Auckland's Urban Forest Canopy Cover: State and Change (2013-2016/2018)

Nancy Golubiewski, Grant Lawrence, Joe Zhao, Craig Bishop

July 2020 Technical Report 2020/009

Research and Evaluation Unit RIMU

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Executive summary

The structure and function of Auckland’s forests are important to the region for both the ecosystem services they provide and their intrinsic value. In recent years, a building boom resulting from economic growth and housing demand has resulted in land-use change that includes noticeable tree removals, especially in urban areas where development activities are both intensifying and expanding the built environment. Across Auckland, urban areas expanded eight per cent between 1996 and 2012 and a further four per cent between 2012 and 2018/19.

This project quantified the extent of tree canopy cover across 16 local boards in the central and mostly urban part of the Auckland region: Papakura, Manurewa, Ōtara-Papatoetoe, Māngere-Ōtāhuhu, Howick, Maungakiekie-Tāmaki, Ōrākei, Waitematā, Albert-Eden, Puketāpapa, Whau, Henderson-Massey, Upper Harbour, Kaipātiki, Devonport-Takapuna, and Hibiscus and Bays. Data collected between 2016 and 2018 were assessed and analysed to identify the characteristics of the canopy in this period and to detect any changes that have occurred since 2013. A canopy height model was produced from Auckland Council’s 2016/18 LiDAR data to serve as a comparable tree canopy cover to the 2013 one.

The extent of tree canopy is an issue of scale: describing coverage depends on the size of the area under consideration. That is, while regional canopy cover is 18 per cent, canopy cover ranges from 8 to 31 per cent across the 16 urban local boards. The composition of land cover and/or land use, and whether one dominates, in the particular boundary area (from parcel through suburb and local board to region) influences the aggregate tree cover. While 11 of the 16 local boards meet the minimum of 15 per cent canopy cover in Auckland’s Urban Ngahere (Forest) Strategy, the five south Auckland local boards in this study are under the 15 per cent minimum threshold for tree canopy cover.

A slight increase (0.5%) in urban forest cover compared to 2013 was detected across all the local boards. Gains and losses across the 16 urban local board areas largely balance each other out. At finer scales, however, more distinct net changes are detectable; for example, the net changes ranged from -8% to +14% at the local board level. Changes also vary according to land cover, land use, and tenure. Importantly, the characteristics of gains and losses differ: gains in canopy cover largely consist of biomass growth of existing vegetation throughout the entire tree canopy – small but ubiquitous instances of tree growth and crown expansion, whereas, tree canopy losses were a combination of small, widespread instances (e.g., from maintenance such as pruning and trimming) and discrete events, usually larger in area than the dispersed new growth. Discrete loss events are far more noticeable, and ecologically different, than small, dispersed growth.

This report on the tree canopy presents early findings of the first comprehensive, regional assessment of Auckland's urban forests and its change over a three to five-year period. It provides an overall assessment, from which more detailed studies can build in the future.

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1.0 Introduction

The structure and function of Auckland's forests are important to the region for both the ecosystem services they provide and their inherent value. In recent years, a building boom resulting from economic growth and housing demand has resulted in land-use change that includes noticeable tree removals, especially in urban areas where development activities are both intensifying and expanding the built environment.

Across Auckland, urban areas (defined coarsely for the purposes of the national Land Cover Database, and including both impervious and vegetative land covers) expanded 8% between 1996 and 2012 (LAWA), and a further 4% between 2012 and 2018. Tree plantings have also occurred in these areas and in exotic forest; the latter also increased 8% between 1996 and 2012 (LAWA), and a further 6% between 2012 and 2018. In contrast, the largest land-cover loss, in terms of both quantity and proportion, was exotic grassland, decreasing 4% between 1996 and 2012 (LAWA), and a further 11% between 2012 and 2018. Due to the resolution of the national land cover dataset, however, detail is missing about vegetation gains and losses within each land-cover category.

Understanding the status of tree cover throughout the region (in particular, in developed urban areas) is of significant interest to numerous groups and individuals, including Auckland Council itself, elected officials, and the general public. Yet, comprehensive information about changes in tree canopy cover within these land-cover and land-use changes has been lacking. Accurate data and robust analyses are needed to fill knowledge gaps in order to provide useful information to the general public and decision-makers.

An initial study was conducted on the Urban Forest of Waitematā Local Board based on data collected in 2013 (Bishop and Lawrence 2017). This was followed by a study of tree loss in Waitematā Local Board between 2006 and 2016 (Lawrence et al. 2018). In March 2019, Auckland Council released the Auckland's Urban Ngahere (Forest) Strategy (Auckland Council 2019a), which includes among its 18 actions one to monitor the status and change of Auckland's tree canopy cover[1]. The need to understand Auckland's tree canopy cover extends to other programmes as well, including ecological corridor modelling and Auckland's greenhouse gas inventory.

