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An updated survey on the use of geospatial technologies in New Zealand's plantation forestry sector

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Abstract

Background: Geospatial technologies have developed rapidly in recent decades and can provide detailed, accurate data to support forest management. Knowledge of the uptake of geospatial technologies, as well as barriers to adoption, in New Zealand's plantation forest management sector is limited and would be beneficial to the industry. This study provides an update to the 2013 benchmark study by Morgenroth and Visser.

Methods: An online survey was sent to 29 companies that own or manage plantation forests in New Zealand. The survey was split into seven sections, composed of multiple-choice and open-ended questions, on the topics of: demographic information, data portals and datasets, global navigation satellite system (GNSS) receivers, and four remote-sensing technologies. These included aerial imagery, multispectral imagery, hyperspectral imagery, and light detection and ranging (LiDAR). Each section included questions relating to the acquisition, application and products created from each remote-sensing technology. 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 Morgenroth and Visser's study conducted five years earlier.

Results: Twenty-three companies responded to the survey and together, those companies managed approximately 1,172,000 ha (or 69% of New Zealand's 1.706 million ha plantation forest estate (NZFOA, 2018)). The size of the estates managed by individual companies ranged from 1,000 ha to 177,000 ha (quartile 1 = 19,000 ha, median = 33,000 ha, quartile 3 = 63,150 ha). All companies used GNSS receivers and acquired three-band, Red-Green-Blue, aerial imagery. Multispectral imagery, hyperspectral imagery and LiDAR data were acquired by 48%, 9% and 70% of companies, respectively. Common applications for the products derived from these technologies were forest mapping and description, harvest planning, and cutover mapping. The main barrier preventing companies from acquiring most remotely-sensed data was the lack of staff knowledge and training, though cost was the main barrier to LiDAR acquisition. The uptake of all remote-sensing technologies has increased since 2013. LiDAR had the largest progression in uptake, increasing from 17% to 70%. There has also been a change in the way companies acquired the data. Many of the companies used unpiloted aerial vehicles (UAV) to acquire aerial and multispectral imagery in 2018, while in 2013 no companies were using UAVs. ESRI ArcGIS continues to be the dominant geographic information system used by New Zealand's forest management companies (91%), though 22% of companies now use free GIS software, like QGIS or GRASS. The use of specialised software (e.g. FUSION, LAStools) for LiDAR or photogrammetric point cloud analysis increased since 2013, but most forestry companies who are processing .las files into various products (e.g. digital terrain model) are using ArcGIS.

Conclusions: This study showed that there had been a progression in the uptake of geospatial technologies in the New Zealand plantation forest management sector. However, there are still barriers preventing the full utilisation of these technologies. The results suggest that the industry could benefit from investing in more training relating to geospatial technologies.

Keywords: Geospatial technologies; GNSS; GPS; remote sensing; GIS; forestry; education; UAV.

Introduction

Geospatial technologies and techniques are used to acquire, manipulate, and analyse geographic data (Wang 2017). Those that are commonly applied to forest description and management include the Global Navigation Satellite System (GNSS), Geographic Information Systems (GIS) and remote sensing (Wing & Sessions 2007). GNSS allows for accurate geographic locations to be ascertained and navigation to be undertaken. Remote sensing refers to acquiring information about features or processes without direct measurement or contact; it is reliant upon sensors designed to receive electromagnetic radiation after it has reflected off of a feature of interest (Wulder & Franklin 2003). Aerial imagery, satellite imagery, and Light Detection and Ranging (LiDAR) are examples of remote sensing. GIS are software designed to manage, analyse, and communicate geographic data. The development of geospatial technologies over the past 50 years has occurred rapidly, producing data that are cheaper and faster to acquire and use (Dash et al. 2016).

The use of geospatial technologies, products, and analyses has been applied to a diverse range of forestry applications including forest health monitoring (Coops et al. 2003), mapping forest disturbances (Savage et al. 2017), harvest and road planning (Abdi et al. 2009; Akay et al. 2009; Holopainen et al. 2014; Olivera et al. 2016), forest inventory and resource mapping (Dassot et al. 2011; Pont et al. 2015; Xu et al. 2019), as well as carbon inventory (Stephens et al. 2012).

