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The Uptake and Barriers of Geospatial Technologies in New Zealand's Plantation Forestry Sector

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Anna Manning

Forest Engineering Honours Project
Supervised by: Dr. Vega Xu, Prof. Justin Morgenroth and Dr. Ning Ye.
NZ School of Forestry, Christchurch, New Zealand

University of Canterbury

Abstract

Geospatial technologies have emerged as a powerful tool for optimising forestry management and enhancing decision-making processes. This study aims to understand which technologies have been adopted by the New Zealand forest industry and to identify any barriers to the uptake of geospatial tools. It is hoped that this will help inform the industry on how to fully capitalise on their acquired data and develop strategies to overcome any barriers identified, ultimately promoting widespread use in the industry. This study provides an update to the 2013 benchmark study and a follow-up study in 2018.

A digital survey was sent to 29 entities. The survey contained ten sections, comprised of multi-choice and open-ended questions. Topics included company demographics, data acquisition, positioning technology, remote sensing technologies, software, and Artificial Intelligence (AI). The five remote sensing technologies included in the survey were aerial photography, aerial imagery, multispectral imagery, hyperspectral imagery, and LiDAR data. Each section contained questions relating to the acquisition and application of the remote sensing technology, and the software used to process the data. When companies identified not using remote sensing data, questions were included regarding the barriers to using technologies. To identify changes in technology usage and uptake, results were compared to the 2013 and 2018 studies.

27 of 29 responded, a 93% response rate. These companies managed 1,283,000 hectares (74% of New Zealand's plantation forest estate), with estate sizes ranging from 7,000 to 200,000 hectares. Company types included forest owners and managers (23), and forest consultancies or research institutes (4). Respondents included GIS-related positions (22), foresters (4), and wood flow managers (1).

Data acquisition methods commonly used included national datasets, aerial imagery (100%), property ownership data (96%), and elevation data (89%). Land Information New Zealand (LINZ) Data Service was the primary data portal (100%). GNSS technology was universally employed, and all companies acquired aerial photography. Multispectral imagery, hyperspectral imagery and LiDAR were acquired by 67%, 4%, and 93% of entities respectively. Common applications of these technologies included cutover mapping, harvest planning, forest mapping, windthrow assessment and road planning. The main barrier preventing companies from acquiring most remotely sensed data was no perceived benefits, though lack of staff knowledge and training was the main barrier to the use of AI. With the exclusion of hyperspectral imagery, all remote sensing technology has seen an increase in uptake. LiDAR had the largest progression in uptake, increasing from 70% in 2018 to 93% in 2023.

ArcGIS is being used by 96% of companies, however, the use of free GIS software such as QGIS or GRASS has seen an increase in usage. The use of specialised software (e.g., LAStools, Agisoft Metashape) for LiDAR and photogrammetric point cloud analysis saw a notable increase, specifically LAStools.

This study showed that there has been an increase in the overall usage of geospatial technology. However, limitations are still present suggesting that the industry should focus on increasing exposure to available technology, as well as provide training on the latest technology such as AI to promote the widespread use of geospatial technologies.

Keywords: *geospatial technologies, GNSS, GPS, remote sensing, GIS, forestry, education, UAV, artificial intelligence*

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List of Tables

Table of Contents

Introduction

The New Zealand forestry industry plays a pivotal role in the country's economy. Over the last decade, it has undergone significant transformations, including the adoption of geospatial technologies to enhance the management of efficiency, productivity, and sustainability.

The rapid development of geospatial technologies over the past 50 years has made data acquisition and utilisation in forest management more cost-effective and efficient. These technologies, including GNSS, GIS, and remote sensing, have the potential to provide accurate and site-specific data for decision-making.

Key constructs in this research project involve assessing the adoption and utilisation of geospatial technologies in New Zealand's forest management sector, identifying barriers to their adoption, and understanding the progress in uptake over the past ten years.

There is an opportunity for up-to-date information on the adoption and utilisation of these technologies in New Zealand's Forest management sector, with the last study conducted five years ago (de Gouw, et al., 2018). Hence, a new survey can help promote geospatial technology usage in the sector.

Background

Various databases were used to identify relevant sources. Google Scholar was initially utilised to obtain a broad sample of articles related to geospatial technologies uptake and barriers. This initial search helped establish a list of primary sourced and peer-reviewed research articles. Subsequently, more refined search terms were employed on databases such as the University of Canterbury Library.

The selected search terms for this analysis included ‘geospatial technologies’, ‘uptake and barriers’, ‘GPS’, ‘remote sensing’, ‘GIS’, ‘New Zealand forest management’, ‘geospatial technology progression’, ‘GNSS’, ‘forestry’, ‘education’, ‘UAV’, ‘LiDAR’, and ‘Artificial Intelligence’. These terms were combined using "AND" and “OR” commands to narrow down the search results and obtain relevant articles. Additionally, the snowball method was used to locate additional articles.

The understanding and utilisation of geospatial technologies in forestry have grown significantly over time (Sonti, 2015). While aerial photography has been employed for forest management since the 1940s (Standish, 1945), the introduction and advancement of remote sensing technologies like LiDAR, photogrammetry and positioning technologies recently has revolutionised precision forestry (Bill, et al., 2022). Precision forestry involves using geospatial technologies and analytical tools to gather high-resolution data tailored to specific forest management needs (Dash, et al., 2016). These technologies have facilitated the creation of various products such as digital elevation models, canopy height models, and vegetation indices, which are invaluable for characterising forest resources and site conditions. The use of aerial videography is another tool used in forestry as UAVs become more common among companies. Applications of aerial videography include communication purposes, mapping, and monitoring controlled burns (McElwee, 2021).

Improved geospatial technologies and products have found application across diverse forestry operations. They have been instrumental in monitoring forest health (Housman, et al., 2018), planning harvesting and road construction (Picchio, et al., 2018; González, et al., 2008), and conducting forest inventory (Lechner, et al., 2020). By combining geospatial technologies with traditional ground-based methods, the accuracy and efficiency of forest descriptions, particularly for forest inventory, have improved (Pascual, et al., 2020). Geospatial technologies allow for rapid data collection over larger areas compared to time-consuming manual measurements. For instance, LiDAR data can be used to calculate individual tree heights within a forest stand without the need for manual measurements (Zörner, et al., 2018).

Remote sensing data acquisition predominantly relies on satellites and aircraft (Fu, et al., 2020). However, advancements in sensor technology and the emergence of unmanned aerial vehicles (UAVs) have brought about changes in geospatial data collection methods (Zhang & Zhu, 2023). UAVs provide forest managers with a timely, efficient and cost-effective means of collecting data for specific target areas (Guimarães, et al., 2020).

Software used within each remote sensing platform is vital to generate an accurate representation of what is being used in the New Zealand Forestry Industry. The following software is commercially available, or free, and openly sourced software used for structure from motion photogrammetry; Pix4Dmapper, Agisoft, COLMAP, RealityCapture, UASMaster, 3DF Zephyr, Maps Made Easy, DroneDeploy, ContextCapture and PhotoModeler (Lipwoni, et al., 2022).

Vegetation indices can be derived from multispectral imagery to aid in analysing vegetation properties, Normalised Difference Vegetation Index (NDVI), Burn Area Index (BAI), Enhanced Vegetation Index (EVI) and Ratio Vegetation Index (RVI) are the most used vegetation indices within the New Zealand forest industry (Scion, 2023).

Artificial Intelligence (AI), refers to the development of computer systems that can mimic human intelligence, including learning from data, problem-solving, and understanding natural language. Subfields of AI include machine learning, deep learning, computer vision, and data analytics, enabling machines to perform tasks autonomously (Döllner, 2020).