This project addresses these needs by constructing and analysing tree canopy cover from data collected between 2016 and 2018 to provide an assessment for this time period and to detect any changes during a nominal three to five- year period (compared

[1] Stated as "Incorporate three-yearly LiDAR surveys in council work programmes".

to the previously developed 2013 tree canopy cover). This will provide both a baseline for the status of tree cover at the time the Auckland Unitary Plan came into effect (operative in part as of November 2016 (Auckland Council 2016a)) and an opportunity in the future to evaluate the effect of changes to tree protection rules and policies, which came into force in 2013.

1.1 Objectives

This report evaluates the state of Auckland's forests as of 2016-18 and changes that have occurred since 2013. This involves:

- Developing tree canopy models (as raster GIS layers) from the most recent available source data (here, Auckland Council's LiDAR data acquisition collected between 2016 and 2018).
- Characterising the state of the tree canopy cover across the 16 predominantly urban local boards located in the central part of the region according to land cover, land use, and tenure.
- Conducting a change detection in tree canopy cover between 2013 and 2016/18.

2.0 Methods

2.1 Study area

For the purposes of this report, the 16 local boards in the central and predominantly urban part of the Auckland region serve as the study area boundary (Figure 1). This corresponds to the boundary used to define the 2013 urban forest canopy cover area (Auckland Council 2019a) and so allows comparisons to be made between the two time periods. The 16 local boards that make up this area are: Papakura, Manurewa, Ōtara-Papatoetoe, Māngere-Ōtāhuhu, Howick, Maungakiekie-Tāmaki, Ōrākei, Waitematā, Albert-Eden, Puketāpapa, Whau, Henderson-Massey, Upper Harbour, Kaipātiki, Devonport-Takapuna, and Hibiscus and Bays. For this report, the tree canopy data are available for the 16 local boards in full.

2.2 Data

LiDAR stands for Light Detection and Ranging; it is an active remote sensing method that uses light (in the form of pulses from a laser) to generate three-dimensional information about the Earth surface. The LiDAR system consists of the LiDAR unit itself, including a laser to scan the earth, a global positioning system (GPS) to record location, an inertial measurement unit (IMU) to track the tilt of the plane, and a computer to record the information. The laser scanner sends and receives up to 400,000 pulses of light per second in the near infra-red part of the spectrum.

To collect LiDAR data, the unit is mounted on an aircraft and flown over the area of interest (in this case, the Auckland region). Distance from the sensor to an object on the ground is translated from the time it takes for the pulse to return to sensor. A GPS unit on board tracks the location of the sensor during the entire flight, from which the geographical position (x, y) and height (z) coordinates are assigned to each pulse. The result is a point cloud (Figure 1), which provides a visual representation of the Earth's surface, including ground, buildings, trees, grass, and water bodies. After collection, every point in the point cloud is classified according to its source, using the standard LiDAR point schema developed by the American Society for Photogrammetry and Remote Sensing (ASPRS) (Figure 2).

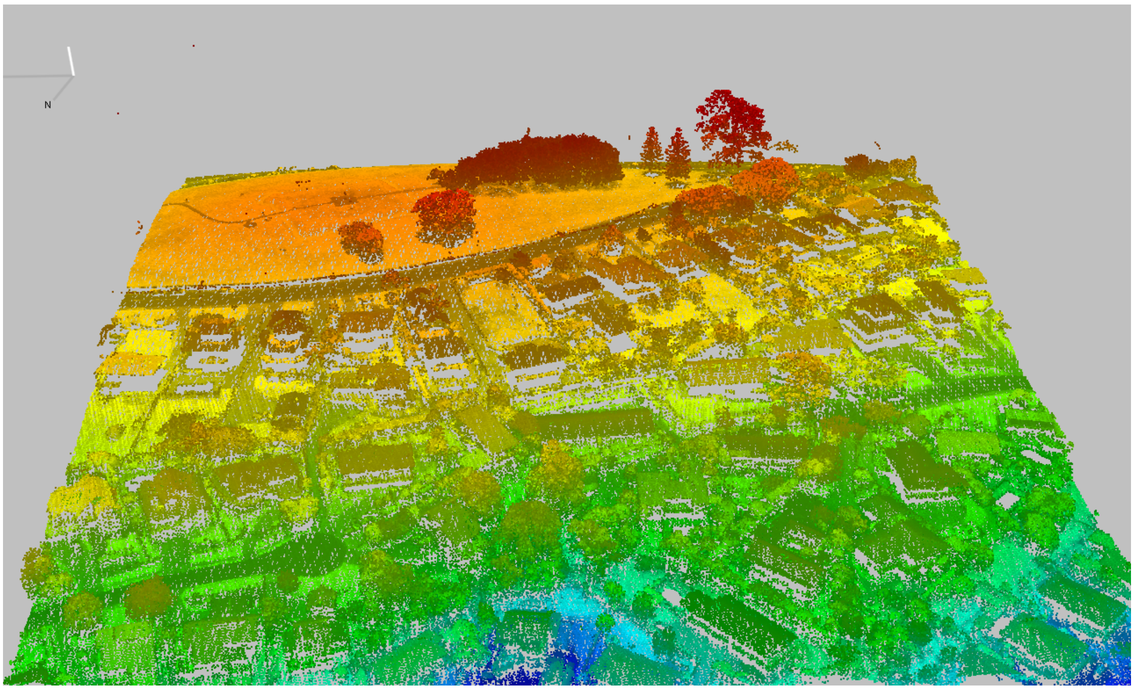

Figure 1 LiDAR point cloud (colour coded by height above sea level), Stockade Hill, Howick

