

# **The Uptake and Barriers of Geospatial Technologies in New Zealand's Forest Management Sector**

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A dissertation submitted in partial fulfilment of the requirements for the  
Bachelor of Forestry Science Degree with Honours

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## Abstract

Geospatial technologies have developed rapidly in recent decades and can provide detailed, accurate data to support forest management decisions. Commonly used technologies include Global Positioning System (GPS), Geographic Information Systems (GIS) and remote sensing technologies. Knowledge of the uptake and barriers of geospatial technologies in the forest management sector will be beneficial to the industry. This knowledge will provide a benchmark and can be used to overcome current barriers so that these technologies are fully utilised.

An online survey was sent out to 29 forest management companies within New Zealand. The survey was split into seven sections, composed of multi-choice and open-ended questions. These sections were demographic information, data portals and datasets, GPS receivers and remote sensing technologies. Four remote sensing technologies were included, aerial photography, multispectral imagery, hyperspectral imagery, and light detection and ranging (LiDAR). Each section included questions that asked about the acquisition, application and products created from each technology that companies used. Questions were also included that related to the barriers preventing the uptake of technologies. To determine the progression in the uptake of these technologies the results were compared to a study conducted five years earlier.

All 23 companies that responded to the survey used GPS receivers and acquired aerial photography. Multispectral imagery and hyperspectral imagery had an uptake of 48% and 9%, respectively. LiDAR had a 70% uptake. Common applications for the products derived from these technologies were, stand or forest mapping and assessment, harvest planning, cutover mapping, and site preparation or silvicultural mapping. The main barriers for companies not using geospatial technologies were the lack of staff knowledge and training, as well as the cost of acquiring the imagery. Some companies did not believe there were any benefits gained from acquiring multispectral or hyperspectral imagery.

The uptake of all four remote sensing technologies increased over the past five years. LiDAR had the largest progression in uptake, increasing from 17% in 2013 to 70% in 2018. In 2013, all aerial photographs were acquired using airplanes but the results from the survey have shown that unmanned aerial vehicles (UAV) were used by 83% of companies. UAVs were also used to acquire multispectral imagery.

This study showed that there had been a progression in the uptake of geospatial technologies in the New Zealand forest management sector. However, there are still barriers that are preventing the full utilisation of these technologies and the results suggest that the industry could benefit from investing in more training relating to geospatial technologies. It is recommended that a similar survey is completed in another five years as the developments of technology are still occurring rapidly.

**Key words:** Geospatial technologies uptake and barriers, GPS, remote sensing, GIS, New Zealand forest management, geospatial technology progression.

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## 1. Introduction

The development of geospatial technologies over the past 50 years has occurred rapidly producing geospatial technologies that are cheaper and faster to acquire and use (Dash et al., 2016). The use of geospatial technologies can provide more detailed and accurate data, which can be applied to forest management practices allowing site-specific operational and tactical plans and decisions to be made.

Geospatial technologies that are commonly applied to forest management include Global Positioning System (GPS), Geographic Information Systems (GIS) and remote sensing technologies (Wing & Sessions, 2007). Four common remote sensing data types are aerial photography, multispectral imagery, hyperspectral imagery and LiDAR. Aerial photography was first used in the 1950s for forest inventory and in recent decades the use of remote sensing technologies has become increasingly common to assist forest management decisions (Dash et al., 2016). The rapid development of these technologies has led to a progression in the awareness and application within in New Zealand's forest management sector.

Gaining knowledge on the uptake of these geospatial technologies and how the data collected is applied to forest management will be beneficial to the industry. Companies will be able to compare how they apply their acquired data to other companies. This could ensure that companies are fully utilising the data they have acquired. Gaining knowledge on the current barriers preventing the uptake of geospatial technologies is also beneficial. This knowledge, when made available to the forest management industry and survey companies, can be used to develop plans to overcome these barriers. This will ensure that these technologies are fully utilised and used to support forest management decisions.

## 2. Research Questions

There is no up-to-date published information on the use of geospatial technologies in the New Zealand forest management sector. Morgenroth & Visser (2013) completed a study looking at the uptake of geospatial technologies within New Zealand's forest management sector five years ago. Since then, there have been rapid developments and advances of geospatial technologies and there is a need for a new survey to be completed.

This study will determine the uptake of these technologies and how the acquired data is being applied. The barriers preventing the uptake of these technologies is also important. Information on the barriers can be used to understand how to increase the uptake and fully utilise the geospatial technologies. The forest management sector can benefit from the full utilisation of these technologies as the data collected can save time and money. In addition to increased efficiency, the data collected can provide products that are not possible using traditional ground-based data collection methods.

The development of geospatial technologies is commonly noted in published literature and the use of these technologies for forest research purposes is known. However, how the uptake of these technologies has progressed in the operational forest management sector over the last five years is unknown.

There are three main questions that this study aims to answer:

1. Which geospatial technologies are currently being used in New Zealand's forest management sector?
2. What are the barriers preventing the uptake of geospatial technologies in New Zealand?
3. Has the uptake of this technology progressed over the last five years?

### 3. Literature review

The knowledge and awareness of how geospatial technologies can be applied to forestry and the benefits they can provide has increased over the years. Aerial photography has been used as a tool for forest management since the 1950s, but the use of other remote sensing technologies such as multispectral imagery and LiDAR over the last 25 years resulted in the greatest progression of precision forestry (Dash et al., 2016). Precision forestry refers to the combined use of geospatial technologies and analytical tools to collect data with high spatial and temporal resolutions for site-specific forest management (Adams, Brack, Farrier, Pont, & Brownlie, 2011; Schmoldt & Thomson, 2003). The use of these geospatial technologies has enabled the creation of many products such as digital elevation models (DEM), canopy height models and vegetation indices. These products are useful for describing the forest resources and site conditions.

The use of improved geospatial technologies and products has been applied to a diverse range of forestry operations: forest health monitoring (Coops et al., 2003), mapping forest disturbances (Savage, Lawrence, & Squires, 2017), harvest and road planning (Abdi, Majnounian, Darvishsefat, Mashayekhi, & Sessions, 2009; Akay, Oğuz, Karas, & Aruga, 2008; Holopainen, Vastaranta, & Hyypä, 2014), forest inventory and resource mapping (Dassot, Constant, & Fournier, 2011; Pont, Kimberley, Brownlie, Morgenroth, & Watt, 2015), as well as carbon inventory (Stephens et al., 2012).