The range of applications to which geospatial technologies are applied potentially reflects the widespread availability of the data, software, and technologies. While many forestry companies acquire their own geospatial data at considerable cost (e.g. aerial imagery, LiDAR data; (Morgenroth & Visser 2013)), data can often be freely downloaded from publicly available data repositories (Dash et al. 2016). For instance, Land Information New Zealand (LINZ) provides free public access to all orthorectified aerial imagery and LiDAR data for New Zealand. Likewise, the entire Landsat satellite image archive, spanning from 1972 until present day, is freely available online (Phiri & Morgenroth 2017). In addition to data being freely available, the hardware required to collect data is becoming more widely available due to low purchase costs. The costs of unpiloted aerial vehicles (UAVs) and accompanying sensors have decreased (Marris 2013), essentially democratising the acquisition of some forms of remotely sensed data.

The advances in geospatial technologies, their widespread availability, and their use in various applications explain why geospatial skills and knowledge have become requirements for many entry-level jobs within forest companies (Sample et al. 2015). Merry et al. (2016) found that 71% of recent graduates from forestry education programmes used GIS at least every second day in their jobs in the United States, which was a 28% increase from 2007 (Merry et al. 2007). A study in the United States for entry-level forestry jobs found that 70% of job advertisements required that the applicant had knowledge and skills relating to mapping technologies (Bettinger & Merry 2018). In another study, 68.7% of forestry employers expected early-career foresters to have geospatial skills, including remote sensing, GIS, and GNSS (Sample et al. 2015). It is clear that geospatial knowledge and skills are considered critical by forestry employers.

The number of forestry education departments requiring a GIS component as a part of the degree has increased. 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). In a follow-up survey conducted in 1999, this rose to 10% (Sader & Vermillion 2000). A different survey conducted in the United States in 2012, reported that 94% of undergraduate forestry degrees required that a geospatial course was taken to complete the degree (Merry et al. 2016).

A study conducted in New Zealand surveyed companies across a variety of industries and found that 44% of those companies believed that there was a shortage of trained GIS specialists across the nation (de Róiste 2014). 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. In addition, the cost of acquiring data and using the hardware and software required for processing and analysing data can be another barrier for companies (Bernard & Prisley 2005; Morgenroth & Visser 2013; White et al. 2016). Clearly there are manifold barriers to uptake of geospatial technologies, so organisational commitment is crucial.

Morgenroth and Visser (2013) completed a study looking at the uptake of geospatial technologies within New Zealand's forest management sector five years ago. Since then, the literature shows rapid developments and advances of geospatial technologies in New Zealand forest research (Dash et al. 2019; Pearse et al. 2018; Pearse et al. 2017; Watt et al. 2016; Watt et al. 2019; Xu et al. 2019; Xu et al. 2017). Whether geospatial technology usage by companies in New Zealand's plantation forestry sector mirrors these research advancements is unknown. As such, there is a need for an update on the 2013 survey results. The objective of this study is to quantify the uptake of geospatial technologies by forestry companies and describe how the acquired data are being applied. Additionally, it will identify the barriers that are limiting the uptake of geospatial technologies in the New Zealand forestry sector. Finally, this study compares these data to previous results to reflect on how geospatial technology adoption has changed over the last five years in New Zealand's plantation forestry sector.

Methods

Data

A web-based questionnaire survey was developed in Google Forms and distributed to prospective respondents (see Additional File). Prior to distribution, a draft survey was sent to two representative respondents from the New Zealand plantation forest industry and their feedback was used to revise the final survey, which was sent to all prospective respondents. The intended recipient of the survey was the company's geospatial manager. On 5 May 2018, the final 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 New Zealand plantation forest industry facts and figures publication (NZ FOA 2018). An additional ten companies were added to the list of survey recipients based on suggestions from forest industry professionals with knowledge of forest management and ownership structures. This approach excluded individual small-scale forest (<1000 ha) owners/managers, but included companies that manage small-scale forests or woodlots on behalf of their owners. When combined, the 29 companies invited to participate manage approximately 80% of New Zealand's plantation forest estate area (1,706,000 ha) (NZ FOA 2018). On 6 June 2018, a personalised follow-up email was sent out to those companies who had not completed the survey. This increased the response rate from 20 to 23 companies. On 22 June 2018, responses were no longer accepted.