The introduction of AI to geospatial technology represents a significant advancement in the field of forest management (Shivaprakash, et al., 2022) and is expected to grow in the coming years (Chasmer, et al., 2021). AI-powered geospatial tools can enhance decision-making processes by utilising the capabilities of machine learning, deep learning, computer vision, and data analytics. By integrating AI into geospatial technology, the forestry industry can achieve enhanced precision and efficiency in various aspects of plantation management. These applications include automated forest inventory and monitoring (Scion, 2023), seedling identification (Fromm, et al., 2019), and resource allocation. AI can analyse large datasets derived from satellite imagery, drones, and ground-based sensors to provide real-time insights, enabling proactive measures to be taken in response to changing environmental conditions and forest health. As a result, the combination of AI and geospatial technology has the potential to optimise plantation forest management, improving resource utilisation, and ultimately contributing to the management of plantation forests.

There are challenges associated with the widespread use of geospatial technologies. Trained GIS specialists, also known as other spatial scientists, have been identified on the "Long term skill shortage list" and the "Skill level classification", (NZI, 2023). The combination of these two classifications can hinder the adoption of these technologies in various sectors, including forestry. Additionally, the cost of acquiring and utilising hardware and software for geospatial data processing can be a barrier for companies. The availability of publicly accessible datasets and the existence of numerous software programs, such as ESRI's ArcGIS and Google Earth, have made geospatial information more accessible and affordable. The increasing adoption of geospatial technologies in everyday forest management practices has made geospatial skills and knowledge essential for entry-level jobs in forestry companies (Bettinger & Merry, 2017). New Zealand forestry graduates are now expected to have expertise in GIS, with a significant rise in the integration of GIS components in forestry education programs (New Zealand School of Forestry, 2023).

Previous studies that have investigated the uptake of geospatial technology identified the following barriers to the use of and entry to GIS; Insufficient staff, training programs, lack of awareness of tools and benefits, and lack of initiatives/mandates (Ye, et al., 2014). Also, lack of support from managers to understand technology, a shortage of technical capacity and trained personnel, a lack of financial capacity and a limited budget and, finally, an unwillingness to change (Kim, et al., 2018). These barriers have been grouped into four categories for this report: cost, no perceived benefits, current staff lack of knowledge or training, and unawareness of the specified technology.

Understanding the uptake, barriers and application of geospatial technologies in New Zealand's forest management sector holds significant importance. It enables companies to optimise data utilisation and identify barriers, helping them develop strategies to overcome these obstacles. This can lead to time and cost savings while providing new insights for decision-making. By shedding light on the current state of geospatial technology uptake, this study contributes to enhancing forest management practices in New Zealand.

This study addresses three main research questions:

- Identifying current geospatial technologies employed in New Zealand's forest management sector.
- Identifying barriers hindering the adoption of geospatial technologies.
- Determining progress in the uptake of geospatial technologies over the past ten years.

Methodology

An online survey was developed and distributed to New Zealand forestry entities using Google Forms. This ensured that participants throughout the country could conveniently and promptly receive and complete the survey. The online survey was designed to ensure no respondents needed a Gmail account to complete it.

The survey was distributed to individuals within each forest entity. The initial list included companies identified in the Forest Owners Association (FOA) New Zealand plantation forest industry facts and figures publication (NZ FOA, 2022), that manage over 10,000 hectares. Additionally, other forestry entities not included in this list were also considered. This approach ensured representation from companies managing a significant portion of New Zealand's plantation forest estate.

All companies were contacted before the survey was distributed to identify the best person within the company to complete the survey. The ideal respondent within each company was a GIS specialist who was using the technology on a day-to-day basis. This was to ensure all questions were understood to allow for accurate representation of the company.

Once the survey had been distributed, a 3-week period was given for respondents to complete the survey. A follow-up email was sent to non-respondents to encourage a higher response rate. All contact with individuals was tailored to the specific person to ensure a positive view of the study.

The survey questions were developed based on the previous study conducted by Morgenroth & De Gouw (2018), with necessary updates to reflect changes in available geospatial technologies. The survey consisted of ten sections covering the following topics:

1. Respondent and company profile

2. Data acquisition
3. Positioning technology
4. Aerial photography
5. Aerial videography
6. Multispectral imagery
7. Hyperspectral imagery
8. LiDAR
9. Software application
10. Artificial Intelligence

Due to the detailed nature of the survey, and an estimated time of 30 minutes to complete the survey, an effort was made to provide multichoice questions, where expected answers had been generalised and provided for the respondent to select. Multiple-choice questions were accompanied by open-ended questions to allow respondents to provide additional details. Respondents also had the option to add answers not provided in the choices through an "other" option. Most questions were compulsory to ensure comprehensive responses.

The survey included conditional questions to tailor the survey flow based on respondents' previous answers. For example, if a company indicated the use of a particular remote sensing technology, subsequent questions would inquire about the data acquisition methods and the application of acquired products in forest management. If a company did not use a specific technology, follow up questions explored the reasons or barriers preventing its adoption.

The final section of the survey, software application, included a table with each software used on the left column and the different types of remote sensing on the top row. Respondents had the option to select which software was used for each remote sensing application, providing an overview of software used within the industry. The layout for this question allowed respondents to complete the survey efficiently, as well as ensure there were no repetitive questions for each remote sensing section as the software used for each application is similar.

To ensure the relevance and comprehensibility of the survey, a draft survey was administered to two industry experts, incorporating their feedback to make necessary revisions and additions. The final survey was then distributed to the selected forest entities, and responses were recorded and analysed using descriptive statistics. Open-ended responses were categorised to identify trends and patterns.

Each technology had a definition associated with it to minimise confusion. **Table 1** shows the definition for each technology.

Table 1: Geospatial technology definitions.

Technology	Definition
Positioning technology	Positioning technology is the use of a global navigation satellite system (GNSS) to provide positioning, navigation, and timing data, this includes GPS, Galileo, GLONASS and BeiDou.
Aerial photography	Aerial photography consists of three bands (red, green, blue) and is acquired from an aerial platform (e.g. plane, UAV).
Aerial videography	Aerial videography refers to motion pictures which consists of three bands (red, green, blue) and is acquired from an aerial platform (e.g. plane, UAV).
Multispectral imagery	Multispectral imagery typically consists of four or more bands (red, green, blue, infrared, etc) and is commonly acquired from an aeroplane, UAV, or satellite.
Hyperspectral imagery	Hyperspectral imagery typically contains hundreds of bands spanning the visible and infrared wavelengths. Hyperspectral imagery is acquired from an aerial or satellite platform.
LiDAR	LiDAR is an active remote sensing technique that stands for Light Detection and Ranging, it is also known as laser scanning.
Artificial Intelligence	Artificial Intelligence (AI) is a technology that enables computers to perform tasks with human-like intelligence, such as analysing data, making decisions, and solving problems. It can include methods such as machine learning and deep learning.

Descriptive statistics was used to analyse the current usage of geospatial technology and barriers associated with these technologies. Opened ended questions were grouped based on similarity to allow for trends to be identified. To determine the uptake and progression of the geospatial technologies, the survey results were compared to the findings of the previous study by de Gouw, et al. (2018) and Morgenroth & Visser (2013).

While this study covered a large range of geospatial technologies and aimed to provide an overview of the current technologies, there were some limitations. Firstly, the study focussed solely on large-scale owners (>10,000ha) and therefore the results are a representation of this. Additionally, the survey results could be influenced by the person filling out the survey. To counter this, caution was used when approaching company's to ensure the best person was identified to answer the survey. This was done by explaining what the survey entailed and the level of knowledge required.