Geospatial technologies can be used in combination with traditional ground-based techniques to improve the quality of forest descriptions for operations such as forest inventory (Dash et al., 2016). The use of geospatial technologies is more efficient than traditional ground-based methods as data can be collected rapidly and for larger extents of a forest estate (Akay et al., 2008; Favorskaya & Jain, 2017; Tesfamichael et al., 2010). An example of this is acquiring LiDAR data to create canopy height models. Using a high point density LiDAR dataset, the height of individual trees within a forest stand can be calculated without the need for a person to go and manually measure every tree (Chen & Zhu, 2012; Wulder et al. 2012).

Satellite and aircrafts are platforms commonly used for remote sensing data acquisition. Methods for geospatial data collection are changing due to improved, smaller and cheaper sensors and aerial platforms such as unmanned aerial vehicles (UAV) (Favorskaya & Jain, 2017; Hartley, 2017; Toth & Jóźków, 2016). The use of UAVs allows forest managers to collect data for target areas of forest (e.g. a stand that is scheduled for harvest) in a timely and efficient manner.

The advances in geospatial technologies indicate that geospatial skills and knowledge have become requirements for many entry-level jobs within forest companies (Sample, Bixler, McDonough, Bullard, & Snieckus, 2015). Merry, Bettinger, Grebner, Boston, & Siry (2016) found that 71% of recent forest qualification graduates used GIS at least every second day in their jobs, this was a 28% increase from 2007 (Merry, Bettinger, Clutter, Hepinstall, & Nibbelink, 2007). A study for entry-level forestry job advertisements found that 70% of graduate jobs required that the applicant had knowledge and skills relating to mapping technologies (Bettinger & Merry, 2018). Fifty-two percent



of the jobs advertised required that the applicant had GIS knowledge and skills (Sample et al., 2015). This shows the increased application of geospatial technologies within everyday forest management practices.

The number of forestry education departments requiring a GIS component as a part of the degree has continuously been increasing. In 1989, 5% of forestry departments in Canada required that undergraduates completed a geospatial or GIS component to obtain their degree (Sader et al., 1989). This rose to 10% in 1999 and by 2012, 94% of undergraduate forestry degrees required that a geospatial course was completed to acquire the degree (Sader & Vermillion, 2000; Merry et al., 2016).

A study conducted in New Zealand by De Róiste (2014) found that 44% of companies surveyed across a variety of sectors believed that there was a shortage of trained GIS specialists across the country. This could be a barrier affecting the uptake of geospatial technologies as companies may lack staff with the knowledge or skills to process, analyse or apply the information and products produced using technologies such as LiDAR or multispectral imaging.

The cost of acquiring and using the hardware and software required when collecting and processing geospatial data can often be another barrier for companies (Bernard & Prisley, 2005; White et al., 2016). However, there is a lot more information available today that can be collected or sourced from publicly available datasets (Dash et al., 2016). These datasets are often free and can easily be accessed and downloaded via websites.

There are many different software programs available today to process and work with the acquired data. The most commonly used software was ESRI's ArcGIS and Google Earth with 84% and 75%, respectively, of forestry graduates using this software in their jobs in the United States (US). No graduates are using free software and 12% used a GIS developed by their employer (Merry et al., 2016).

## 4. Method

To answer the research questions, a questionnaire survey was developed and distributed to prospective respondents. The majority of business in New Zealand use the internet so Google Forms was used to produce and distribute the survey. This web-based survey ensured participants throughout New Zealand were able to receive and complete the survey in a convenient and expeditious manner (Roztocki, 2001; Stats NZ, 2017). The use of internet surveys to collect data for academic studies is increasing and similar approaches have been used in previous studies, such as Merry et al. (2016) (Buchanan & Hvizdak, 2009). Online surveys are also cost-effective and can speed up the rate that responses are received in comparison to tradition pen and paper surveys (Van Selm & Jankowski, 2006).

On 5<sup>th</sup> May 2018, the survey was distributed to 29 New Zealand forest management companies. Of these 29 companies, 19 were identified using the list of forest management companies in the 2016/17 Forest Owners Association (FOA) New Zealand plantation forest industry facts and figures publication (FOA, 2017). An additional 10 companies were added to the list of survey recipients based on suggestions from industry professionals. These 29 companies combined managed approximately 80% (1,704,747 ha) of New Zealand's plantation forest estate area (FAO, 2017). A personalised cover letter asking for the respondent to participate in the study was emailed with the hyperlink to the respondent to help increase the response rate (Van Selm & Jankowski, 2006). On 6<sup>th</sup> June 2018, a follow-up email was sent out to those companies who had not completed the survey, this was done to increase the response rate.

The questions used in Morgenroth & Visser (2013) were used as the basis for the new survey questions. These questions were updated to reflect the changes in the available geospatial technologies. Moreover, the survey delivery was adapted to suit an online format. Standardising the current survey to the 2013 survey allowed for a comparison of results to determine how the uptake and barriers preventing the use of geospatial technology had changed over the past five years in New Zealand.

The survey, which is available in its entirety in Appendix A, is comprised of seven sections:

1. Demographic information
2. Data acquisition
3. Positioning technologies
4. Aerial photography
5. Multispectral imagery
6. Hyperspectral imagery
7. LiDAR

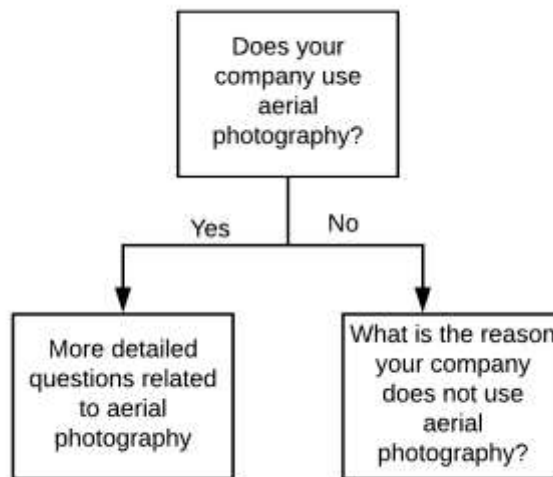
The first section of the survey, demographic information, was created to acquire information such as the respondent's job title and the net stocked forested area managed by the responding company. Demographic information was important to confirm the appropriate person within the

company answered the survey. This ensured that only applicable survey responses were included in the analysis of the results and that each company was only represented once. It also provided an estimate of the percentage of New Zealand's plantation forestry estate that was being managed using each of the geospatial technologies. Finally, it allowed for a comparison of results across forestry companies of varying sizes.