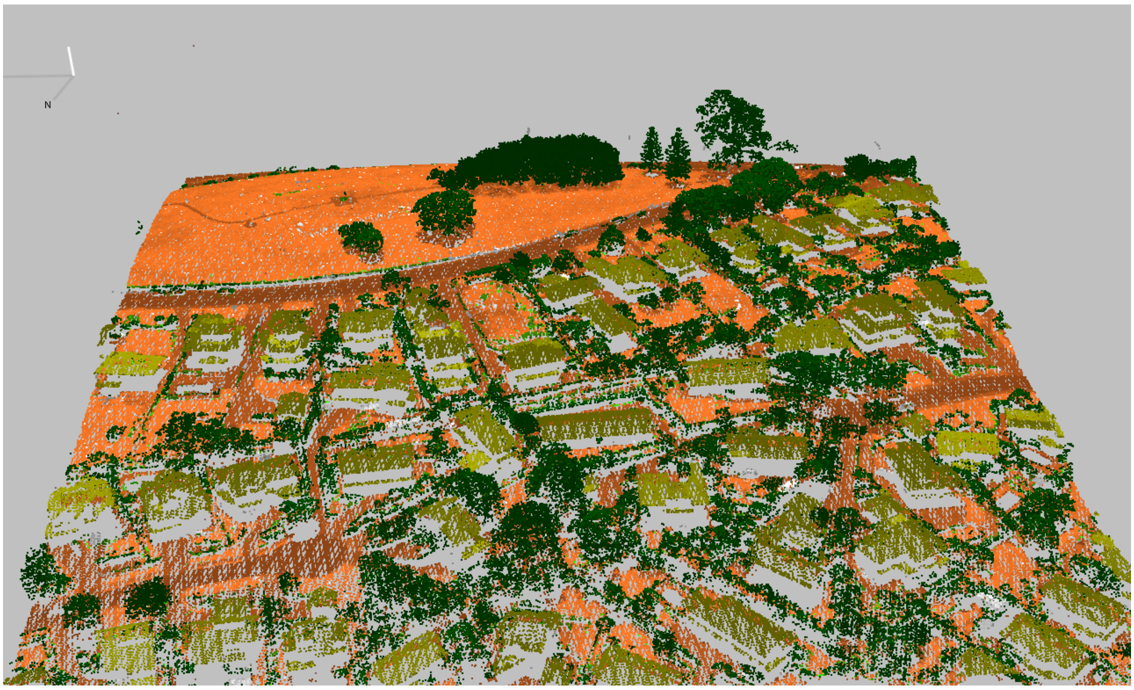

Figure 2 Classified LiDAR point cloud (greens: vegetation classes, yellow: buildings, orange: ground), Stockade Hill, Howick

In a previous project (Bishop and Lawrence 2017), an “urban forest tree canopy cover” dataset was developed from LiDAR source data captured between 17th July and 23rd November 2013. It is a raster with a 1-m cell resolution containing values of average vegetation height per pixel (assigned to one of six height brackets), with a final four way majority filter applied (Bishop and Lawrence 2016, G. Hinchliffe (AUT), personal communication, June 2019).