Results and Discussion

Demographic information

Twenty-nine companies were contacted, and 27 of them completed the survey, resulting in a 93% response rate. The total area managed by the respondent companies was approximately 1,283,000 hectares (ha), which accounted for 74% of New Zealand's 1.73 million ha plantation forest estate. The size of the estates managed by individual companies ranged from 7,000 ha to 200,000 ha.

In terms of company types, 85% (n=23) were identified as forest owners and/or managers and 15% (n=4) were forest consultants or research institutes. The intended recipient of the survey was each company's geospatial manager; however, companies that did not have an appointed geospatial manager had the most appropriate staff member respond to the survey. Among the respondents, most of them were in GIS-related positions, except 15% were foresters and 4% were wood flow managers.

Data Acquisition

Data acquisition from publicly available data portals was used by all entities to support forest management. These portals and the percentage of usage can be found in **Table 2**. Aerial imagery was the most used product, with 100% of respondents employing it, followed by property ownership and boundaries (96%) and elevation data such as Digital Elevation Models (DEMs) (89%). Other derived datasets, including Land Cover Database (LCDB) (78%), hydrological features (67%), topographic maps (63%), roads and addresses (59%), the National Environmental Standards for Plantation Forestry (NES-PF) Erosion Susceptibility Classification (59%), and the digital soil map (S-MAP) (56%) were accessed by over 50% of respondents. Other datasets and online data portals were used by forestry companies but had lower uptake.

Table 2: Online data portal usage by companies.

Portal	Usage (%)	Link
LINZ	100	https://data.linz.govt.nz/data/
Koordinates	81	https://koordinates.com/data/
Council	81	NA
MPI	59	https://data-mpi.opendata.arcgis.com/
LRIS	56	https://lris.scinfo.org.nz/
MfE	56	https://data.mfe.govt.nz/data/
NIWA	30	https://data-niwa.opendata.arcgis.com/explore
Stats NZ	15	https://datafinder.stats.govt.nz/

Positioning Technology

Every company used Global Navigation Satellite System (GNSS) technology, and 70% of the companies used two or more types of receivers. Consumer-grade receivers built into devices (e.g., iPhone) were the most widely used (81%), followed by consumer-grade handheld receivers (e.g., Garmin GPSMAP 62s) (70%). Survey grade receivers were used by 37% of companies, and 26% used mapping grade receivers. Two companies (8%) used Satellite Based Augmentation Systems (e.g., SouthPAN) to improve the precision and accuracy of their GNSS receivers.

The primary applications of GNSS receivers included stand/forest mapping (48%), field navigation (44%), ground control points (30%) and hazard identification (15%). Forest inventory, road mapping, and cutover mapping were all used by 11% of companies. Less common applications included operational planning, historic or cultural site identification and species identification.

Aerial photography

Aerial photography was the most used form of remotely sensed data, with every company indicating they acquired aerial photography. Unmanned Aerial Vehicles (UAV) were the most used platform to acquire aerial photography (93%), followed by aeroplane acquisition (63%). Eleven percent of companies acquired imagery via helicopter, and one company used Google Earth, which is a combination of aerial photography and satellite imagery. Ninety-six percent of companies derived true-colour orthophotos, and 48% of companies derived photogrammetric point clouds. The most used products from photogrammetric point clouds were DEMs and stem counts.

Factors that determined the frequency of aerial photography acquisition were generally operation specific. This included to coinciding with activities like pre- and post-harvest, post-planting, and cutover mapping. Companies also acquired estate-wide aerial imagery at intervals varying from monthly to every 3 years, depending on the method of collection and estate size. Some forest management companies indicated that aerial imagery via UAVs was captured as frequently as every month to provide regular updates to forest owners.

The spatial resolution of aerial photography varied depending on the acquisition method and the intended application. Fifty-six percent of companies acquired aerial photography at two or more different levels of resolutions. UAVs offered spatial resolutions ranging from 0.02 m to 0.5 m, while imagery acquired from aeroplanes ranged from 0.1 m to 0.5 m. However, some companies did not disclose the spatial resolution of each collection method separately, and these spatial resolutions ranged from 0.02 m to 10 m. Some companies indicated that larger spatial resolutions were application dependant, therefore did not need higher resolution images, such as cutover mapping.

However, some companies indicated only using spatial resolutions of 2 m or larger, which in these cases may indicate errors in responses, as aerial photography acquired by UAVs and aeroplanes typically has a higher spatial resolution than 2 m.

Aerial Videography

Fifty-six percent of companies that responded to the survey acquired aerial videography. The main barrier to not using aerial videography was no perceived benefit (83%), and the current staff's lack of knowledge or training (42%). Cost (17%) and ignorance of aerial videography (17%) were also companies' barriers. For respondents who used aerial videography, they all acquired via UAVs (100%), and 20% also used helicopters to acquire aerial videography. Companies only acquired aerial videography as required, with the most common factors influencing this being environmental impact assessments such as assessing effects of windthrow.

Multispectral imagery

Multispectral imagery was acquired by 67% of forestry companies. The three main reasons for not using multispectral imagery included no perceived benefits, current lack of staff knowledge or training, and cost. Three companies indicated they may use multispectral imagery in the future.

Multispectral imagery was mostly acquired from satellite platforms (89%), followed by aeroplanes (44%), and UAVs (22%). The most common satellite sensors used by companies included Sentinel (87%), PlanetScope (53%), and Landsat (33%). Other sensors, including Worldview and RapidEye, were less commonly used. Low usage of RapidEye was expected as it has not been operating since 2020, however, the usage by a small number of companies suggests an interest in historic imaging.

Companies derived various products from multispectral imagery, including true colour composites, false colour composites, and vegetation indices. The main vegetation index used by companies was the Normalised Difference Vegetation Index (NDVI).

The spatial resolutions of the multispectral imagery differed depending on the platform used for data acquisition. The spatial resolution acquired using a UAV was 5 to 10 cm, aeroplane-acquired multispectral imagery had spatial resolutions ranging from 0.05 to 3 m, and satellite-acquired multispectral imagery ranged from 0.5 to 60 m.

Hyperspectral imagery

Only one company that responded to the survey acquired hyperspectral imagery. The barriers to not using hyperspectral imagery included no perceived benefits (73%), current staff lack of knowledge or training (42%), cost (38%), and ignorance of hyperspectral imagery (8%). Two companies indicated that they might consider using the imagery in the future. Hyperspectral imagery was collected on an as-needed basis, acquired using UAVs or satellites. The spatial resolution of hyperspectral imagery was 30 cm or less.

LiDAR data

LiDAR data, aerial and terrestrial, was used by 93% of entities. The companies not using LiDAR managed fewer than 10,000 ha and did not acquire LiDAR data due to barriers including no perceived benefits (50%), cost (50%), and current staff lack of knowledge or training to use LiDAR data (50%). All companies managing 10,000 ha or more acquired LiDAR data.

When considering the acquisition and application of LiDAR data, there were notable differences between research institutes and consultancies, and forest management companies. Therefore, the following data analysis for LiDAR data will be split into two categories: forest management companies and research institutes/consultancies.

Forestry management companies responded that aeroplanes (67%) and open data portals (57%) were the most common platforms to acquire LiDAR data, followed by UAVs (29%) and satellites (10%). The density of the LiDAR point clouds acquired by forestry companies ranged from 1 to 25 points per m^2. Five companies acquired LiDAR data with a point cloud density of 4 points per m^2 or less. For companies that acquired their own LiDAR data, six companies collected data for their entire forest estates once, with two of them continuing to collect LiDAR data on a regular cycle, ranging between three to five years. Other companies acquired LiDAR data as needed, influenced by factors like budget constraints, inventory requirements, and harvest planning.