The questions developed by Morgenroth and Visser (2013) were used as the basis for the questions in the present survey. Questions were updated to reflect changes in the available geospatial technologies. Standardising the current survey to the 2013 survey allowed for a comparison of results to determine how uptake and barriers had changed over the past five years. The survey comprised seven sections, and asked recipients to answer questions about their company (demographic data), their use of freely available spatial data, their use of positioning technologies, and their acquisition and use of aerial imagery, multispectral imagery, hyperspectral imagery, and LiDAR data.

To minimise confusion, we provided respondents with definitions of the various technologies to which the survey referred. Of particular note, we defined three grades of GNSS as consumer, mapping, and survey grade. These are generic terms to describe GNSS receivers, whereby we described consumer grade receivers as being capable of low positioning accuracy (<10 m) and costing less than $1000. Mapping grade receivers yielded <5 m accuracy and cost $1,000 – $20,000, and survey grade receivers yielded <0.5 m accuracy and cost more than $20,000. In terms of remotely-sensed data, we defined 'aerial imagery' as typically consisting of three bands in the visible wavelengths (red, green, blue) and being acquired from an aerial platform (e.g. aeroplane, UAV). We defined 'multispectral imagery' as typically consisting of four or more bands in the visible and invisible wavelengths (red, green, blue, infrared, etc.) and being commonly acquired from an aeroplane, UAV or satellite platform. 'Hyperspectral imagery' was defined as typically consisting of hundreds of contiguous bands spanning the visible and infrared wavelengths and being acquired from an aeroplane, UAV or satellite platform. LiDAR (also referred to as laser scanning), was described as being acquired aerially or terrestrially and yielding a three-dimensional point cloud that could be used to produce digital terrain models, canopy height models and structural descriptions of forests via LiDAR metrics.

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. Multiple-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 multiple-choice question by having an 'other' choice. Most of the questions within the survey were compulsory and required an answer before the respondent could continue to the next section of the survey. This ensured that no questions were left unanswered.

Analysis

Descriptive statistics were used to summarise the survey results. The answers to open-ended questions were compiled and categorised 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 and Visser (2013) study were compared to the results from the present survey.

Results

Demographic information

Of the 29 companies contacted, 23 responded to the survey (79% response rate). The total forest area managed by those companies was approximately 1,172,000 ha (69% of New Zealand's 1.706 million ha plantation forest estate (NZ FOA 2018)). The size of the estates managed by individual companies ranged from 1,000 ha to 177,000 ha (quartile 1 = 19,000 ha, median = 33,000 ha, quartile 3 = 63,150 ha).

Fifty-two percent of the companies that responded to the survey identified themselves as forest owners and managers, 44 percent were forest management companies. While the intended recipient of the survey was each company's geospatial manager this was not always possible. One management company 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 their behalf. Other smaller management companies did not have an employee appointed as a geospatial manager, so the most appropriate staff member responded to the survey.

Data acquisition, processing, and barriers to uptake

The acquisition of freely available data was common and supported plantation forest management for all 23 companies who responded to the survey. Orthorectified aerial imagery was the most commonly used product (83% of respondents), while satellite imagery was acquired by 65% of respondents. With respect to derived geographic datasets, the Land Cover Database (LCDB, Manaaki Whenua – Landcare Research) was acquired by 70% of companies, followed by datasets in the Fundamental Soil Layers (FSL, Manaaki Whenua – Landcare Research) (61%). Other derived datasets, including the Land Use Carbon Analysis System (LUCAS) layers (Ministry for the Environment) (39%), S-map (Manaaki Whenua – Landcare Research) (30%), and virtual climate station network data (NIWA) (17%) were acquired by fewer than 40% of respondents. In terms of online spatial data repositories, the Land Information New Zealand (LINZ) Data Service portal was used by 91% of companies, while Koordinates (78%), the Land Resource Information System (LRIS) portal (57%), and the Ministry for the Environment data service (52%) were also used by more than half of the respondents. Other datasets and online data portals were used by forestry companies, but less commonly.

Positioning technology

All of the forest management companies used global navigation satellite system technology. Sixty-one percent used two or more grades of receivers. Consumer grade handheld receivers (e.g. Garmin 60CSx) were the most commonly used (83%). Consumer grade receivers built in to devices such as a mobile phone or tablet were also used by 65% of the respondents. Survey and mapping grade receivers that can provide more accurate and precise positioning, each had the same level of uptake (22%).

