	26	103	160	18277	**0.921**
Eucalyptus	81	71	113	5754	25	74	36	63	15	58	64	6354	**0.906**
Larch	0	17	10	0	478	6	2	7	2	1	3	526	**0.909**
Mixed species	12	31	87	24	18	1556	31	13	13	19	8	1812	**0.859**
Other exotics	0	4	14	3	3	8	541	1	1	1	9	585	**0.925**
Pine	10	7	19	31	3	21	10	1798	0	1	11	1911	**0.941**
Poplar	0	1	1	2	2	26	1	0	514	0	3	550	**0.935**
Radiata	12	57	130	127	3	75	5	15	0	11530	39	11993	**0.961**
Redwood	2	42	59	37	3	8	12	2	9	6	1718	1898	**0.905**
Total	**758**	**3970**	**17328**	**6160**	**627**	**2148**	**780**	**2062**	**580**	**11742**	**2053**	**48208**	
PA	**0.584**	**0.896**	**0.972**	**0.934**	**0.762**	**0.724**	**0.694**	**0.872**	**0.886**	**0.982**	**0.837**		**0.928**

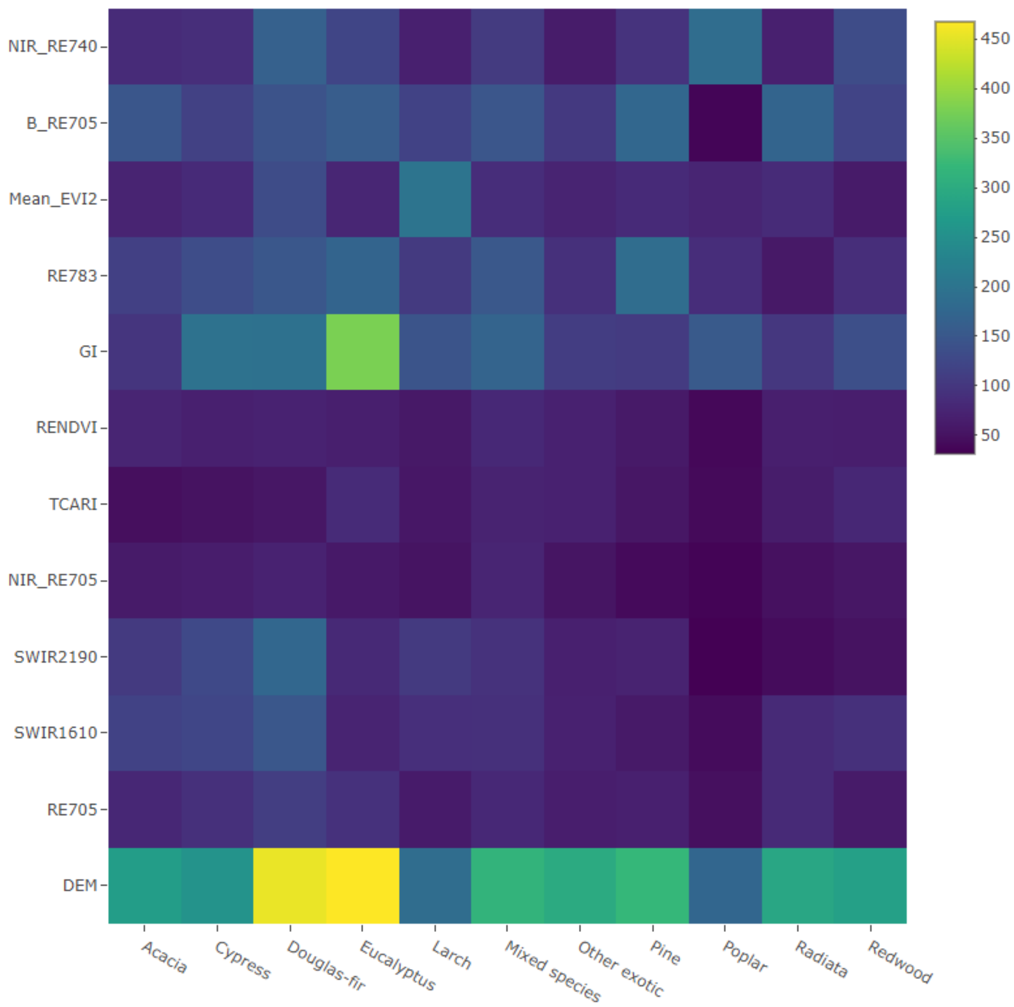

Figure 2: The importance score of the selected variables for each species class

*Table 9: Area summary of alternative species in Hawke's Bay. The small-scale areas were estimated using the classification, and the large-scale areas were from survey. *The survey to large-scale owners in stage 1 did not include Douglas-fir, the area of 187 ha of Douglas-fir was added based on the survey of all large-owners received in June/July 2021.*