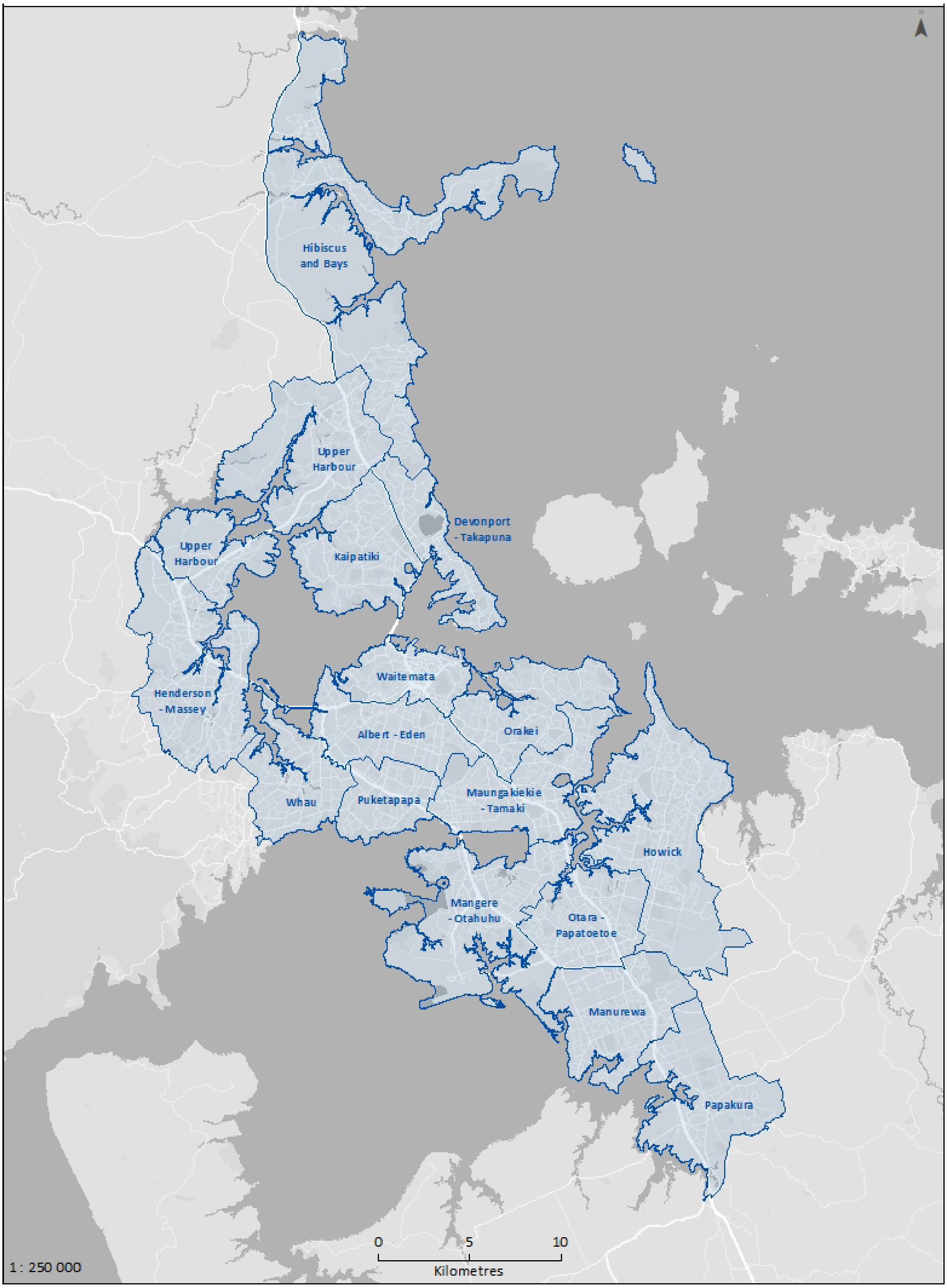

Figure 3 Study area: Auckland's 16 urban local boards

The urban forest status and change detection research presented in this new report was predicated on the availability of Auckland Council's most recent LiDAR data acquisition, which was collected over three flight seasons: 2016, 2017, and 2018 (August 2016 through August 2018) by two aerial survey companies; hereafter, it is referred to as the 2016/18 LiDAR (Auckland Council 2019b). The northern two-thirds of the region (including Hauraki Gulf Islands) were collected between 16 August 2016 and 9 August 2018 (Aerial Surveys Limited 2018). The southern third of Auckland Council's territory was captured between 9 September 2016 and 6 February 2017 (AAM 2018). The project specification was for a minimum of 4 pulses per square metre, with a point cloud accuracy to be ≤0.10 m RMS (vertical) and ≤ 30 cm RM (horizontal), which was met (Auckland Council 2019b). The raw point cloud was classified according to the ASPRS international standard LiDAR classification system, with a specification for 99% classification accuracy ground point (AAM 2018). The resulting LiDAR dataset consisted of a classified 3D point cloud consisting of 90 billion points, in the NZTM map projection and the Auckland 1946 vertical datum.

Within the study area, a high proportion of data collected for both the 2013 LiDAR and the 2016/18 LiDAR timestamps was flown over the winter and spring months, however the alignment of these areas is limited and therefore the seasonal difference between areas could have an impact on the accuracy of the respective derived canopy datasets and resultant change detection. However, the LiDAR sensors are sensitive enough to detect tops of trees/branches during the 'leaf-off' period, and improvements in sensor technology means that there is now little material difference in the average number of ground points between periods (leaf-on or leaf-off). A thorough visual inspection of areas of known deciduous vegetation did not present any obvious issues. This will be further investigated as part of an accuracy assessment.

A number of ancillary datasets were used for data assessment and analysis. For instance, the land boundary of the Auckland region is defined as the level of mean high water springs (MHWS-10), which would be exceeded by 10% of predicted tides in any given year. It is considered a practical measure of the current natural land-sea boundary. As the most recent MHWS line available in Auckland Council's geospatial data store, the Coast Boundary MHWS-10 (MeanHighWaterSpring10m polyline feature class) (Auckland Council 2013) was used to define the region's land-sea boundary. From this, a polygon was created to represent Auckland Council's land base. Other geographical datasets included boundaries for local boards and NZ Fire Service suburbs.