The second section, data acquisition, asked which geographic data portals and databases the company used to acquire geographic data. Section three pertained to the Global Positioning System (GPS) receiver(s) used by the company and the applications for which it is used. Sections four to seven were all comprised of similar questions, but each section focused on a different remote sensing technology. These technologies were defined at the beginning of each section so that the technologies were not confused with one another and the respondent could correctly answer the questions. These definitions can be viewed in Appendix A, at the beginning of each remote sensing section of the survey.

The survey questions were written in a manner that was directed at the company as opposed to the individual respondent. This reinforced to the respondent that they were answering on behalf of the company. The survey collected predominantly qualitative data, but some questions required quantitative answers. Multi-choice questions were often followed by open-ended questions to allow respondents to provide additional details about their answer(s) in the preceding question. Respondents were also given the opportunity to add an answer that was not provided as one of the default choices in the multi-choice question by having an 'other' choice, followed by an editable text box. Most of the questions within the survey were compulsory and required answers to questions before the respondent could continue to the next section of the survey. This ensured that no questions were left unanswered.

The survey made use of conditional questions. An illustration of how the conditional questions were applied can be seen in Figure 1. The initial question for sections four to seven asked whether a particular type of remote sensing data was used by the company. If the respondent answered 'yes', then subsequent questions asked how this data was acquired and how the acquired products were applied for forest management purposes. Answering 'no' to the use of a remote sensing technology prompted a question about the reason(s) or barrier(s) that were preventing the company from acquiring the remotely-sensed data.



**Figure 1:** Example of conditional question

To ensure the survey was relevant and easy to comprehend, a pilot survey was administered to two respondents. The feedback from these respondents was used to revise the survey. The revision involved adding a new section to include questions that were not previously included in the survey. An email invitation and a hyperlink leading to the final survey was then sent to the previously selected forest management companies.

The responses from the survey were recorded in a table making it easy to analyse and summarise the survey answers. Descriptive statistics were used to illustrate the survey results. The answers to open-ended questions were summarised and placed into categories to make it easier to analyse the data and identify trends.

To analyse the progression of the uptake of geospatial technologies, the responses from Morgenroth & Visser (2013) study were compared to the results from the survey. An area-based analysis was also completed to compare the area managed using each remote sensing technology in 2013 and 2018. The proportion of New Zealand plantation forest area managed using each of the technologies was calculated. This area was based on the total net stocked area managed by each company that stated that they used the technology.

## 5. Results

### 5.1 Demographic Information

Of the 29 companies contacted, 23 responded to the survey (79% response rate). The total area managed by the respondent companies was approximately 1,171,000 ha (69% of New Zealand's 1.71 million ha plantation forest estate). The size of the estates managed by individual companies ranged from 1,000 ha to 176,776 ha (Table 1).

Fifty-two percent of the companies that responded to the survey were identified as forest owners and managers, 44% percent were forest management companies. One of the smaller management companies did not have a geospatial manager and outsourced all mapping, surveying and terrain planning, so the photography and mapping services contractor completed the survey on behalf of the forest management company. Other smaller management companies did not have an employee appointed as a geospatial manager, so the most appropriate staff member responded to the survey (Table 1).

**Table 1:** Demographic information of respondent companies; the position of the respondent and the area of land managed by the company

Position of Respondent	Area Managed (ha)
Harvest operations manager	1,000
Harvesting manager	6,500
GIS coordinator	8,000
Establishment manager	12,500
General manager	16,000
Geospatial analyst	18,000
Managing director	20,000
GIS analyst	20,000
GIS analyst	20,500
Technical & resource manager	25,200
GIS analyst	30,000
Forest manager	33,000
GIS officer	35,000
Forest information specialist	36,000
GIS analyst	36,000
Environmental & compliance manager	50,000
Forest information officer	61,300
Forest information/GIS analyst	65,000
Geospatial manager	106,000
Forest information manager	113,000
Land information manager	130,000
GIS analyst	152,000
Forest information team leader	176,000
<b>TOTAL</b>	<b>1,171,000</b>

## 5.2 Data Acquisition

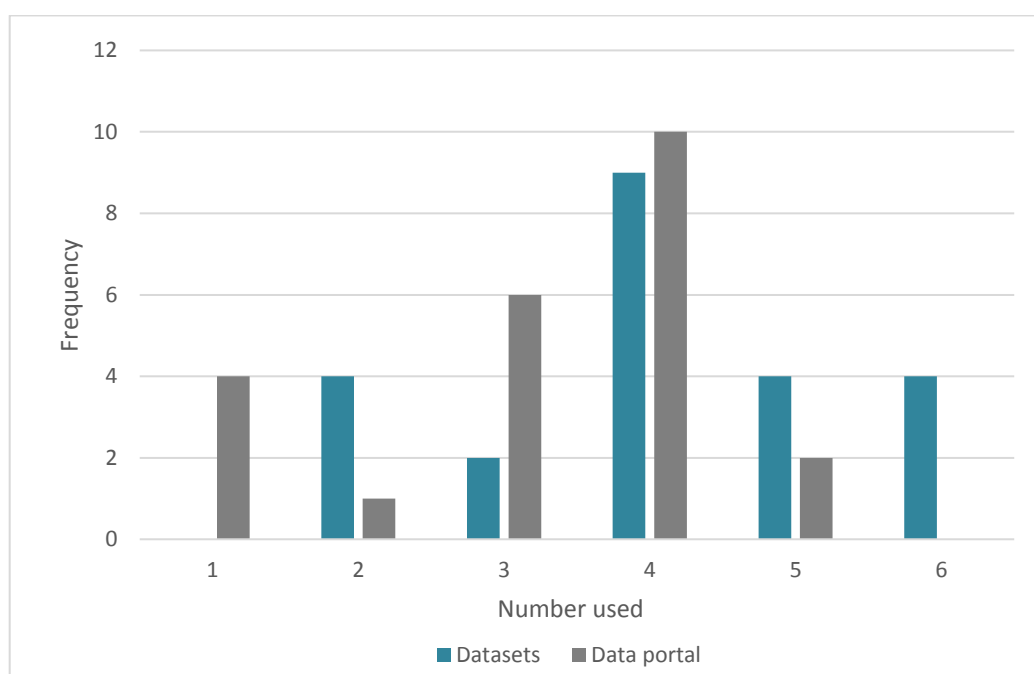
Data acquisition from nationally available data was commonly used and freely available to support forest management. National datasets and data portals were used by all 23 companies. Aerial photography and land cover information from the Land Cover Database (LCDB) were the two most commonly acquired data sets, with 83% and 70% of the management companies, respectively, acquiring this data (Table 2). The Land Information New Zealand (LINZ) Data Service data portal was used by 91% of companies (Table 3). Koordinates and Land Resource Information Systems (LRIS) Portal were also commonly used by companies. Most companies used four or more datasets (65%) or data portals (91%) (Figure 2).