Three companies were unaware of the point cloud density, and another ten companies indicated varying point cloud densities, or only reported minimum point cloud densities. Companies acquiring UAV LiDAR should have point cloud densities over 100 points per m^2.

Regarding LiDAR data processing, 76% of companies engaged a third-party organisation with the remaining 24% of companies processing the raw point cloud data in-house. The main processing method employed by companies was generating surfaces (80%), with less common methods such as filtering and cleaning point clouds undertaken by one-third or fewer companies.

On the other hand, research institutes and consultants (n=4) used open data portals (100%), UAVs (50%), aeroplanes (50%), static terrestrial platforms (50%), and mobile terrestrial platforms (50%) to acquire LiDAR data. Twenty five percent of research institutes used helicopters, satellites, and vehicular platforms. The point density of LiDAR data collected by research institutes ranged from 100-30,000 points/m^2. Research institutes collected LiDAR data as needed, influenced by research programs being undertaken, with examples including thinning operations, survival analysis, and yield modelling. The use of terrestrial platforms by research companies and consultants explains why point clouds have a significantly larger density than forest management companies.

Application of remotely sensed imagery

The most common applications of aerial imagery were cutover mapping, stand and forest mapping, and windthrow assessment (**Table 3**). Multispectral imagery was used mostly for cutover and forest stand mapping. LiDAR data was used primarily for harvesting planning and road mapping. Hyperspectral imagery had the lowest application rate, only being used for cutover mapping, forest health assessments, harvest planning, and species identification.

Table 3: Application of remote sensing imagery to forest management with the top five applications in bold.

	Aerial Photography	Multispectral Imagery	Hyperspectral Imagery	LiDAR Data
Application	n	n	n	n
Cutover Mapping	**27**	**13**	0	6
Harvest Planning	**27**	**13**	0	6
Stand/Forest Mapping	**26**	**13**	0	**12**
Windthrow Assessment	**26**	**8**	0	6
Road Mapping	**22**	3	0	**15**
Site Preparation	21	2	0	9
Hydrological Features	19	2	0	**12**
Silvicultural Planning	19	3	0	9
Forest Inventory	18	5	0	**13**
Hazards	16	0	0	9
Forest Health Assessment	15	**9**	**1**	4
Species Identification	15	7	**1**	4
Fire Assessment	13	1	0	3
Historic/Cultural Site Identification	13	0	0	**11**
Landslide/Soil Displacement Assessment	11	3	0	7

Software

Companies employed ArcGIS Pro and ArcGIS Desktop as their primary software for working with data collected from aerial photography, multispectral imagery, and hyperspectral imagery (**Table 4**). QGIS, a free open-source software, was also commonly used by companies for aerial photography and multispectral imagery. ENVI was the only software used to analyse hyperspectral imagery.

The most common software used to collect and generate photogrammetric point clouds included DroneDeploy (36%), Pix4Dmapper (36%), Agisoft Metashape (29%), and ESRI Drone2Map (14%). SkyCan, Site Scan, Maps Made Easy, and DJI Terra were also used by one company each. Processing and analysing photogrammetric point clouds and LiDAR point clouds was primarily undertaken in Python and LASTools, though, open-source package LidR and other related packages in R were also commonly used (**Table 5**).

Table 4: Software used to visualise and analyse each type of imagery.

		Aerial Photography	**Multispectral Imagery**	**Hyperspectral Imagery**
Software class	**Software**	**n**	**n**	**n**
Geographic Information System	ESRI ArcGIS Pro	24	16	0
	ESRI ArcGIS Desktop (e.g. ArcMap)	20	13	0
	QGIS (free)	10	6	0
	Google Earth Engine	4	4	0
	Global Mapper	2	1	0
	GRASS GIS (free)	1	1	0
Image analysis	ENVI	1	1	1
	ERDAS IMAGINE	0	0	0
	Trimble eCognition	0	0	0
Geospatial data programming	R (free)	4	4	0
	Python (free)	3	4	0
	GDAL (free)	2	2	0
Specialist forestry software	ATLAS GeoMaster	7	3	0

Table 5: Software used to process and analyse point clouds.

	Photogrammetry point cloud	LiDAR point cloud
	n	n
Cloudcompare	2	**3**
Computree	1	1
DJI Terra	1	1
Fusion	2	2
LASTools	2	**7**
LiDAR360	1	1
Python	**4**	**3**
R - LidR package	**3**	**4**
R - other packages	**3**	**3**

Artificial Intelligence

Artificial intelligence (AI) was used by 30% of forestry companies when working with geospatial data. The barriers to not using artificial intelligence included current staff's lack of knowledge or training (68%), no perceived benefits (21%), not being aware of AI models (21%), and cost (11%). Two companies indicated the use of artificial intelligence may occur in the future.

The most common AI models used were Random Forest (57%), Convolutional Neural Networks (57%), Yolo (29%), and XGBoost (14%). These AI models were typically used in conjunction with remote sensing data, with aerial photography (88%) being the primary source, followed by multispectral imagery (50%) and LiDAR (50%). The most common applications of AI were stand/forest mapping (50%), forest inventory (50%), and tree detection (38%). Following these applications were cutover mapping (25%), forest health assessment (25%), and silvicultural planning (25%). Less common applications included fire assessment, landslide or soil displacement assessment, species identification, and windthrow assessment, each used by one company.

Changes to uptake and barriers between 2013 and 2023

The uptake, barriers and use of geospatial technologies and data have changed over the last ten years since the first (Morgenroth & Visser, 2013) and second (de Gouw, et al., 2018) comparable surveys were undertaken.

There have been changes in the proportions of companies using each grade of GNSS receivers, whereby ten years ago, no companies reported using consumer-grade receivers built into devices (such as mobile phones), this increased to 65% of companies in 2018 and further increased to 70% in 2023 (**Table 6**). In contrast, companies using dedicated handheld consumer-grade devices (e.g., Garmin 60CSx) have decreased from 100% in 2013 to 83% in 2018, and most recently, 70% in 2023. Evidently, GNSS receivers built into other devices, like mobile phones, are replacing the need for dedicated consumer-grade GNSS devices. This is potentially due to the increasing availability, adaptability, and accuracy of smartphones and their low cost (Zangenehnejad & Gao, 2021).

Another interesting trend is the change in the use of both mapping and survey-grade receivers. The use of mapping-grade receivers decreased from 41% in 2013 to 22% in 2018 but increased slightly in 2023 to 26% of companies. Survey grade receivers are continuing to increase in usage, with 37% of companies using these in 2023, an increase from 12% in 2013 and 22% in 2018. It is suggested that this increase is related to the increased use of remotely sensed data sets, particularly LiDAR data acquisition. The increase in the use of survey-grade receivers may be due to the need to accurately map legal boundaries and the importance of co-registration of LiDAR data and ground plots. Additionally, survey-grade receivers offer enhanced accuracy under forest canopies, as this can be one of the most limiting factors when working in closed canopy forests.

Table 6: Comparison of percentage of respondents using GNSS receivers by grade in 2013, 2018 and 2023.

Year	Consumer - built into device	Consumer - handheld	Mapping	Survey
2013	-	100	41	12
2018	65	83	22	22
2023	81	70	26	37

The uptake of remote-sensing technologies included in the survey has generally increased over the past five and ten years, except for hyperspectral imagery. Hyperspectral imagery was used by 9% of companies in 2018 and decreased to 4% of companies in 2023. LiDAR showed the most significant progression over the last five years, with its uptake increasing from 17% in 2013, and 70% in 2018 to 93% of companies in 2023 (**Table 7**). Identical to five years ago, aerial photography was used by 100% of companies, and the progression in the uptake of multispectral imagery (+19%) was modest.