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

Aerial imagery

Aerial imagery was the most commonly acquired form of remotely sensed data, with all responding companies acquiring aerial imagery. Unpiloted aerial vehicles and aeroplanes were the most commonly used platforms to acquire aerial imagery, with 83% of respondents indicating that one or both platforms were used. One company used a helicopter to acquire their aerial imagery.

When asked if the company acquired their aerial imagery on a regular basis, thirteen companies (57%) acquired aerial imagery on an as-needed basis. This was facilitated by the use of UAVs to acquire imagery 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 imagery on an annual basis for their entire estate in addition to irregularly collecting imagery for areas of interest. Eight companies (35%) only acquired aerial images on a regular cycle. These regular acquisition cycles ranged from quarterly up to three years.

The spatial resolution of the aerial imagery acquired via UAV was frequently finer than that acquired via an aeroplane. Thirty-five percent of the companies acquired aerial imagery at two or more differing spatial resolutions. The reported resolution of aerial imagery ranged from 0.1 m to 5 m, with the latter suggesting that despite respondents being provided with a definition of aerial imagery, there may have been some confusion or there was a typo in the response. This is because it is not likely that 3-band RGB aerial imagery, acquired by UAV or aeroplane, would have a spatial resolution as poor as 5 m. Nevertheless, respondents stated that the acquired imagery were used to produce true-colour orthophotos (91%) and photogrammetric point clouds (32%).

Multispectral imagery

Multispectral imagery was acquired by 48% (n = 11) of the forestry companies, with another two companies stating they were planning on acquiring the imagery in the near future. The lack of staff knowledge or training was the most common barrier preventing companies from acquiring multispectral imagery (50%), followed by the cost of acquiring multispectral imagery (42%). Finally, one third of companies did not perceive any benefit from acquiring multispectral imagery.

Multispectral imagery was most frequently obtained from satellite platforms (82%), with Sentinel imagery being most commonly acquired (73%). RapidEye and Landsat imagery were also used by 36% and 27% of companies, respectively. UAVs and/or aeroplanes were also used to acquire multispectral imagery by two of the eleven (18%) companies that acquired multispectral imagery. Ten of the eleven companies acquired multispectral imagery only when it was required. The one company that did acquire multispectral imagery on a regular basis did so annually.

The spatial resolutions of the multispectral imagery differed depending on the platform from which data were acquired. The spatial resolution of multispectral imagery acquired using a UAV was 10 cm. In contrast, acquisition of the imagery via satellite resulted in spatial resolutions ranging from 3 m 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 who use multispectral imagery derived the Normalised Difference Vegetation Index (NDVI), while one company also derived the Enhanced Vegetation Index (EVI).

Hyperspectral imagery

Only 9% (n=2) of the companies that responded to the survey 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%).

Despite respondents being provided with a definition of hyperspectral imagery, the detail in the responses suggest there may have been some confusion. Both companies acquiring hyperspectral imagery responded that they did so via satellite, though neither specified which imagery they acquired. However, the companies did report the spatial resolution of their hyperspectral imagery, with one company reporting 3 m to 5 m resolution and the other 10 m to 20 m resolution. Given that we are not aware of any hyperspectral sensors on satellite platforms capable of acquiring data at those resolutions, we suggest that the companies misconstrued multispectral satellite imagery as hyperspectral imagery.

LiDAR data

LiDAR data were used by 70% (n=16) of the companies, with two additional 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.

Aeroplanes were the most common platforms for acquiring LiDAR data (94%), but UAVs were used by 13% of the companies. The density of the LiDAR point clouds ranged from 2 to 20 points m^{-2}. Ten companies (63%) acquired LiDAR data with a resulting point cloud density of 4 points m^{-2} or less. LiDAR data were 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 collected LiDAR data with no intention of acquiring it again in the future.

All companies that acquired LiDAR data used it to derive digital terrain models (DTM). Canopy height models (CHM) (69%) were also commonly derived, while volume estimates and stem counts were estimated from LiDAR data by seven companies (44%). There were products that companies were not acquiring or deriving but would want to obtain in the future. These products, including estimates of stocking, biomass, individual tree height and volume, grade mix, and phenotyping could provide more detailed forest description for managers.