**Table 2:** Uptake of nationally available datasets

Dataset	Response Rate	
	n	%
Aerial photography from Land Information New Zealand (LINZ)	19	83%
Land cover database from Landcare Research	16	70%
Satellite imagery from Land Information New Zealand (LINZ)	15	65%
Fundamental soils layer from Landcare Research	14	61%
LUCAS land use map from Ministry for the Environment	9	39%
S-map from Landcare Research	7	30%
Virtual climate station network from NIWA	4	17%
ESC/NES resources	2	9%
LINZ dataset for utilities and infrastructure	1	4%
Cadastral data	1	4%
Topo50	1	4%
Critchlow	1	4%
Local council contours	1	4%
Earth Explorer	1	4%
Esri	1	4%

**Table 3:** Uptake of Nationally available data portals

Data Portals	Response Rate	
	n	%
LINZ data service	21	91%
Koordinates	18	78%
LRIS portal	13	57%
Ministry for the Environment (MFE) data service	12	52%
Stats NZ	7	30%
Council maps	3	13%
Retro Lens	1	4%
NRC online maps	1	4%
Eagle technology base map services	1	4%
Earth Explorer	1	4%

**Figure 2:** Number of data set or data portals used by companies

### Positioning technology

All of the forest management companies used GPS technology. Sixty-one percent ( $n = 14$ ) used two or more grades of receivers. Consumer grade handheld receivers (e.g. Garmin 60CSx) were the most commonly used (83%). Consumer grade receivers in devices such as a cell phone or tablet were also used by 65% of the respondents. Survey and mapping grade receivers had the same level of uptake (22%).

GPS receivers were used to record points and tracks. Recording the location of infrastructure and utilities such as landings, roads, fire ponds and trails were the most common uses of GPS receivers. Boundary mapping and mapping for legal purposes, plot location, hazard and historic site location, as well as cutover mark-ups were also applications for GPS data. Less common applications included GPS referenced photos for resource consent compliance and ground control points for UAV mapping.

### Aerial photography

Aerial photography was the most commonly acquired form of remotely sensed data, all responding companies acquired aerial photography. Unmanned aerial vehicles (UAV) and airplanes were the most commonly used platforms to acquire aerial photographs, with 83% of respondents indicating that one or both platforms were used. Aerial photography was acquired via satellite or the LINZ Data Service for 18% of the companies. One company used a helicopter to acquire their aerial photography and several other companies used alternative sources such as Google imagery, council imagery or imagery from neighbouring forests.

When asked if the company acquired their aerial photography on a regular basis, 59% (n =13) acquired aerial photography when required. UAVs were commonly used to acquire photographs when collecting data on an irregular basis for areas of interest such as stands during harvest planning, mapping cutover areas after harvest completion or assessing the effects of a windstorm. Four companies acquired aerial photographs on an annual basis for the entire estate in addition to irregularly collecting photos for areas of interest. Eight companies only acquired aerial photographs on a regular cycle. These regular acquisition cycles ranged from quarterly up to three years.

The spatial resolution of the aerial photography acquired ranged from 0.1 metre (m) to 30 m. The spatial resolution of the aerial photographs acquired via UAV was frequently finer (commonly 0.3 m) than that acquired via an airplane (commonly 0.5 m). Thirty-five percent of the companies acquired aerial photographs at two or more differing spatial resolutions.

True colour composites were derived from the acquired aerial photographs by 96% of the forest management companies. Five percent of the true colour composites were orthophotos. Photogrammetric point clouds were also derived by 32% of companies.

### Multispectral imagery

Multispectral imagery was used by 48% (n = 11) of the forest management companies. The lack of staff knowledge or training was the most common barrier preventing companies from acquiring multispectral imagery. The lack of education was also listed in conjunction with the cost of acquiring multispectral imagery being too high (42%) or that the company did not perceive any benefit from acquiring the imagery (33%). Several companies either believed the imagery took too long to acquire or were not aware of multispectral imaging. Two companies stated that they were planning on acquiring multispectral imagery in the future.



To acquire multispectral imagery 82% of the respondents used satellites. The most commonly used satellite sensor was Sentinel (73%). Rapid Eye (36%) and Landsat (27%) sensors were also used by several companies. UAV and/or airplanes were also used to acquire multispectral imagery by 18% of the companies. The majority of companies (n=10), did not acquire multispectral imagery on a regular cycle, but only when it was required. The one company that did acquire data on a regular basis did so annually.

The spatial resolutions of the multispectral imagery ranged from 3 m up to 30 m. Three companies acquired multispectral imagery that had a spatial resolution of 5 m or less, another three companies acquired multispectral imagery that had a spatial resolution of 10 m. There were also several companies that acquired their imagery at 15 m or 30 m resolutions. Companies derived true colour composites (91%) and false colour composites (82%), as well as vegetation indices from the multispectral imagery. Seventy-three percent (n=8) of the companies derived a Normalised Difference Vegetation Index (NDVI). One company also derived an Enhanced Vegetation Index (EVI) in addition to a NDVI.

### Hyperspectral imagery

Only 9% (n=2) of the companies acquired hyperspectral imagery. The main barriers for companies not using hyperspectral imagery were the lack of staff knowledge and training (57%) as well as the cost of acquiring the imagery (48%). Some companies did not believe there was any benefit of acquiring hyperspectral imagery (29%) or were unaware of it or its potential benefits (15%).

Hyperspectral imagery was acquired via satellite. However, the spatial resolution differed between the two companies. One company used imagery that ranged from 3 m to 5 m and the other from 10 m to 20 m. One company acquired their hyperspectral imagery on an annual basis, and the other company only as they required it.