Table 7: Comparison of percentage of respondents using remotely sensed imagery in 2013, 2018 and 2023.

Year	Aerial Photography	Aerial Videography	Multispectral Imagery	Hyperspectral Imagery	LiDAR Data
2013	88	-	35	-	17
2018	100	-	48	9	70
2023	100	56	67	4	93

The number of companies acquiring aerial photography has remained the same at 100%. This consistency suggests that forestry companies continue to place high value on this remote sensing data. Whilst the derivation of true colour orthophotos remained similar, deriving photogrammetric point clouds increased from 32% in 2018 to 48% in 2023. This could be due to the lower costs associated with photogrammetric point clouds compared to LiDAR point clouds despite similar accuracies. (Liu & Boehm, 2015; Cao, et al., 2019). A high-end photogrammetry system could cost up to USD 30,000 whereas manned LiDAR or UAV LiDAR systems can cost upwards of USD 150,000 and USD 120,000 respectively (Wingtra, 2023). Aerial videography, although not included in previous surveys, has a high usage rate in the forest management industry, with 56% of companies using it. The most common barriers preventing the use of aerial videography were no benefit and no knowledge or training to use aerial videography. With 100% of aerial videography being acquired using UAVs, it could be expected to increase in the use of aerial photography as more companies begin to understand the benefits and the accessibility of UAVs increases.

The uptake of multispectral imagery increased from 48% in 2018 to 67% in 2023. The most common barrier preventing companies from using multispectral imagery was no perceived benefits. The spatial resolution of multispectral imagery had a larger range than that of 2018. The resolution of UAVs has become even finer, up to 5 cm, and satellite-acquired multispectral imagery was recorded to be as fine as 50 cm. As suitable sensors for multispectral imagery become more accessible and affordable for UAVs, the acquisition of multispectral imagery using UAVs may see further growth in the future.

Hyperspectral imagery was used by one company, a decrease from the 2018 survey. However, the 2018 survey suggested that the companies using hyperspectral imagery may have incorrectly filled out the survey based on their reported spatial resolutions. The low uptake of hyperspectral imagery was expected due to the extensive data processing required when dealing with a high number of bands, as well as the acquisition costs (Hycza, et al., 2018). Applications currently used by companies for hyperspectral imagery were limited to forest health assessments and species identification. The use of photogrammetric processing has proven to be a viable alternative for species identification (Guimarães, et al., 2020), limiting the potential benefits of hyperspectral imagery to companies. The most common barrier was that companies saw no benefits to acquiring hyperspectral imagery. The cost of hyperspectral imagery has slowly decreased over time, (Hycza, et al., 2018). However, due to the low volume of hyperspectral data providers in New Zealand (Schimel, 2020), the cost of acquisition still remains high. As hyperspectral imagery becomes more widely available on free data platforms such as EnMAP, the uptake could increase in the future, however, the low spatial resolution of spaceborne hyperspectral imagery could restrict how applicable it is to forest areas.

The uptake of LiDAR has had the most significant increase over the past 10 years, with 93% of companies now using this remote sensing data. One of the biggest changes in LiDAR data acquisition between 2018 and 2023 was the introduction of open data portals. This was one of the most common ways companies acquired LiDAR data. The National Elevation Programme, which aims to provide LiDAR coverage across approximately 80% of the country (LINZ, 2023), has contributed to the availability of freely accessible lidar data in New Zealand. Whilst this data is still limited to some parts of New Zealand, it covers a significant portion of New Zealand's plantation forestry. The introduction of this accessible data has created opportunities for smaller companies that were restricted by the cost of acquiring LiDAR data. Furthermore, the availability of ready-to-use products derived from LiDAR data, such as DEMs and Digital Surface Models (DSMs), has benefited forest managers who previously did not have the expertise or resources to process LiDAR data themselves. Both the 2013 and 2018 surveys suggested that cost was the largest barrier to acquiring LiDAR data, the 2023 survey indicates that cost is as much a barrier as staff training and lack of perceived benefits. As more LiDAR data becomes openly available, it can be expected to see an increase in usage. This survey was the first time forest research institutes were also invited to complete the survey, with results indicating what technology forestry companies may use in the future. When it comes to LiDAR acquisition, research institutes appear significantly more advanced than forest management and consultancy companies. Static and mobile terrestrial platforms were only used by two entities, this is most likely due to their unsuitability for large-scale forests (Chen, et al., 2019). Most forestry companies that process their own LiDAR data tend to use a low number of processing methods, primarily focusing on generating surfaces, whereas research institutes undertake detailed processing of point clouds and work with cutting-edge technologies.

The increasing use of Artificial Intelligence in society is reflected in its growing use by a notable portion of forestry companies. However, the most common barrier preventing companies from using AI models was the lack of staff knowledge and education. More education and training for geospatial professionals will be required to understand the processes AI models utilise. Tertiary education and training providers will likely have the most impact on the future uptake of AI models. AI models were most used in conjunction with high-resolution aerial photography highlighting the importance aerial photography, will always have in the forestry industry.

The most common barrier identified in preventing the uptake of geospatial technology was no perceived benefits. This differs from the two previous studies where lack of staff education and the cost of acquiring the data were the largest barriers. This could indicate an increase in skilled GIS analysts entering the workforce, potentially influenced by undergraduate and postgraduate geospatial courses being taught at 12 tertiary institutes around New Zealand (LINZ, 2023) and over 50% of young geospatial professionals having postgraduate degrees (de Róiste, 2016).

There has been an overall increase in the uptake of most software, compared to five and ten years ago (**Table 8**). The largest increase was in the uptake of free GIS software, which grew from 6% in 2013 to 22% in 2018 and then 37% in 2023. ERSI ArcGIS has experienced the next largest increase in use, rising by 14% compared to 2013. In contrast, the use of MapInfo dropped from 18% in 2013 to 0% in 2018, it has continued to have no usage within the industry in 2023. In terms of image analysis software, ERDAS and Trimble e-Cognition software both showed decreases of 13% and 4%, respectively between 2018 and 2023. There was a significant increase in companies reported using point cloud analysis and processing software in 2023, with LAStools increasing by 26% since 2013.

Table 8: Progression of uptake of software used when processing and using products from the geospatial technologies included in the survey.

		Companies using software (%)				
Software class	**Software**	**2013**	**2018**	**2023**	**10-yr change**	**5-yr change**
Geographic Information Systems	ESRI ArcGIS (Desktop and Pro)	82	91	96	+14	+5
	MapInfo	18	0	0	-18	+0
	Global Mapper	0	9	7	+7	-2
	Free GIS (QGIS, GRASS GIS)	6	22	37	+31	+15
	Google Earth Engine	-	-	19	N/A	N/A
Image Analysis	ERDAS IMAGINE Image Analysis Software	12	13	0	-12	-13
	Trimble eCognition Image Analysis Software	0	4	0	+0	-4
	ENVI	-	-	4	N/A	N/A
Geospatial data programming	GDAL	-	-	7	N/A	N/A
	Python	-	-	15	N/A	N/A
	R (LidR or other)	-	-	15	N/A	N/A
LiDAR or photogrammetric point cloud analysis and processing cloud analysis and processing	FUSION	0	9	7	+7	-2
	LAStools	0	9	26	+26	+17
	QT Modeller	0	9	0	+0	-9
	Agisoft Metashape (previously Photoscan)	0	9	15	+15	+6
	Cloudcompare	-	-	11	N/A	N/A
	Computree	-	-	4	N/A	N/A
	DJI Terra	-	-	4	N/A	N/A
	LiDAR360	-	-	4	N/A	N/A
Specialist forestry software	ATLAS GeoMaster	35	43	26	-9	-17

Conclusion

The survey results provide insights into the geospatial technologies used in the New Zealand plantation forest management sector, how they are used, and the barriers to their use.