Four different datasets were used to consider land cover, land use, and tenure:

1) Land cover: The most recent (2018/19) version of the Land Cover Database (LCDB), v5.0 – produced from summer 2018/19 satellite imagery and containing 33 classes – provided land-cover information (Landcare Research New Zealand Ltd. 2020).
2) Land Use: RIMU's land use layer was used for this study (Hu 2018). Digital Valuation Roll data (describing rateable units) has been combined with parcel (land) data in order to ascribe a dominant use based on floor area as the land use with the greatest summed rates assessment area on a given parcel. This avoids double counting both land uses (e.g. where there are multiple rates assessments for each land parcel, such as apartments or commercial units) and land area. For this analysis, land-use data representing 'flattened' rates assessments combined with parcel data as at 17 July 2018 were used.
3) Zoning: Unitary Plan Zones-Base Zones as defined in the Auckland Unitary Plan (Operative in Part) (Auckland Council 2016a) describe the current base zoning for the Auckland region (Auckland Council 2016b), and were used for another perspective on land use.
4) Tenure: A dataset developed for the analysis of the 2013 urban forest to indicate tenure (ownership) (Bishop and Lawrence 2017) was also used. RIMU's Publicly Owned Land proxy dataset (Fredrickson, 2018) was combined with primary road parcels (formed and unformed) and a spatial database of public parks administered by Auckland Council to map public land and roads; all remaining primary parcels were tagged as private parcels.

2.3 Analyses

Vegetation canopy height and canopy cover models were produced via raster extraction from the classified LiDAR point cloud. To do so, raster images with a 1-m cell size for canopy heights and canopy densities were created using points classified as low, medium, or high vegetation (classes 3, 4, or 5) using the Fusion software developed by the USDA Forest Service (McGaughey 2018). Subsections of the region were first processed (based on local board boundaries) and then mosaicked into a complete coverage in ArcMap (ESRI 2017).

In order to make comparisons between time periods, a 2016/18 canopy height model (CHM) was developed following the 2013 approach for consistency and to avoid introducing any data anomalies. The values for the average height of vegetation per cell were assigned to one of five height classes (Table 1) and then passed through a majority filter (4-cell rule) in ArcMap (ESRI 2017). The CHM was also cross-checked with a canopy cover model produced from first returns.

Table 1 Height classes assigned to height values in 2016/18 tree CHM raster

Height (m)	Height Class
0-1	0*
1-3	1*
3-5	3
5-10	5
10-15	10
15-20	15
20-30	20
30+	30

*NB: There was no height class 1 (denoting vegetation between 1 and 3 m) in the 2013 tree canopy cover classification (rather, all vegetation under 3 m was assigned to 0), but it was produced and retained in the 2016/18 tree canopy dataset in order to be available for future analyses.

The resulting regional classified CHM was interpreted as the tree canopy cover model for 2016/18 (following the practice used for the 2013 CHM, as noted above). To understand the 2016/18 status of Auckland's forests, the area of tree canopy cover was calculated for local boards as well as land cover, land use, zoning, and tenure using Spatial Analyst tools in ArcMap (ESRI 2017). Tree canopy cover refers to the percentage of a defined area (e.g. a local board or the full study area) covered by the canopy (Barbour et al. 1987).

In order to identify changes in Auckland's tree canopy cover, a change analysis was conducted between the 2013 and 2016/18 tree canopy covers. The 2013 tree canopy was subtracted from the 2016/18 cover in order to identify areas of gain and loss on a pixel by pixel basis. This approach provides initial insight on the fine-scale change dynamics of the urban forest canopy cover and will be used in further investigations. For the summary statistics presented in this report, change is presented as net change, meaning the change at an aggregate or landscape level to quantify the difference in tree canopy cover for a certain area between the two dates. Net change results are presented in hectares, as a percentage of a defined area, and as the percentage of the 2013 tree canopy cover in a defined area.

3.0 Results

3.1 Production of tree canopy cover information from LiDAR

In this report, the 2016/18 urban forest canopy cover was developed as a canopy height model (CHM) for vegetation using Auckland Council's 2016/18 LiDAR classified point cloud to correspond with the 2013 urban tree forest canopy cover. Each 1 m cell value represents the height class (Table 1) derived from average height of vegetation points in that cell, smoothed by a 4-way filter (cf. Section 2.3). The CHM assumes full coverage for any 1-m cell in which vegetation was detected.

For forestry applications, including vegetation and structure modelling, the recommended nominal aggregate pulse density is 3-8 per square metre and recommended returns per pulse is >4 (Laes et al. 2008). Initial quality assessment/ quality control (QA/QC) checks were conducted prior to the construction of the CHM via a QA/QC return intensity analysis in Fusion. These criteria were met or exceeded across the majority of each local board area, with a few exceptions in some areas of low intensity data capture and at the land/sea margin[2], indicating that the source data were of high enough quality to produce robust forest canopy models.

Post-production quality assessment was limited to visual scanning due to the constraints of project timing but could be developed more thoroughly in the future. The NDVI coverage was explored as a filter for identifying false positives and detection of false negatives, but differences in NDVI applicability across land cover/land use types prevented its use as a broad filter. Whereas low NDVI values could broadly identify false positives in largely non-vegetated land uses (such as industrial areas), low NDVI values in forested areas would overcorrect where they could indicate difference in vegetative conditions on the ground (e.g. leaf off). Therefore, the NDVI approach was not used in this particular study but may be further explored in future work for further refinement of the method and resulting dataset.

The 2016/18 tree canopy cover produced for this report (Figure 2) extends fully across Auckland's 16 central, largely urbanized, local boards (Section 2.1).

[2] Return intensity quality assessment and quality control tables and images are not included in this report but are available upon request.