### LiDAR

LiDAR was used by 70% (n=16) of the companies, with two companies planning on acquiring LiDAR data in the future. The main barrier for companies not using LiDAR was the cost of acquiring it (57%). Lack of estate scale and the lack of staff knowledge or training was a barrier for 29% and 14% of the companies, respectively. The smaller companies managing 16,000 ha or less did not acquire LiDAR data.

LiDAR was acquired by airplane for 94% of the companies. UAVs were used by 13% of the companies. The point density of the LiDAR data ranged from 2 to 20 points/m<sup>2</sup>. Ten companies (63%) acquired LiDAR with a point density of 4 points/m<sup>2</sup> or less. LiDAR data was only acquired as required by 81% of the respondents, with two other companies acquiring their LiDAR data on a regular three or five-year cycle. One company only collected their LiDAR data as a one off.

All companies derived DEMs from their LiDAR data. Canopy height models (69%) and the mean top height (MTH) (69%) were also commonly derived products. Volume estimates and stem counts were also produced from seven companies' LiDAR data. There were products that companies were not acquiring but would want to obtain in the future (Table 4). These products could provide more detailed information about the forest stands to managers.

The processing of the raw LiDAR files was outsourced to an aerial surveying company for 63% (n=10) of the companies, 56% (n=9) also outsourced the processing to a third-party organisation. Some products were derived in-house by 31% (n=5) of the companies, but no company produced all their LiDAR products in-house.

**Table 4:** Responses to the open answer question; what products would your company want to obtain from LiDAR data collection and processing in the future?

<b>Desired future products obtained from LiDAR</b>		
	<b>n</b>	<b>%</b>
Stocking	7	44%
Biomass	2	13%
Inventory	2	13%
Contours	1	6%
Stem volume	1	6%
Optimum crop stocking model	1	6%
Tree heights	1	6%
Grade mix	1	6%
Phenotype information	1	6%

### 5.3 Application of remotely sensed imagery

The most common application for aerial photography and LiDAR was harvest planning (Table 5). Aerial photography and LiDAR had other mutual applications which included site preparation/silvicultural planning and hazard and historic site identification. Aerial photography had the widest variety of applications, multispectral and LiDAR also had many varied applications.

All the technologies, except LiDAR, were used for cutover mapping. Multispectral imagery and hyperspectral imagery were applied to tasks such as forest health evaluation and species identification. Hyperspectral, imagery unlike multispectral imagery, was not used for mapping. Multispectral imagery and aerial photography were used for natural event assessment, examples of this include windthrow mapping, assessing snowfall damage and fire damage.

**Table 5:** Application of remote sensing imagery to forest management

	<b>Aerial Photography</b>		<b>Multispectral Imagery</b>		<b>Hyperspectral Imagery</b>		<b>LiDAR</b>	
<b>Application</b>	<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>
Stand/forest mapping/assessment	14	64%	5	45%	.	.	.	.
Harvest planning	13	59%	.	.	.	.	12	75%
Cutover mapping	13	59%	3	27%	1	50%	.	.
Site preparation/silvicultural planning	8	36%	.	.	.	.	7	44%
Road mapping	6	27%	.	.	.	.	.	.
General forest overview	5	23%	.	.	.	.	.	.
Natural event assessment	2	14%	3	27%	.	.	.	.
Hazards/historic site identification	2	9%	.	.	.	.	5	31%
Species identification	.	.	5	45%	1	50%	.	.
Forest health assessment	.	.	5	45%	1	50%	.	.
Where aerial photography is not available	.	.	2	18%	.	.	.	.
Wilding identification	.	.	1	9%	.	.	.	.
Inventory	.	.	.	.	.	.	5	31%
Slope management	.	.	.	.	.	.	3	19%
Forest valuation	.	.	.	.	.	.	3	19%
3D models	.	.	.	.	.	.	1	6%

## 5.4 Software

Environmental Systems Research Institute (ESRI) ArcGIS was the most commonly used software. ArcGIS was used when working with data collected from all four remote sensing technologies (Table 6). Atlas GeoMaster and free GIS software such as Quantum GIS (QGIS) or Geographic Resources Analysis Support System (GRASS) were also commonly used when working with the acquired imagery. FUSION, LAS tools, and Quick Terrain (QT) Modeller were only used when working with LiDAR files.

The majority of companies used two or more different types of software when working with their imagery. The size of the area managed by the company did not correlate to the software that they used. For example, smaller companies were not necessarily the ones using the free GIS software.

**Table 6:** Software used when working with acquired imagery

Software	Aerial Photography		Multispectral Imagery		Hyperspectral Imagery		LiDAR	
	n	%	n	%	n	%	n	%
ESRI ArcGIS	21	91%	11	100%	2	100%	5	56%
ATLAS GeoMaster	10	45%	2	18%	1%	50%	.	.
Free GIS	4	18%	1	9%	1%	50%	.	.
AgiSoft Photoscan	2	9%	.	.			.	.
Global Mapper	2	9%	.	.			.	.
Avenza Map App	1	5%	.	.			.	.
ERDAS IMAGINE Image Analysis Software	1	5%	1	9%			.	.
Trimble eCognition Image Analysis Software	1	5%	1	9%			.	.
FUSION	.	.	.	.			2	22%
LAS tools	.	.	.	.			2	22%
QT Modeller	.	.	.	.			2	22%

### 5.5 Progression of uptake

There was a progression in the uptake of GPS receivers. The proportions of companies using each grade of GPS receivers has changed. Five years ago none of the companies surveyed were using consumer grade receivers built into devices (such as a tablet). The results from the most recent survey showed that 65% of companies were using this grade of receiver (Table 7). There were fewer companies using consumer (e.g. Garmin 60 CSx) and mapping grade receivers compared to five years ago. The percentage of the total forest area managed by the companies using each of the receiver grades has shown comparable changes to the respondent uptake.

**Table 7:** Progression of uptake of GPS receivers by grade

		Consumer handheld	Consumer in device	Mapping	Survey
Percentage of Respondents	<b>2013</b>	100%	.	41%	12%
	<b>2018</b>	83%	65%	22%	22%
Area Managed (ha)	<b>2013</b>	1,060,420	.	335,000	93,500
	<b>2018</b>	1,044,147	850, 647	232,721	253,091

The uptake of the remote sensing technologies included in the survey increased over the past five years. Hyperspectral imagery was not included in Morgenroth and Visser's (2013) study and consequently could not be compared to the uptake in 2018. LiDAR showed the greatest progression over the last five years with its uptake increasing from 17% in 2013 to 70% in 2018 (Table 8). The progression in the uptake of aerial photography and multispectral imagery was similar. However, less than half of the portion of companies were using multispectral imagery in comparison to aerial photography.