The survey, representing 27 forestry companies, shows a high usage of online data portals and associated freely available datasets. GNSS receivers and aerial photography were the most common geospatial technology, used by all forestry companies. Aerial videography, multispectral imagery and LiDAR were also used by a significant portion of forestry companies. Artificial intelligence has been used by a few forestry companies; however, companies indicated the potential to use it in the future. Hyperspectral imagery has decreased in usage.

The most common barriers restricting the use of geospatial technologies were no perceived benefits. In comparison to barriers identified by de Gouw, Morgenroth and Xu in 2018, staff knowledge and education are increasing and the cost of acquiring the data is becoming less of a barrier. In 2018, cost was the main barrier for companies not using LiDAR. The increasing availability and usage of free online data portals and data sets, such as LiDAR from the NZ National Elevation Programme may have impacted these barriers. The uptake of artificial intelligence was primarily limited by a lack of staff training, indicating the need for further training in this area of geospatial technology.

The results of this survey show the continuing use and importance of geospatial technology in the forest management industry. The results from this study will help inform the industry on how to fully capitalise on their acquired data and develop strategies to overcome any barriers identified, ultimately promoting widespread use in the industry.

The adoption of geospatial technology in New Zealand's forest management sector reveals a continually changing landscape driven by accessibility, utility, cost-effectiveness, and the growing awareness of technology's potential. As barriers are identified and knowledge gaps closed, geospatial technologies are positioned to play an important role in the productive management of New Zealand's plantation forests.

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Appendix

Appendix A: Survey Questions

We are particularly interested in gathering information relevant to the present. Please answer the following questions based on your company's current geospatial technology usage.

* Required

Company Profile

1. What is your name? *
2. What is your position title? *
3. What is the name of your company? *
4. Type of company? *
    a. Forest Owner and Manager
    b. Forest Manager
    c. Forest Consultant
    d. Other (please specify):
5. What is the net stocked area (hectares) of forests that your company manages in New Zealand? *
6. What stand record system do you use? (e.g. Geomaster)
7. What forest estate model do you use? (e.g. Woodstock or Tigermoth)

Public Data Acquisition

8. Does your company use the Land Information New Zealand (LINZ) geographic data portal? *
    a. Yes
    b. No
9. Which of the following datasets does your company use from the Land Information New Zealand (LINZ) data portal?
    a. Aerial photography
    b. Elevation (e.g. Digital Elevation Models)
    c. Property Ownership & Boundaries
    d. Roads and Addresses
    e. Topographic maps
    f. Hydrological features (e.g. rivers, wetlands)
    g. Other (please specify):

10. Does your company use the Koordinates geographic data portal? *
    a. Yes
    b. No
11. Which of the following datasets does your company use from the Koordinates data portal?
    a. Virtual climate station network from NIWA
    b. Aerial photography
    c. Elevation (e.g. Digital Elevation Models)
    d. Property Ownership & Boundaries
    e. Roads and Addresses
    f. Topographic maps
    g. Hydrological features (e.g. rivers, wetlands)
    h. Land Cover Database (LCDB)
    i. New Zealand Environmental Data Stack (e.g. soil particle size, slope, annual precipitation)
    j. The digital soil map (S-MAP)
    k. Fundamental Soils Layer (FSL) (e.g. Soil Drainage)
    l. Territorial Authority Boundaries
    m. Statistical Area Boundaries
    n. Land Use Carbon Analysis System (LUCAS)
    o. Land Environments New Zealand (LENZ)
    p. Climate (e.g. annual rainfall)
    q. Scion's Geospatial Surfaces (e.g. Site productivity layers)
    r. Other (please specify):
12. Does your company use the Land Resource Information Systems (LRIS) geographic data portal? *
    a. Yes
    b. No
13. Which of the following datasets does your company use from the Land Resource Information Systems (LRIS) data portal?
    a. Land Cover Database (LCDB)
    b. New Zealand Environmental Data Stack (e.g. soil particle size, slope, annual precipitation)
    c. The digital soil map (S-MAP)
    d. Fundamental Soils Layer (FSL) (e.g. Soil Drainage)

e. Elevation (e.g. Digital Elevation Models)
f. Land Environments New Zealand (LENZ)
g. Other (please specify):

14. Does your company use the Ministry for the Environment (MFE) geographic data portal? *
    a. Yes
    b. No
15. Which of the following datasets does your company use from the Ministry for the Environment (MfE) data portal?
    a. Land Use Carbon Analysis System (LUCAS) Land Use Map
    b. Land Use Carbon Analysis System (LUCAS) NZ Forest Clearing 2008-2020
    c. Climate (e.g. annual rainfall)
    d. Hydrological features (e.g. rivers, wetlands)
    e. Other (please specify):
16. Does your company use the Stats NZ data portal? *
    a. Yes
    b. No
17. Which of the following datasets does your company use from the Stats NZ data portal?
    a. Territorial Authority Boundaries
    b. Statistical Area Boundaries
    c. Other (please specify):
18. Does your company use Council geographic data portals? *
    a. Yes
    b. No
19. Which of the following datasets does your company use from the Council's data portals?
    a. Property Boundaries
    b. Aerial Photography
    c. Other (please specify):
20. Does your company use any other geographic data portals?
    a. No
    b. MPI data portal – NES-PF Erosion Susceptibility Classification
    c. NIWA - Virtual climate station network
    d. Other (please specify):

Positioning Technology

Positioning technology is the use of a global navigation satellite system (GNSS) to provide positioning, navigation, and timing data, this includes GPS, Galileo, GLONASS and BeiDou.

21. What grade of global navigation satellite system (GNSS) does your company use? *
    a. Consumer grade receiver built into device (e.g. iphone)- capable of <10m accuracy
    b. Consumer grade receiver (e.g. Garmin GPSMAP 62s)- capable of <10 m accuracy, cost <$1,000
    c. Mapping grade receiver (e.g. Trimble Nomad)- capable of <5 m accuracy, cost $1,000-$5,000
    d. Survey grade receiver (e.g. Trimble GeoExplorer)- capable of <0.5 m accuracy, cost $5,000 +
    e. None
22. Does your company use Satellite Based Augmentation Systems (e.g. SouthPAN)- capable of <0.1 m accuracy?
    a. Yes
    b. No
23. How does your company use its GNSS receiver(s)? * (e.g. boundary mapping)

Aerial Photography

Aerial photography consists of three bands (red, green, blue) and is acquired from an aerial platform. (e.g. plane, UAV).