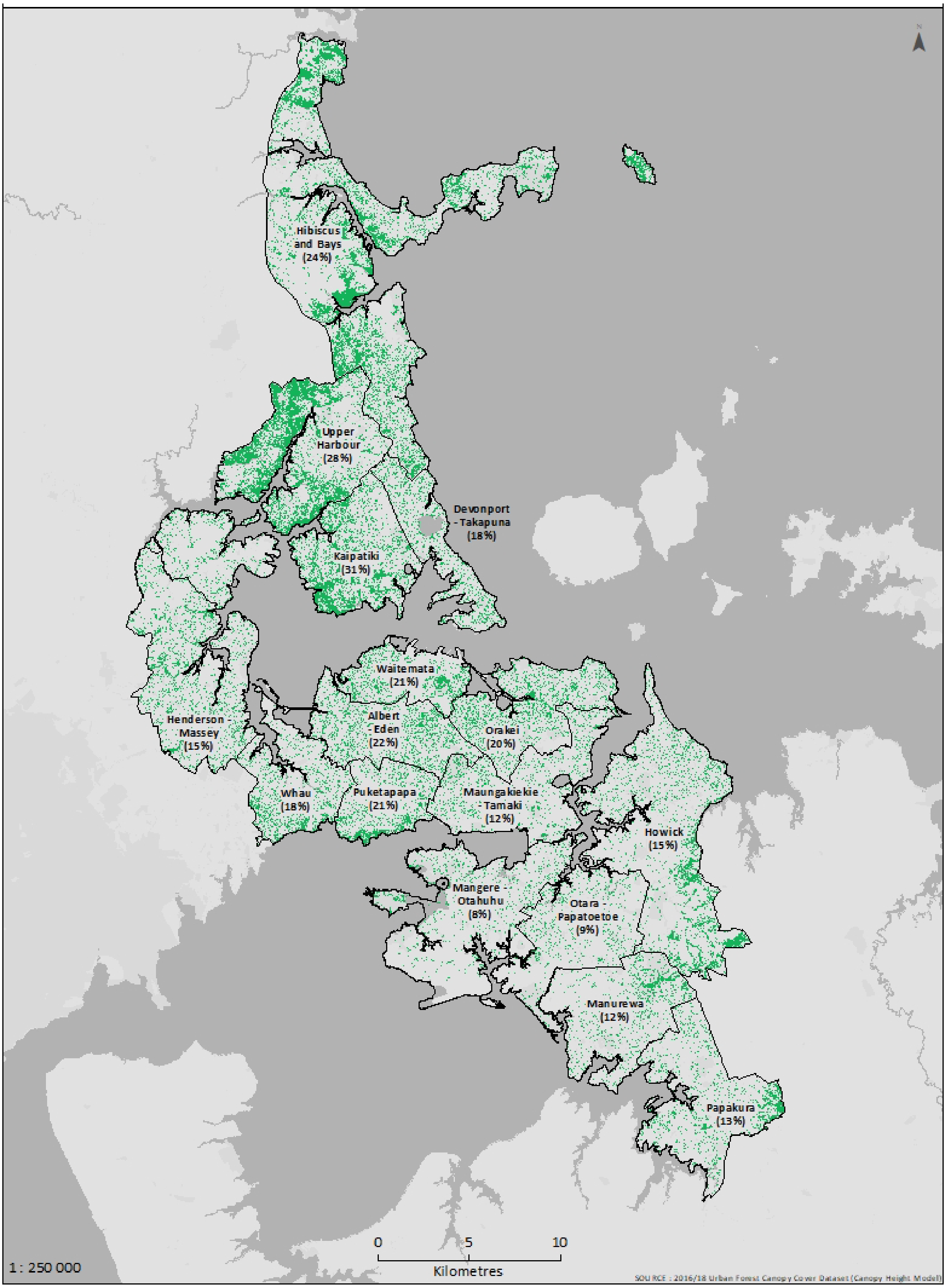

Figure 4 Canopy cover height model developed from 2016/18 LiDAR for 16 urban local boards

3.2 Tree canopy in urban Auckland

3.2.1 Tree canopy characteristics: cover and height distribution

In Auckland, tree canopy cover is 18% across the combined area of the 16 urban local boards (Figure 5). Canopy cover varies across the region, depending on the scale considered. At the local board level, canopy cover ranges from 8% in Māngere-Ōtāhuhu to 31% in Kaipātiki (Figure 5). The distribution of coverage at the local board level is evenly split: seven have low canopy coverage (8-15%) and seven have medium canopy coverage (18-24%); in addition, Upper Harbour and Kaipātiki have higher canopy coverages (28% and 31%, respectively) (Figure 5).