The area managed by respondent companies using aerial photography increased by approximately 163,097 ha over the last five years. The areas managed using multispectral imagery and LiDAR also increased 399,367 ha and 925,647 ha, respectively (Table 8).

**Table 8:** Progression of uptake of remote sensing technologies

		<b>Aerial Photography</b>	<b>Multispectral Imagery</b>	<b>Hyperspectral Imagery</b>	<b>LiDAR</b>
Percentage of Respondents	<b>2013</b>	88%	35%	.	17%
	<b>2018</b>	100%	48%	9%	70%
Area managed (ha)	<b>2013</b>	1,008,420	399,500	.	146,420
	<b>2018</b>	1,171,517	798,867	53,721	1,072,067

There was an increase in the uptake of all the software stated in the most recent survey compared to five years ago (Table 9). ArcGIS was still the most commonly used software when working with remote sensing imagery, followed by GeoMaster. The largest increase was in the uptake of free GIS software. Uptake of ERDAS and Trimble e-Cognition software showed a small increase.

**Table 9:** Progression of uptake of software used when processing and using products from the geospatial technologies included in the survey

		<b>Arc GIS</b>	<b>GeoMaster</b>	<b>ERDAS</b>	<b>Free GIS</b>	<b>Trimble E- Cognition</b>
Percentage of Respondents	<b>2013</b>	82%	35%	12%	6%	0%
	<b>2018</b>	91%	43%	13%	22%	4%
Area managed (ha)	<b>2013</b>	1,036,420	572,500	148,000	25,000	0
	<b>2018</b>	1,105,517	226,241	1,000	14,0221	106,000

## 6. Discussion

The results from the survey show that all the geospatial technologies included in this study are used within the New Zealand forest management sector. All the respondent companies were using GPS receivers. However, there has been a change in the most commonly used grade of receiver that companies are using compared to five years ago. The increase in the uptake of GPS receivers within devices such as tablets and phones is aided by the improvement in technology and the versatility of these devices. The decrease in the uptake of mapping grade receivers may be a result of the accuracy of these receivers not being sufficient for legal boundary mapping, but achieving similar accuracies to the consumer grade receivers, including receivers within newer devices (Tomašík, Tomašík, Saloň, & Piroh, 2016). Companies may not be willing to pay for mapping grade receivers when consumer grade receivers can achieve similar accuracies for applications such as locating fire ponds, culverts and skid sites.

The number of companies acquiring aerial photography has increased by 14% since 2013, all the forest management companies stated that they acquired aerial photography. The applications for aerial photography have remained similar over the past five years but how the aerial photographs are acquired has changed. The use of UAVs to capture aerial photographs was not previously used by forest management companies. As mentioned earlier in the literature review the development of cheaper, smaller sensors and UAVs has increased forest managers' accessibility to this technology. The use of UAVs allows managers to collect photographs when required for a target area. The ease of deploying a UAV and capturing aerial photography is not possible with an airplane or satellite as the acquisition is operationally complex and costly (Whitehead & Hugenholtz, 2014). UAVs can also obtain imagery when cloud cover would hinder the acquisition of imagery from a satellite or airplane in these conditions.

Future studies may find that the number of companies acquiring aerial photography via UAVs increases as more employees obtain a licence to fly a drone. However, the use of UAVs to capture aerial photography is unlikely to completely replace airplanes to acquire aerial photos in the foreseeable future as the spatial extent of the UAVs is currently limited (Heaphy, Watt, Dash, & Pearse, 2017).

The cost of acquiring aerial photography was previously the barrier preventing the uptake of this technology. The availability of freely available photography from sources such as LINZ has

contributed to aerial photographs being more accessible. The uptake of these free datasets was seen in the answers to the data acquisition questions in the survey. LINZ aerial photography is available for 95% of New Zealand commonly at 0.4 m spatial resolution and is available as fine as 0.1 m for some areas (LINZ, 2018). The frequency that these public databases are updated may not be often enough for forest managers. This will be one factor that results in forest management companies acquiring their own photographs despite the cost of acquisition.

The uptake of LiDAR has seen the most significant increase of all the remote sensing technologies included in the survey. The uptake of LiDAR has increased 53% since 2013 (Morgenroth and Visser, 2013). The uptake of LiDAR in the New Zealand forest sector is similar to the uptake in the US in which a recent study found that 46% of recent forestry program graduates used LiDAR in their job (Merry et al., 2016). This was a significant increase from only 10% of recent US forest graduates using LiDAR in a previous study (Merry et al., 2016). New Zealand was one of the first countries to use LiDAR in an operational context so the survey results in comparison to the US are not unexpected (Wulder et al., 2012).

The main barrier preventing uptake in both 2013 and 2018 was the cost of acquiring LiDAR. New Zealand industry professionals stated the midpoint cost of acquiring LiDAR today can range from \$5 to \$12 per hectare (AAM surveying, personal communication 2018; Port Blakey, personal communication 2018). Smaller companies are not acquiring LiDAR data due to the cost and estate scale. Economies of scale apply as the cost per hectare of acquiring LiDAR typically decreases as the forest area increases. The connectivity of these forests will also affect the cost of acquiring LiDAR (Adams et al., 2011).

LiDAR is more expensive to acquire than aerial photography or multispectral imagery (Kelly & Di Tommaso, 2015). However, it is believed that the products from LiDAR can pay for the cost of acquiring this information within five years (Mannes, 2009). The results from the survey imply that forest management companies believe the benefits they gain are worth the cost of acquiring the data. It should also be noted that the cost of acquiring LiDAR can be more cost-effective in comparison with intensive fieldwork. In the future as it becomes increasingly difficult to source employees willing to complete manual fieldwork, there may be a further increase in the uptake of LiDAR for inventory purposes.