24. Does your company use aerial photography? *
    a. Yes
    b. No
25. What are the reasons for not using aerial photography? *
    a. Cost
    b. No perceived benefits
    c. Current staff lack of knowledge or training to use aerial photography
    d. Was not aware of aerial photography
    e. Other (please specify):
26. How is your aerial photography acquired? *
    a. Unmanned Aerial Vehicle (drone)
    b. Airplane

c. Helicopter
d. Other (please specify):

27. Do you derive true colour orthophotos (contain only red, green and blue bands (RGB)) and are geometrically corrected) from aerial photography? *
    a. Yes
    b. No
28. Do you derive Photogrammetric Point Clouds from aerial photography? *
    a. Yes
    b. No
29. What product(s) does your company derive from Photogrammetric Point Clouds? *
    a. Digital Elevation Model (DEM)
    b. Canopy Height Models (CHM)
    c. Mean Top Height (MTH) estimates
    d. Stem count or stocking
    e. Stem volume estimates
    f. Biomass or carbon estimates
    g. Other (please specify):
30. For what applications do you use your aerial photography? *
    a. Cutover Mapping
    b. Fire Assessment
    c. Forest Health Assessment
    d. Harvest Planning
    e. Hazards
    f. Historic/Cultural Site Identification
    g. Hydrological Features
    h. Forest Inventory
    i. Landslide/Soil Displacement Assessment
    j. Road Mapping
    k. Silvicultural Planning
    l. Site Preparation
    m. Species Identification
    n. Stand/Forest Mapping
    o. Windthrow Assessment
    p. Other (please specify):

31. What are the factors that determine when you acquire aerial photography? * (e.g. We acquire aerial photography once a year or as needed, which is pre-harvest and post-harvest)
32. What is the spatial resolution of your aerial photography? * (e.g. 2 metres)

Aerial Videography

Aerial videography refers to motion pictures which consists of three bands (red, green, blue) and is acquired from an aerial platform (e.g. plane, UAV).

33. Does your company use aerial videography? *
    a. Yes
    b. No
34. What are the reasons for not using aerial videography? *
    a. Cost
    b. No perceived benefits
    c. Current staff lack of knowledge or training to use aerial videography
    d. Was not aware of aerial videography
    e. Other (please specify):
35. How is your aerial videography acquired? *
    a. Unmanned Aerial Vehicle (drone)
    b. Airplane
    c. Helicopter
    d. Other (please specify):
36. For what applications do you use your aerial videography? *
37. What are the factors that determine when you acquire aerial videography? * (e.g. We acquire aerial videography once a year or as needed, which is pre-harvest and post-harvest)

Multispectral Imagery

Multispectral imagery typically consists of four or more bands (red, green, blue, infrared, etc) and is commonly acquired from an airplane, UAV, or satellite.

38. Does your company use multispectral imagery? *
    a. Yes
    b. No
39. What are the reasons for not using multispectral imagery? *
    a. Cost
    b. No perceived benefit

    c. Current staff lack of knowledge or training to use multispectral imagery
    d. Was not aware of multispectral imagery
    e. Other (please specify):

40. How is your multispectral imagery acquired? *
    a. Airplane
    b. Satellite
    c. Unmanned Aerial Vehicle (e.g. drone)
    d. Helicopter
    e. Other (please specify):
41. If you acquire satellite imagery, which sensor(s) do you use? *
    a. Sentinel
    b. RapidEye
    c. Landsat
    d. PlanetScope
    e. Worldview
    f. Other (please specify):
42. What products does your company derive from the multispectral imagery? *
    a. True-colour composites (includes only red, green and blue bands (RGB))
    b. False-colour composites (including RGB and other bands)
    c. Vegetation Indices (e.g., Normalised Difference Vegetation Index (NDVI))
    d. Other (please specify):
43. If you use vegetation indices, which do you use? *
    a. Normalised Difference Vegetation Index (NDVI)
    b. Soil Adjusted Vegetation Index (SAVI)
    c. Burn Area Index (BAI)
    d. Enhanced Vegetation Index (EVI)
    e. Ratio Vegetation Index (RVI) also known as Simple Ration (SR)
    f. Other (please specify):
44. For what applications do you use your multispectral imagery? *
    a. Cutover Mapping
    b. Fire Assessment
    c. Forest Health Assessment
    d. Harvest Planning
    e. Hazards

f. Historic/Cultural Site Identification
g. Hydrological Features
h. Forest Inventory
i. Landslide/Soil Displacement Assessment
j. Road Mapping
k. Silvicultural Planning
l. Site Preparation
m. Species Identification
n. Stand/Forest Mapping
o. Windthrow Assessment
p. Other (please specify):

45. What are the factors that determine when you acquire multispectral imagery? * (e.g. We acquire multispectral imagery once a year or as needed, which is pre-harvest and post-harvest)
46. What is the spatial resolution of your multispectral imagery? * (e.g. 10 metres)

Hyperspectral Imagery

Hyperspectral imagery typically contains hundreds of bands spanning the visible and infrared wavelengths. Hyperspectral imagery is acquired from an aerial or satellite platform.

47. Does your company use hyperspectral imagery? *
    a. Yes
    b. No
48. What are the reasons for not using hyperspectral imagery? *
    a. Cost
    b. No perceived benefits
    c. Current staff lack knowledge or training to use hyperspectral imagery
    d. Was not aware of hyperspectral imagery
    e. Other (please specify):
49. How is your hyperspectral imagery acquired? *
    a. Unmanned Aerial Vehicle (e.g. drone)
    b. Airplane
    c. Helicopter
    d. Satellite
    e. Other (please specify):

50. If you acquire hyperspectral imagery, which sensor(s) do you use? *
51. For what applications do you use your hyperspectral imagery? *
    a. Cutover Mapping
    b. Fire Assessment
    c. Forest Health Assessment
    d. Harvest Planning
    e. Hazards
    f. Historic/Cultural Site Identification
    g. Hydrological Features
    h. Forest Inventory
    i. Landslide/Soil Displacement Assessment
    j. Road Mapping
    k. Silvicultural Planning
    l. Site Preparation
    m. Species Identification
    n. Stand/Forest Mapping
    o. Windthrow Assessment
    p. Other (please specify):
52. What are the factors that determine when you acquire hyperspectral imagery? * (e.g. We acquire hyperspectral imagery once a year or as needed, which is pre-harvest and post-harvest)
53. What is the spatial resolution of your hyperspectral imagery? * (e.g. 3 metres)

LiDAR

LiDAR is an active remote sensing technique that stands for Light Detection and Ranging, it is also known as laser scanning.

54. Does your company use LiDAR data? * (this includes LiDAR-derived products such as Digital Elevation Models)
    a. Yes
    b. No
55. What are the reasons for not using LiDAR? *
    a. Cost
    b. No perceived benefits
    c. Current staff lack knowledge or training to use LiDAR data

d. Was not aware of LiDAR

e. Other (please specify):

56. How is your LiDAR data acquired? *

a. Unmanned Aerial Vehicle (e.g. drone)

b. Airplane

c. Helicopter

d. Satellite (e.g. Global Ecosystem Dynamics Investigation (GEDI))

e. Static Terrestrial platform (e.g. LiDAR sensor mounted on tripod)

f. Mobile Terrestrial platform (e.g. LiDAR sensor mounted on backpack or handheld)

g. Vehicular platform (e.g. LiDAR sensor mounted on ute)

h. Open data portal (e.g. Open Topography)

i. Other (please specify):

57. If you acquire LiDAR, which sensor(s) do you use?

a. DJI Zenmuse L1

b. Emesent Hovermap

c. Grenvalley LiAir series

d. Leica BLK series

e. Riegl laser scanners

f. Other (please specify):

58. What are the factors that determine when you acquire LiDAR data? * (e.g. We acquire LiDAR data once a year or as needed, which is pre-harvest and post-harvest)

59. If you know, could you please provide the point density of the LiDAR data you acquire? * (e.g. 10 points/m^2)

60. How do you process the raw point clouds (i.e. las or laz files)? *

a. We process the raw point clouds data in-house

b. We engage a third-party organisation (e.g. surveying company or consultants) to process point clouds data