Species	**Small- scale (ha)**	**Large-scale (ha)**	**Total Area (ha)**
Acacia	4	7	11
Cypress	388	74	462
Douglas-fir	154	187*	341
Eucalyptus	671	598	1270
Larch	18	23	42
Mixed species	212	19	231
Other exotics	164	23	187
Pine	13	29	42
Poplar	373	47	420
Redwood	154	57	212
Total	**2,151**	**1,066**	**3,217**

In Stage 1, there were 3792 ha of alternative species mapped using 0.3 m aerial photos which included 1747 ha of forests that were over 1 ha, 885 ha that were sized between 0.5 ha and 1 ha, and 1163 ha were less than 0.5 ha.

The classification using random forest classifier produced a raster image, which was then clipped to the extent of previously mapped alternative species. It resulted in a total area of 2151 ha of classified species (Table 9), which means 1641 ha of the previously mapped polygons did not get classified. This is likely due to the lower image resolution compared with aerial photos and the nature of raster that is formed by 10 x10 m pixels. Additionally, the clipping process could potentially result in loss of some pixels as they could not align with mapped forest boundaries, especially for very tiny ones. All forests that are over 1 ha were captured in the image classification, and 71% of the over 0.5 ha were also captured. However, some forest stands that are very small and narrow (less than 10 m wide) were not picked up by the image classification.

Table 10: The total area of alternative species compared in Hawke's Bay with NEFD 2019 area (MPI, 2020). The area estimated in this study include both large-scale and small-scale, as well as unclassified area. Other species are aggregated due to different species class definition in NEFD.

Species	Estimated in this study (ha)	NEFD Area (ha)
Douglas-fir	341	445
Cypress	462	368
Eucalypt	1,270	961
Other	1,145	1,416
Total	***3,217***	***3,190***
Small-scale unclassified area (ha)	1,641	
Total Area	**4,858**	

In Hawke's Bay, the classification suggests that most common alternative species for small owners is eucalyptus with 671 ha mapped accounting for 31% of all small-scale alternative species (Table 9), followed by cypress and poplar (18% and 17% respectively). Acacia, pine and larch are the least planted alternative species (less than 20 ha) in Hawke's Bay region. The mixed and other species together account for 17% of all small-scale plantations (376 ha), but the actual species distribution is unknown due to limited truthing information.

When summarised together with the data provided by the large-scale owners, the total area of all alternative species in Hawke's Bay can be obtained (Table 9). The total area of alternative species is 3217 ha, which is only 27 ha more than the NEFD area (Table 10). However, because the classification failed to pick up very small stands so potentially there are 1641 ha more alternative species, which brings the total area of alternative species in Hawke's Bay to 4858 ha. Therefore, NEFD underestimated the area of small-scale alternative species. At species level, apart from Douglas-fir, both cypress and eucalyptus were estimated to have more area than the NEFD area.

Limitation and Future Research

This study applied a random forest classifier to automatically classify species within pre-defined alternative species boundaries. The region of interest Hawke's Bay did not contain enough truthing data so that CNI data were also used to boost the size of the truthing data. In addition, as shown from the classification results, the larger the truthing dataset, the higher the classification accuracy. Therefore, the high classification accuracies for Hawke's Bay may be largely driven by the large amount of truthing data in CNI. A limitation of this study that there is insufficient truthing data for Hawke's Bay.

We tested the classification using the training data from CNI only and applied to Hawke's Bay, but the results were not good as there are regional variations in the topography, climate and species composition. Therefore, the transferability of classification derived from one region to another region is low. In order to map the national cover of alternative species, truthing data that cover a range of species from all regions are required.

Another limitation with the study is that pre-defining the geographic boundaries of alternative species is required to define the extent of classification, as the current small-scale plantation map developed by the School of Forestry may not pick up all the alternative species. Without the pre-defined boundaries, the classification approach tends to map other land covers as alternative species plantations due to a similar spectral signature.