Processing of the tiled LiDAR files into various products (e.g. DTM, CHM, LiDAR metrics) was outsourced to an aerial surveying company for 63% (n=10) of the companies, while 56% (n=9) of companies also outsourced parts of LiDAR processing to a third-party organisation. Some LiDAR products were derived in-house by 31% (n=5) of the companies, but no company produced all their LiDAR products in-house.

Application of remotely sensed imagery

The most common application of aerial imagery was for general forest overviews and mapping. LiDAR and aerial imagery were commonly used for harvest planning (Table 1). Aerial imagery and LiDAR had other mutual applications which included site preparation, silvicultural planning and road mapping. LiDAR had the widest variety of applications, followed by aerial and multispectral imagery.

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 imagery were used for natural event assessment, examples of which include windthrow mapping, assessing snowfall damage and fire damage.

Software

ArcGIS (Environmental Systems Research Institute, Redlands, California, USA) was the most commonly used software for working with data collected from all four remote-sensing technologies (Table 2). Free GIS software such as QGIS (QGIS Development Team) or Geographic Resources Analysis Support System (GRASS) (GRASS Development Team) were also commonly used geographic information systems. Agisoft Photoscan (Agisoft LLC, Russia) (now called Agisoft Metashape) was used by two companies for photogrammetric point cloud data processing. FUSION (McGaughey 2018), LAStools (rapidlasso GmbH, Germany), and Quick Terrain (QT) Modeller (Applied Imagery, United States of America) were used when working with LiDAR data, though each was only used by two companies; in contrast, five companies used ArcGIS to process .las tiles into products (i.e. DTM, CHM). The majority of companies used two or more different types of software when working with remotely sensed data. ATLAS GeoMaster, a spatial stand record system, was used by ten companies.

Changes to uptake between 2013 and 2018

The uptake of use of different technologies and data has changed over the last five years. There was a progression in the uptake of GNSS receivers, with the proportions of companies using each grade of GNSS receiver having changed. Five years ago, none of the companies surveyed reported using consumer grade receivers built into devices (such as a mobile phone or tablet). The results from the most recent survey showed that 65% of companies were using this grade of receiver (Table 3). In 2018, there were fewer companies using consumer and mapping grade receivers compared to five years ago. In contrast to these decreases, the proportion of companies using survey grade receivers nearly doubled, going from 12% in 2013 to 22% in 2018.

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% of companies in 2018 (Table 4). Comparably, the progression in the uptake of aerial imagery (+12%) and multispectral imagery (+13%) were modest, though both had much higher rates of use in 2013.

There was an increase in the uptake of most software stated in the most recent survey compared to five years ago (Table 5). The largest increase was in the uptake

TABLE 1: Application of remote sensing imagery to forest management. n = number of companies adopting remote sensing for a particular application. % = percentage of all companies adopting a particular remote sensing type that applied it to a particular application.

	Aerial Imagery		**Multispectral Imagery**		**Hyperspectral Imagery**		**LiDAR Data**	
Application	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
General forest overview and mapping	15	68	5	45	-	-	-	-
Harvest planning	13	59	-	-	-	-	12	75
Cutover mapping	13	59	3	27	1	50	-	-
Site preparation	5	23			-	-	4	25
Silvicultural planning	3	14			-	-	1	6
Road mapping	6	27			-	-	-	-
Natural event assessment	2	14	3	27	-	-	-	-
Historic site identification	-	-	-	-	-	-	3	19
Hazard identification	2	9	-	-	-	-	2	6
Species identification	-	-	5	45	1	50	-	-
Forest health assessment	-	-	5	45	1	50	-	-
Where aerial imagery is not available	-	-	2	18	-	-	-	-
Wilding identification	-	-	1	9	-	-	-	-
Inventory	-	-	-	-	-	-	5	31
Slope management	-	-	-	-	-	-	3	19
Forest valuation	-	-	-	-	-	-	3	19
3D models	-	-	-	-	-	-	1	6

TABLE 2: Software used when working with acquired imagery. n = number of companies using the software.