Terrestrial LiDAR was not acquired by any of the forest management companies. Terrestrial LiDAR is not suitable to collect data for large areas, but it can provide detailed tree information at a plot scale. Terrestrial LiDAR is suited to measuring the below canopy structure, such as stem form, branching and stand density (Dassot et al., 2011; White et al., 2016). The development and improvement of mobile handheld laser scanners, which are more portable than previous tripod-based scanners, may see a future increase in the uptake of terrestrial LiDAR. However, the limits imposed by steep terrain forests and the inaccuracy of these handheld scanners need to be improved first (Dash et al., 2016). The products that companies wish to attain from LiDAR in the future can be produced from data acquired via terrestrial LiDAR and may result in an increase in the uptake of terrestrial LiDAR.

The uptake of multispectral imagery increased from 35% in 2013 to 48% in 2018. The most common barrier preventing companies from using multispectral imagery was the lack of staff education; this differs to the cost of the imagery being the most common barrier five years ago as multispectral imagery becomes cheaper and even free. The lack of best practice guidelines and the low technical capacity of the industry needs to be improved to fully utilise technologies such as multispectral imagery. A future survey may see the uptake of multispectral imagery increase as more companies become aware of the technology and its benefits. As seen from the survey results there are already two other companies who are working towards acquiring multispectral imagery in the future.

All companies which acquired multispectral imagery also acquired LiDAR data, except for one company which did not. The combined use of multispectral imagery and LiDAR is seen in several published studies and was reviewed by Xu et al. (2015). For example, Watt et al. (2015) used a combination of satellite imagery and LiDAR to estimate site index, other studies have used a combination of two technologies to determine biomass (Estornell et al., 2012), volume (Tonolli et al., 2011) and to classify forest cover (Dupuy et al., 2013).

A question was not asked to see if companies fused data from two or more sensor technologies. However, seventy-four percent of the companies acquired data for at least two of the remote sensing technologies included in the survey. This suggests that it is possible for companies to combine the data from two technologies to produce products similar to the aforementioned products. A similar question would be beneficial to include in a future survey.



The uptake of hyperspectral imagery by only two companies was not unexpected. The imagery can contain hundreds of bands, spreading across the electromagnetic spectrum, and processing can be complex. This processing complexity and the fact that hyperspectral imagery is expensive to acquire combined with the development of hyperspectral imagery being continuous has an influence on the uptake and can be considered by companies as significant barriers (Adão et al., 2017).

The companies that acquired hyperspectral imagery also acquired multispectral imagery. When further analysis was completed a follow-up question was sent out to one company who explained that their use of both imaging technologies was due to the limitations of multispectral imagery. They found that the imagery was unable to capture data on steep, shadowed slopes during the winter months for up to 40% of their forest area. Spectral detail that is not noticeable in multispectral imagery can be seen in hyperspectral imagery. This company did say that with the development of UAVs and new sensors the need to acquire hyperspectral imagery for these applications may not be necessary in the future. Adão et al. (2017) stated that as technological developments are made hyperspectral imaging will be cheaper to acquire.

The improvement of UAVs and sensors which will mount on to these platforms will not overcome the barrier that the lack of staff knowledge and training poses. This lack of knowledge is not just industry specific and can be seen across a range of industries in New Zealand (De Róiste, 2014). More education for geospatial professionals will be required to analyse and process remote sensing technologies so the acquired data can be fully utilised in the future.

The results from this study will be of use to forest management companies within New Zealand. Companies can use this study as a benchmark to compare which technologies other companies are using and additional applications for the data and products they have already acquired. Aerial surveying companies are also interested in what technologies forest management companies are using and the barriers preventing companies from acquiring data. The Forestry industry and the aerial surveying companies can use the results from this study to overcome and minimise these barriers that are preventing the optimum utilisation of these technologies. The collection and application of accurate, detailed data acquired from these technologies will result in better forest management decisions. The improvement of forest management operations and decisions will lead to greater commercial gains (Melville, Stone, & Turner, 2015).

## 6.1 Limitations

The main limitation of this study was that the area-based analysis only applied to the total area managed by each company. The technology may not be applied to the entire estate, but instead only certain areas, so an assumption was made that it applied to the entire area that a company managed. It would be difficult to collect information on the exact area (hectares) that each technology was applied to.

It was also assumed that the respondent answered the questions in a manner that represented the entire company. The survey cover letter that was emailed to the respondent and the questions were worded and aimed at the company and not the level of the individual. This was to minimise the potential of the respondent only stating the technologies they used within their job.

There may be some error in the responses to the open-ended question such as those questions that asked for the applications of the related technology. It is possible that the respondent did not list all the applications of the technology as they may not be known to the respondent especially in larger companies and those companies with regional offices.

## 7. Conclusion and Recommendations

The results from this study have shown that GPS and aerial photography are the most commonly used geospatial technologies in the New Zealand forest management sector. The most common barriers preventing the uptake of geospatial technologies was the lack of education and the cost of acquiring the data. These barriers are comparable to barriers five years ago and suggest that the industry needs to invest in more training to fully utilise these technologies. Over the last five years, there has been a progression in the uptake of all the technologies included in the survey, with LiDAR having the largest increase in uptake.

It is recommended that a similar survey is completed in another five years. The developments in technology are occurring rapidly and the use of UAVs is changing the acquisition cycles and applications for remote sensing technologies. The development of sensors which fit on these UAV platforms and other geospatial technologies is also continuous. The advancement of geospatial technologies will have an influence on the uptake and applications of the acquired data.

A future survey could ask for details on the species composition of the companies' estates as this information could be beneficial to the study. Collecting information relating to the midpoint price that companies pay to acquire the remote sensing data would also be beneficial. This would allow a benchmark price to be identified and will allow a good comparison between the costs of the technologies as this information is currently difficult to source.

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## 9. Appendix A

### Uptake of Geospatial Technologies in the New Zealand Forest Industry Survey

\* 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? \*
  - Forest owner and manager
  - Forest manager
  - Forest consultant
  - Other...
5. What is the net stocked area (hectares) of forests that your company manages? \*

#### Data Acquisition

6. Which of the following geographic data portals does your company use? \*
  - Stats NZ data service
  - Koordinates
  - Ministry for the Environment (MFE) data service
  - Land Resource Information Systems (LRIS) Portal
  - Land Information New Zealand (LINZ) data service
  - None
  - Other...
7. Which of the following datasets does your company use? \*
  - Fundamental soils layer from Landcare Research
  - Landcover database from Landcare Research
  - S-map from Landcare Research
  - Aerial photography from Land Information New Zealand (LINZ)
  - Satellite imagery from Land Information New Zealand (LINZ)
  - Virtual climate station network from NIWA
  - LUCAS land use map from Ministry for the Environment
  - None
  - Other...