Moving forward to Stage 3, random forest classification can be performed with the truthing data acquired from the large-scale owners across NZ, given that the geographic boundaries of alternative species are digitised based on high-resolution aerial photos. Specifically, we will train an operator to manually map the boundaries of all small-scale alternative species across New Zealand that are over 0.5 ha, as the classification tends to miss forests that are less than 0.5 ha. Then a random forest classification will be applied using 70% of the large-scale truthing data, and validated using the remaining 30% truthing data.

In addition, to further improve the mapping of alternative species in New Zealand, below are some potential directions:

- Collect more truthing data for alternative species, especially the data from small-scale owners.
  This may require field verification of species by either visiting the forests with a GPS or doing drone surveys of representative alternative species plantation. There is also potential to differentiate more alternative species with more truthing data.

- Use higher resolution imagery
  As very small forests stands are not picked up by Sentinel imagery, there is opportunity to perform classification using higher resolution imagery, such as Worldview, Planet Scope and even aerial photos, to classify species for very small forests.

- Identify different age classes
  This study did not differentiate different age classes due to limited truthing data. However, understanding the age-class distribution of alternative species is critical for planning for potential woodflow and processing facilities. Once there is sufficient truthing data that covers a wide range of age class, there is potential to estimate the approximate age of each mapped forest.

Conclusions

This study provides a proof of concept of using remote sensing to classify species of small-scale plantation at a regional level and achieved high classification accuracies for most species. The classification accuracy of using machine learning classifier highly depends on the availability of truthing data. In total, 2151 ha of alternative species were classified for Hawke's Bay and a majority of them are eucalyptus, cypress and poplar. The approach developed here could be applied for all regions of New Zealand given more truthing data that cover a range of species and age classes.

Appendix

Appendix 1: Input variables used in Random forest classification

Abbreviation	Name
Spectral bands	
Blue	Blue band
Green	Green band
Red	Red band
RE705	Red Edge 705 nm
RE740	Red Edge 740 nm
RE783	Red Edge 783 nm
NIR	Near Infrared nm
RE865	Red Edge 865 nm
SWIR1610	Short-wave infrared 1610 nm
SWIR2190	Short-wave infrared 2190 nm
Textural	
GLCM_Mean	Local mean of Gray-Level Co-Occurrence Matrix (GLCM)
GLCM_Variance	Local variance of GLCM
GLCM_Homogeneity	GLCM Homogeneity
GLCM_Contrast	GLCM Contrast
GLCM_Dissimilarity	GLCM Dissimilarity
GLCM_Entropy	GLCM Entropy
GLCM_2ndMoment	GLCM 2nd Moment
GLCM_Correlation	GLCM Correlation
Phenology	
Mean EVI2	The average Enhaced Vegetation Index 2 (EVI2)
EVI2 phase	The phase of EVI2
EVI2 amplitude	The amplitude of EVI2
Topography	
DEM	Resampled 10 m Digital Elevation Model
Vegetation Indices	
EVI	Enhanced Vegetation Index
GEMI	Global Environmental Monitoring Index
GARI	Green Atmospherically Resistant Index
GCI	Green Chlorophyll Index
GI	Greenness Index
GNDVI	Green Normalised Difference Vegetation Index
LAI	Leaf Area Index
MCARI_I	Modified Chlorophyll Absorption Ratio Index – Improved
MNLI	Modified Non-Linear Index
MNDWI	Modified Normalised Difference Water Index
MSR	Modified Simple Ratio
MSAVI2	Modified Soil Adjusted Vegetation Index 2
MTVI_I	Modified Triangular Vegetation Index – Improved
NDVI	Normalised Difference Vegetation Index
OSAVI	Optimized Soil Adjusted Vegetation Index
RENDVI	Red-Edge Normalised Difference Vegetation Index
REPI	Red Edge Position Index
RGRI	Red Green Ratio Index
RDVI	Renormalized Difference Vegetation Index
SAVI	Soil Adjusted Vegetation Index
SR-NR	Simple Ratio (NIR/red)
SR-BRE1	SimpleRatio_blue_RE705
SR-BRE2	SimpleRatio_blue_RE740
SR-BRE3	SimpleRatio_blue_RE783
SR-NB	SimpleRatio_NIR_blue
SR-NG	SimpleRatio_NIR_green
SR-NRE1	SimpleRatio_NIR_RE705
SR-NRE2	SimpleRatio_NIR_RE740
SR-NRE3	SimpleRatio_NIR_RE783
TCARI	Transformed Chlorophyll Absorption Reflectance Index
TVI	Triangular Vegetation Index

Abbreviation	Name
VARI	Visible Atmospherically Resistant Index
WDRVI	Wide Dynamic Range Vegetation Index

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