		Aerial Imagery		**Multispectral Imagery**		**Hyperspectral Imagery**		**LiDAR Data**	
Software class	**Software**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Geographic Information System	ESRI ArcGIS	21	91	11	100	2	100	5	56
	Free GIS	4	18	1	9	1	50	-	-
	Global Mapper	2	9	-	-	-	-	-	-
Image analysis	ERDAS IMAGINE Image Analysis Software	1	5	1	9	-	-	-	-
	Trimble eCognition Image Analysis Software	1	5	1	9	-	-	-	-
LiDAR or photogrammetric point cloud analysis and processing	FUSION	-	-	-	-	-	-	2	22
	LAStools	-	-	-	-	-	-	2	22
	QT Modeller	-	-	-	-	-	-	2	22
	Agisoft Photoscan	2	9	-	-	-	-	-	-

TABLE 3: Progression of uptake of GNSS receivers by grade.

		Consumer – handheld	Consumer – in device	Mapping	Survey
Percentage of respondents using the technology	2013	100	-	41	12
	2018	83	65	22	22

TABLE 4: Progression of uptake of remote sensing technologies.

		Aerial Imagery	Multispectral Imagery	Hyperspectral Imagery	LiDAR Data
Percentage of respondents using remotely-sensed imagery	2013	88	35	-	17
	2018	100	48	9	70

of free GIS software, from 6% in 2013 to 22% in 2018. ArcGIS saw the next largest increase in use, up 9% on 2013 use, while MapInfo use dropped from 18% in 2013 to 0% in 2018. In terms of image analysis software, ERDAS and Trimble e-Cognition software both showed small increases of 1% and 4%, respectively. Only two companies (9% of respondents) reported using point cloud analysis and processing software in 2018, though none reported using it in 2013.

Discussion

The results from the survey identify the geospatial technologies used within the New Zealand plantation forest management sector, how they are used, and the barriers to their use.

All the respondent companies used GNSS receivers, however, there has been a change in the most commonly used grade of receiver compared to five years ago. The use of dedicated consumer grade GNSS receivers decreased from 100% in 2013 to 83% in 2018, which is possibly a consequence of companies using positional data from devices (e.g. tablets, mobile phones) with built-in GPS receivers. These latter devices were not reported as being used by any companies in 2013, but were used by 65% of respondents in 2018. The increase in the uptake of GNSS receivers within devices, such as tablets and smart phones, is likely aided by the improvement in technology and the versatility of these devices. The decrease in the uptake of mapping grade receivers, from 41% (2013) to 22% (2018) may be a consequence of the improved accuracy and precision of consumer grade receivers (Tomaštík et al. 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. In contrast, the increase in use of survey grade receivers may result from the need to ensure ground-

TABLE 5: 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**	**Change**
Geographic Information System	ESRI ArcGIS	82	91	+9
	MapInfo	18	0	-18
	Global Mapper	0	9	N/A
	Free GIS	6	22	+16
Image Analysis	ERDAS IMAGINE Image Analysis Software	12	13	+1
	Trimble eCognition Image Analysis Software	0	4	+4
LiDAR or photogrammetric point cloud analysis and processing	FUSION	0	9	+9
	LAStools	0	9	+9
	QT Modeller	0	9	+9
	Agisoft Photoscan	0	9	+9
Specialist forestry software	ATLAS GeoMaster	35	43	+8

based data can be co-located with high-resolution remotely sensed data, in particular LiDAR data. This is because of the common practice of correlating ground-based inventory measurements with LiDAR plots, such that LiDAR metrics can subsequently be used for forest description across entire estates. Moreover, the shift to survey grade receivers may also indicate a desire to minimise positional error associated with multi-pathing beneath forest canopy.

The number of companies acquiring aerial imagery has increased by 14% since 2013, with all forest management companies stating that they acquired aerial imagery. The applications for aerial imagery have remained similar over the past five years but how the aerial imagery is acquired has changed. While in the 2013 survey, the cost of acquisition was the main barrier to uptake, that no longer appears to be an issue; perhaps this is because many companies (83% of them) are now using UAVs to acquire aerial imagery. The use of UAVs to capture aerial imagery was not reported by forest management companies in Morgenroth and Visser's 2013 study, but presumably, the development of cheaper, smaller sensors and UAVs has improved access to this technology. Respondents reported that UAVs allowed them to collect imagery when required for a target area and also when cloud cover would hinder the acquisition of imagery from a satellite or aeroplane. Whether UAVs completely replace aeroplanes to acquire aerial images in the foreseeable future will depend on whether the shortcomings of UAVs (e.g. battery life, payload limitations, the regulatory framework, easy to use software; Coops et al. (2003); Heaphy et al. (2017)) can be solved.