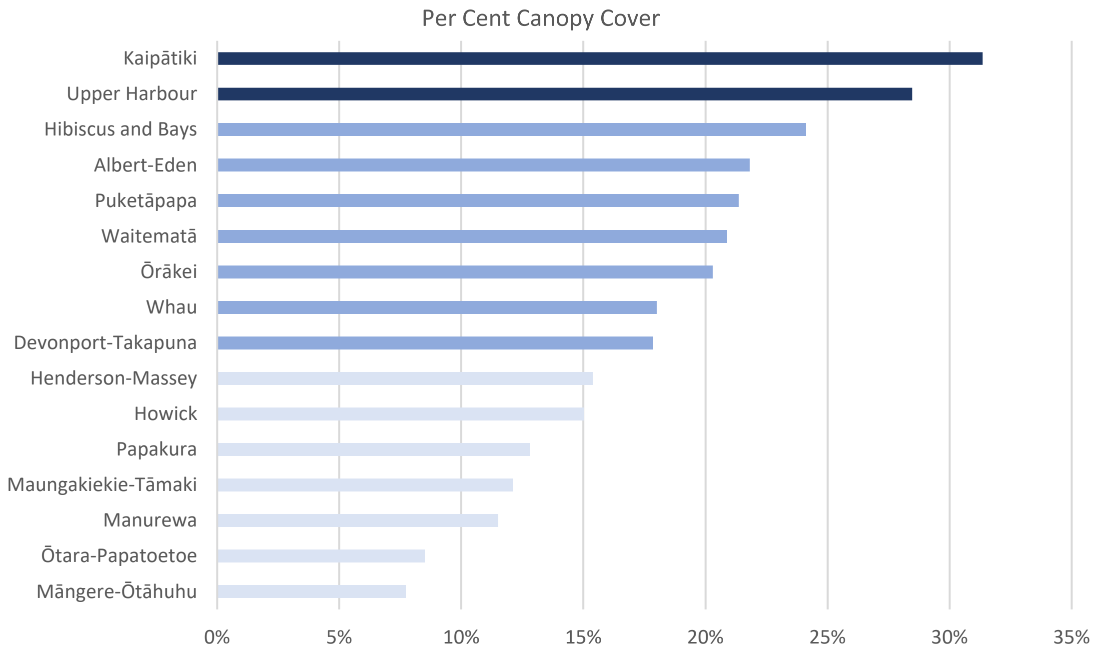

Figure 5 Tree canopy cover above 3 m in 2016/18 for Auckland's 16 urban local boards

The height distribution of the canopy surface is skewed toward the lower height classes: the 3-5 m and 5-10 m height classes comprise almost 75% of the canopy surface area (Figure 6). Less than 5% of the canopy surface occupies heights 20 m and above (Figure 6). It is important to note that the height distribution describes only the canopy surface area on a per pixel basis; it does not describe height classes of crowns or individual trees. While it does describe the height of the tree canopy overall (akin to a blanket that would lie across all the trees), it is not an accurate substitute for forest structure or height class distribution, as high height classes are underestimated (i.e., tall trees have area present in the lower height classes in addition to their maxima) and low height classes are overestimated (i.e., some of the area present in lower height classes actually belongs to tall trees). Further crown segmentation work will clarify the structural size distribution for Auckland's urban tree canopies.

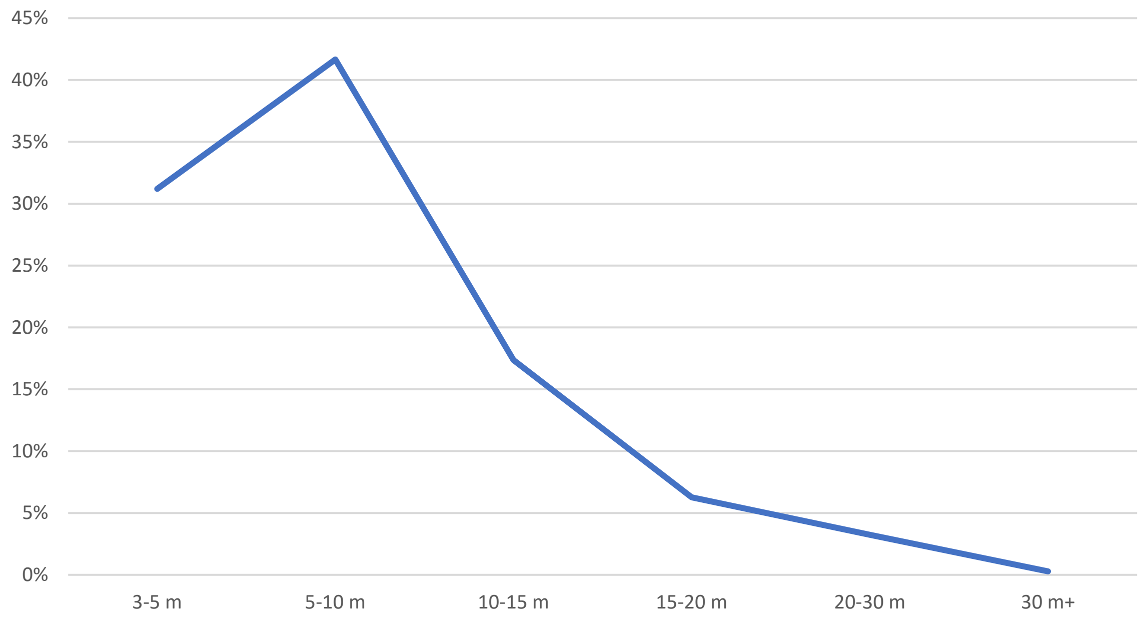

Figure 6 Height distribution of tree canopy surface area (2016/18) across Auckland's 16 urban local boards