61. What do you do to process and analyse the raw point clouds? *

a. Filtering and cleaning point cloud

b. Classifying points to ground and non-ground points

c. Classifying points to detailed classes (e.g., water, high vegetation, low vegetation)

d. Generating surfaces (e.g., DEM, DSM, CHM)

e. Detecting and segmenting individual trees

f. 3D model construction of individual trees

   g. Deriving LiDAR metrics at plot-level
   h. Deriving LiDAR metrics at tree-level
   i. Other (please specify):

62. What product(s) does your company derive from LiDAR data collection and processing? *
   a. Canopy Height Model (CHM)
   b. Digital Elevation Model (DEM)
   c. Mean Top Height (MTH) estimates
   d. Stem count or stocking
   e. Stem volume estimates
   f. Biomass or carbon estimates
   g. Other (please specify):
63. If a DEM is derived, what spatial resolution is it?
64. For what applications do you use your LiDAR products? *
   a. Cutover Mapping
   b. Fire Assessment
   c. Forest Health Assessment
   d. Harvest Planning
   e. Hazards
   f. Historic/Cultural Site Identification
   g. Hydrological Features
   h. Forest Inventory
   i. Landslide/Soil Displacement Assessment
   j. Road Mapping
   k. Silvicultural Planning
   l. Site Preparation
   m. Species Identification
   n. Stand/Forest Mapping
   o. Windthrow Assessment
   p. Other (please specify):

Additional Remote Sensing Data

65. If you use any other types of remote sensing data for your forest management (e.g., radar), please specify the data type used, and the corresponding application.

Software

66. If you use imagery (including aerial photography, multispectral and/or hyperspectral) for your forest management, what software do you use to visualise and analyse each type of imagery? Please tick all the answers that apply.

Software	Aerial Photography	Multispectral Imagery	Hyperspectral Imagery
ATLAS GeoMaster			
ENVI			
ERDAS IMAGINE			
ESRI ArcGIS Desktop (e.g. ArcMap)			
ESRI ArcGIS Pro			
GDAL			
Global Mapper			
Google Earth Engine			
GRASS GIS			
Python			
QGIS			
R			
Trimble eCognition			

67. If your company uses any other software to visualise and analyse imagery, please list the software name, and the corresponding imagery.
68. If you use photogrammetry points, what software do you use to collect and process ***photogrammetry point clouds*** (creating point clouds from structure from motion)? Please tick all the answers that apply.
    a. Agisoft Metashape
    b. COLMAP
    c. DJI Terra
    d. DroneDeploy
    e. ESRI Drone2Map
    f. LiMapper
    g. Pix4Dmapper

h. Other (please specify):

69. If you use point cloud data (including photogrammetry and LiDAR) for your forest management, what software do you use to ***collect and process point clouds***? Please tick all the answers that apply.

Software	**Photogrammetry point cloud**	**LiDAR point cloud**
Cloudcompare		
Computree		
DJI Terra		
Fusion		
LASTools		
LiDAR360		
Python		
R - LidR package		
R - other packages		

70. If your company uses any other software to ***collect and process*** photogrammetry and/or LiDAR point clouds please list the software name, and the corresponding point cloud type (i.e. LiDAR or photogrammetry).

Artificial Intelligence

Artificial Intelligence (AI) is a technology that enables computers to perform tasks with human-like intelligence, such as analysing data, making decisions, and solving problems. It can include methods such as machine learning and deep learning.

71. Does your company use AI when working with geospatial data? *
    a. Yes
    b. No
72. What are the reasons for not using AI? *
    a. Cost
    b. No perceived benefits
    c. Current staff lack knowledge or training to use AI models
    d. Was not aware of AI models
    e. Other (please specify):

73. What AI models does your company use? * (e.g. Random Forest or Convolutional Neural Network)
74. What types of remote sensing data is used in AI models? *
    a. Aerial Photography
    b. Multispectral Imagery
    c. Hyperspectral Imagery
    d. LiDAR
    e. Other (please specify):
75. For what applications do you use AI? *
    a. Cutover Mapping
    b. Fire Assessment
    c. Forest Health Assessment
    d. Harvest Planning
    e. Hazards
    f. Historic/Cultural Site Identification
    g. Hydrological Features
    h. Forest Inventory
    i. Landslide/Soil Displacement Assessment
    j. Road Mapping
    k. Silvicultural Planning
    l. Site Preparation
    m. Species Identification
    n. Stand/Forest Mapping
    o. Windthrow Assessment
    p. Other (please specify):
76. Thank you for completing the survey. Would you like to receive a copy of the final report?
    a. Yes
    b. No

Appendix B: Guideline Script for Contacting Companies

Introduction

You are being invited to participate in a research project concerning geospatial technologies used in the New Zealand Forest Industry. This is being conducted by a final-year student from the School of Forestry, University of Canterbury, undertaking a Bachelor of Forest Engineering with Honours. This is the third time that the School of Forestry has run this survey, with previous surveys having been sent to industry in 2012 and 2018.

The intended recipient of this survey is your company's geospatial manager or a person with knowledge of your company's use of geospatial data, methods, software, and hardware. Before you decide to take part or not, it is important to understand the rationale for the research, and what participation involves.

Please read the following information. Feel free to discuss this with others, or ask for any clarification from the research team, and take time to decide whether to take part or not.

Why is this research being conducted?

The aim of this project is to understand the uptake of geospatial technologies in the New Zealand forestry industry. Specifically, the project seeks to understand which technologies have been adopted by the New Zealand Forest industry and to identify any barriers to the uptake of geospatial tools. It is hoped that this will help inform the industry on how to fully capitalise on their acquired data, as well as develop strategies to overcome any barriers identified, ultimately promoting widespread use in the industry.

Do I have to participate?

Participation is voluntary. In 2012, 17 companies participated, while in 2018, 23 companies participated. If you do not wish to participate or wish to withdraw from the questionnaire after starting it, please close your web browser, as incomplete questionnaires will be discarded. Doing so does not require a reason and has no consequences.

What will happen if I choose to take part?

If you do choose to participate, you will be invited to complete an online questionnaire, that will take approximately 30 minutes to complete. We may contact you to clarify your responses, if necessary.

What are the advantages of taking part?

There are no immediate benefits, financial incentives, rewards, or otherwise for participating in this research. However, it is hoped that this research project will help inform the industry on the current uptake of geospatial technologies and contribute to maximising the efficiency and effectiveness of forest management practices in New Zealand. Importantly, it helps to ensure that the geospatial curriculum at the School of Forestry continues to meet industry's needs by identifying commonly used data, methods, software, and hardware.

What are the possible disadvantages of taking part?

The research team anticipates no significant disadvantages associated with participation.

If I choose to take part, what will happen to the data?

The results of this survey will be used in comparison with the previous surveys completed in 2012 and 2018 to identify how the use of geospatial technologies has changed. All responses to the survey will be aggregated such that no individual company's geospatial strategy is detailed or compromised. The use of this data will be limited to addressing the research purpose.

At the end of this research project, a publicly available dissertation, including summaries of the anonymised data will be written. In addition, the research team may write and publish a journal article. In either case no information identifying participants or companies will be accessible. Examples of how the previous survey data were used can be found here and here.

Contact Details

If you would like more information, or have any questions about the project or your participation, please use the contact details below:

Primary contact

Name: Anna Manning

Role: BE(Hons) Forest Engineering Final Year Student

Email: ama557@uclive.ac.nz

Supervisor

Name: Dr Vega Xu

Role: Dissertation supervisor

Email: cong.xu@canterbury.ac.nz

If you have concerns about any aspect of this research project please contact Anna Manning in the first instance, then escalate to Vega Xu, the Supervisor.