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 availability of free satellite imagery with spatial resolution ≤ 30 m (e.g. Landsat 8, Sentinel-2, PlanetScope), may have resulted in forestry companies experimenting with the utility of this data. The lack of best practice guidelines and the developing technical capacity of the industry needs to improve to fully utilise technologies such as multispectral imagery. This lack of knowledge is not specific to the forestry sector and can be seen across a range of industries in New Zealand (de Róiste 2014). More education and training for geospatial professionals will be required to process and analyse remotely sensed data such that it can be better utilised in the future. Tertiary education and other training providers have a role to play here. While the survey was not designed to question educational or training preferences, previous research on GNSS training found a strong preference for formal hands-on training, as opposed to online or in-person lectures (Bettinger et al. 2019). In the future, the uptake of multispectral imagery may 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. As with the increase in aerial imagery acquisition between 2013 and 2018, multispectral imagery acquisition may increase in future as suitable sensors become available for UAVs at sufficiently low costs.

All but one of the companies that acquired multispectral imagery also acquired LiDAR data. 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 data 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), stand age (Xu et al. 2018) and to classify forest cover (Dupuy et al. 2013). Though no survey question specifically asked about data fusion, 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 optimise the information that can be extracted from analyses.

Though two companies did report acquiring hyperspectral imagery, we suspect their responses were incorrect; based on the reported spatial resolutions. It is likely that respondents had actually acquired multispectral satellite imagery. Nevertheless, the low uptake of hyperspectral imagery was not unexpected. While its benefits can be considerable, the imagery and its acquisition suffer from a number of drawbacks (Adão et al. 2017). The imagery contains hundreds of bands, spreading across the electromagnetic spectrum, and processing can be complex. Moreover, the limited conditions under which imagery can be acquired and the cost of acquisition can have an influence on the uptake of hyperspectral imagery. Anecdotally, there are few hyperspectral data providers in NZ, thus the cost remains high in the absence of competition. Finally, there can be a trade-off between spectral resolution and spatial resolution. It may be that companies value spatial resolution more than spectral resolution for many forestry applications. Many of the survey respondents listed the factors above as reasons for not acquiring hyperspectral imagery.

The uptake of LiDAR data and its products has seen the most significant increase of all the remote-sensing technologies included in the survey, increasing from 17% to 70% of companies since 2013 (Morgenroth & Visser 2013). Since the 2013 survey, methods to operationalise aerial LiDAR data have been developed (Dash et al. 2015), so the increased use shown in the present study is not surprising. 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 42% of recent forestry programme 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 conducted in 2007 (Merry et al. 2007; Merry et al. 2016).

The main barrier preventing uptake of LiDAR in both 2013 and 2018 surveys was the cost. Smaller companies are not acquiring LiDAR data due to 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 imagery or multispectral imagery (Kelly & Di Tommaso 2015). However, the results from the survey indicate that forest management companies were willing to acquire LiDAR, despite the cost, due to perceived benefits. It should also be noted that the cost of acquiring LiDAR, when acquired and processed efficiently, is more cost-effective in comparison with intensive fieldwork (Hummel et al. 2011).

Given the cost barrier for LiDAR data acquisition and the growing acquisition of aerial imagery via UAV, perhaps future requirements for three-dimensional forest description will look towards photogrammetric point clouds, rather than LiDAR-derived point clouds. Photogrammetric point clouds have been shown to be useful for a number of forest inventory purposes (Iglhaut et al. 2019; Pearse et al. 2018; White et al. 2013) and were already produced by 32% of surveyed companies.

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 obtain 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 survey response rate was imperfect, with 23 of 29 companies responding. Nevertheless, the results presented are from companies with net stocked areas comprising 69% of New Zealand's 1.706 million ha plantation forest estate (NZ FOA 2018). We believe the results of this survey to be generalisable to medium- and large-scale plantation forest managers or owners in New Zealand, though acknowledge the potential bias against small-scale forest owners or managers. Moreover, we did not control for non-response bias, so it is possible that presented results are non-representative of New Zealand's entire plantation forestry sector. Finally, it's worth noting the importance of respondents having a clear understanding of the terms used in survey questions. A small number of responses to questions about aerial imagery and hyperspectral imagery suggested respondent confusion or misunderstanding. While we provided respondents with clear definitions of those terms, it may not have been sufficient to prevent incorrect responses to questions about spatial resolution.