## Positioning Technology

8. What grade of global positioning system does your company use? \*
- Consumer grade receiver built into device (e.g. iphone)- capable of <10 m accuracy
  - Consumer grade receiver (e.g. Garmin 60 CSx)- capable of <10 m accuracy, cost <\$1,000
  - Mapping grade receiver (e.g. Trimble Nomad)- capable of <5 m accuracy, cost \$1,000-\$20,000
  - Survey grade receiver (e.g. Trimble GeoExplorer 6000)- capable of <0.5 m accuracy, cost >\$20,000
  - None
9. How does your company use its GPS receiver(s)? (e.g. Boundary mapping, plot centre location)

## Aerial Photography

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

10. Does your company use aerial photography? \*
- Yes
  - No

## Aerial Photography Barriers

11. What are the reasons for not using aerial photography? \*
- Cost
  - No perceived benefits
  - Current staff lack knowledge or training to use aerial photography
  - Other...

## Aerial photography Acquisition

12. How is your aerial photography acquired? \*
- Unmanned Aerial Vehicle (aka drone)
  - Airplane
  - Helicopter
  - Other...
13. What products does your company derive from aerial photography? \*
- True colour composites (this imagery includes only red, green and blue bands (RGB))
  - Photogrammetric point clouds
  - None
  - Other...
14. For what applications do you use your aerial photography? \* (e.g. Harvest planning)
15. Does your company acquire aerial photographs on a regular cycle? \* (e.g. every two years or only as required)

16. What software do you use when working with your aerial photography? \*

- Esri ArcGIS
- MapInfo
- ATLAS GeoMaster
- Open/Free GIS (e.g. QGIS, GRASS)
- ENVI Image Analysis Software
- Trimble e-Cognition Image Analysis Software
- ERDAS IMAGINE Image Analysis Software
- Other...

17. What is the spatial resolution of your aerial photography? \* (e.g. 2 metres)

### 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

18. Does your company use multispectral imagery? \*

- Yes
- No

### Multispectral imagery Barriers

19. What are the reasons for not using multispectral imagery? \*

- Cost
- No perceived benefit
- Current staff lack knowledge or training to use multispectral imagery
- Was not aware of multispectral imagery
- Other...

### Multispectral imagery Acquisition

20. How is your multispectral imagery acquired? \*

- Airplane
- Satellite
- Unmanned Aerial Vehicle (aka drone)
- Helicopter
- Other...

21. If you acquire satellite imagery which sensor do you use?

- Landsat
- Sentinel

- Rapid Eye
  - SPOT
  - IKONOS
  - GeoEye
  - Pleiades
  - Worldview
  - Other...
22. What products does your company derive from the multispectral imagery? \*
- True-colour composites (includes only red, green and blue bands (RGB))
  - False-colour composites (including RGB and other bands)
  - NDVI (Normalized Difference Vegetation Index)
  - Other vegetation indices (e.g. SAVI, EVI, SR)
  - None
  - Other...
23. If you use an alternative vegetation index to NDVI what is it? (e.g. SAVI)
24. For what applications do you use your multispectral imagery? \*
25. Does your company acquire multispectral imagery on a regular cycle? \* (e.g. every two years or only as required)
26. What software do you use when working with your multispectral imagery? \*
- Esri ArcGIS
  - MapInfo
  - ATLAS GeoMaster
  - Open/Free GIS (e.g. QGIS, GRASS)
  - ENVI Image Analysis Software
  - Trimble e-Cognition Image Analysis Software
  - ERDAS IMAGINE Image Analysis Software
  - Other...
27. 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.

28. Does your company use hyperspectral imagery? \*
- Yes
  - No

## Hyperspectral Imagery Barriers

29. What are the reasons for not using hyperspectral imagery? \*

- Cost
- No perceived benefits
- Current staff lack knowledge or training to use hyperspectral imagery
- Was not aware of hyperspectral imagery
- Other...

## Hyperspectral Imagery Acquisition

30. How is your hyperspectral imagery acquired? \*

- Unmanned Aerial Vehicle (aka drone)
- Airplane
- Helicopter
- Satellite
- Other...

31. For what applications do you use your hyperspectral imagery? \*

32. Does your company acquire hyperspectral imagery on a regular cycle? \* (e.g. every two years or only as required)

33. What software do you use when working with your hyperspectral imagery? \*

- Esri ArcGIS
- MapInfo
- ATLAS GeoMaster
- Open/Free GIS (e.g. QGIS, GRASS)
- ENVI Image Analysis Software
- Trimble e-Cognition Image Analysis Software
- ERDAS IMAGINE Image Analysis Software
- Other...

34. What is the spatial resolution of your hyperspectral imagery? \* (e.g. 20metres)

## LiDAR

LiDAR stands for Light Detection and Ranging, it is also known as laser scanning

35. Does your company use LiDAR data? \*

- Yes
- No

## LiDAR Barriers

36. What are the reasons for not using LiDAR? \*

- Cost
- No perceived benefits
- Current staff lack knowledge or training to use LiDAR data

- Was not aware of LiDAR
- Other...

## LiDAR Acquisition

37. How is your LiDAR data acquired? \*

- Unmanned Aerial Vehicle (aka drone)
- Airplane
- Helicopter
- Terrestrial platform (e.g. LiDAR sensor mounted on tripod)
- Vehicular platform (e.g. LiDAR sensor mounted on ute)
- Other...

38. What is the point density (points/m<sup>2</sup>) of the LiDAR data you acquire? \*

39. Does your company acquire LiDAR data on a regular cycle? \* (e.g. every two years or only as required)

40. Do you process the raw .las files in-house or do you use LiDAR products (eg. digital elevation model) produced by an external provider? \*

- Products are derived in-house from raw LiDAR data (i.e. las files)
- Products are provided by an aerial surveying company
- Products are derived by a third-party organisation (eg. consultants) from raw data provided by surveying company

41. If you process raw .las files what software do you use?

- FUSION
- LAStools
- ESRI
- R
- Other...

42. What product(s) does your company derive from LiDAR data collection and processing? \*

- Digital elevation model
- Canopy height model
- Mean top height estimates
- Volume or biomass estimates
- Stem count
- Other...

43. For what applications do you use your LiDAR products? \*

44. What products would your company want to obtain from LiDAR data collection and processing in the future?