Conclusions

The results from this study have shown that all forestry companies that were surveyed were making use of online data portals and acquiring freely available datasets (e.g. aerial photography, soil and climate data). GNSS and aerial imagery were the most commonly used geospatial technologies in New Zealand's forestry sector. Companies were also making use of multispectral imagery and LiDAR data.

The most common barriers preventing the uptake of geospatial technologies were the lack of staff education and the cost of acquiring the data. These barriers are comparable to barriers identified during Morgenroth and Visser's 2013 survey and suggest that in order to get the most out of available technologies, forest industry may need to invest in more training. Despite these barriers, 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 (from 17% to 70%).

The results suggest that the application of geospatial technologies and remotely sensed data to plantation forest management is a rapidly growing field in New Zealand. This supports similar rapid growth in these fields in other parts of the world (White et al. 2016). The collection and application of accurate and detailed data acquired from these technologies will support better forest management decisions. The improvement of forest management operations and decisions should lead to greater commercial gains (Melville et al. 2015). The results of this survey will be informative for forest managers who have an interest in remaining on the cutting edge, educators who want to ensure teaching material is relevant, and the wider geospatial industry who are likely to be interested in the barriers, actual or perceived, to adoption of the technologies reported on in this study.

List of abbreviations

CHM	Canopy Height Model
DTM	Digital Terrain Model
EVI	Enhanced Vegetation Index
GIS	Geographic Information System
GRASS	Geographic Resources Analysis Support System
GNSS	Global Navigation Satellite System
LRIS	Land Resource Information System
LUCAS	Land Use Carbon Analysis System
MTH	Mean Top Height
NDVI	Normalised Difference Vegetation Index
QGIS	Quantum GIS
QT Modeller	Quick Terrain Modeller
UAV	Unpiloted Aerial Vehicle

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

JM conceived the study. SdG, JM, and CX contributed to the design of the study and distribution of the survey to the wider industry. SdG collated survey responses, summarised data, and wrote the manuscript. JM and CX advised on data interpretation and revised the manuscript. All authors read and approved the final manuscript.

Additional Files

Additional File 1: survey sent to respondents.

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An updated survey on the use of geospatial technologies in New Zealand's plantation forestry sector

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Additional File 1: Survey sent to respondents.

Survey title: Uptake of Geospatial Technologies in the New Zealand Forest Industry

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

10. Does your company use aerial photography? Aerial photography typically consists of three bands (red, green, blue) and is acquired from an aerial platform (e.g. plane, UAV)
    - ☐ Yes – go to question 12
    - ☐ No – go to question 11
11. What are the reasons for not using aerial photography?
    - ☐ Cost
    - ☐ No perceived benefit
    - ☐ Current staff lack knowledge or training to use aerial photography
    - ☐ Was not aware of aerial photography
    - ☐ Other:
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

18. Does your company use multispectral imagery? Multispectral imagery typically consists of four or more bands (red, green, blue, infrared, etc) and is acquired from an airplane, UAV or satellite.
    - ☐ Yes – go to question 20
    - ☐ No – go to question 19
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:
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

28. Does your company use hyperspectral imagery? Hyperspectral imagery typically consists of hundreds of bands spanning the visible and infrared wavelengths and being acquired from an airplane, UAV or satellite platform
    - ☐ Yes – go to question 30
    - ☐ No – go to question 29
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:
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. 20 metres.

LiDAR

35. Does your company use LiDAR data? LiDAR stands for Light Detection and Ranging, it is also known as laser scanning. LiDAR data is acquired aerially or terrestrially and yields a three-dimensional pointcloud that can be used to produce digital terrain models, canopy height models and structural descriptions of forests via LiDAR metrics.
    - ☐ Yes – go to question 37
    - ☐ No – go to question 36
36. What are the reasons for not using LiDAR imagery?
    - ☐ Cost
    - ☐ No perceived benefits

- ☐ Current staff lack knowledge or training to use LiDAR
- ☐ Was not aware of LiDAR
- ☐ Other:

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 cloud density (points/m^2) 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 (e.g. 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 (e.g. 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?