Across the individual local boards, the height distribution of the 2016/18 tree canopy surface follows the same general pattern as the combined one (Figure 7). Local boards with higher canopy cover, such as Kaipātiki and Upper Harbour, have a higher proportion of canopy surface area in the larger height classes (and less in the smallest height class) than other local boards. No local board has more than 1% of its canopy surface area in the 30+ m height class; those with the highest proportion in the >30 m height class (0.4% - 0.6%) are Henderson-Massey, Maungakiekie-Tāmaki, and Upper Harbour. Devonport-Takapuna Local Board has the lowest proportion of surface area in the 30+ m height class.

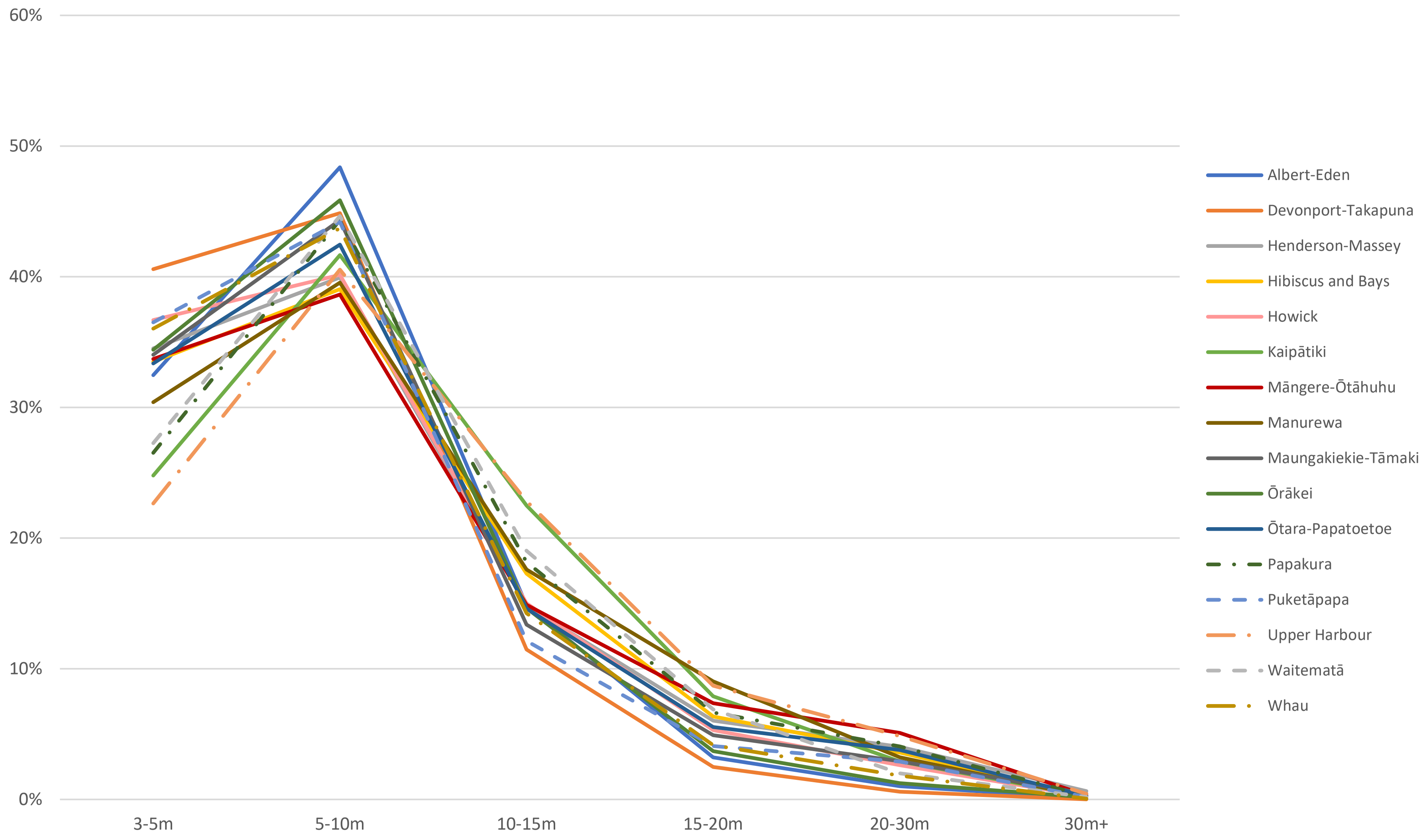

Figure 7 Height distribution of tree canopy surface area (2016/18) in 16 local boards

3.2.2 Forest canopy changes in local boards

Across the 16 local boards, there was a net increase in tree canopy cover of 60 ha, equivalent to 0.1% of the combined local board area. As with canopy cover and structure, the dynamics of forest gain and loss varies across the region with land cover, land use, and management classes. At an individual local board level, there was a net decrease of tree canopy area in six local boards and a net increase in 10, corresponding to 1-2% of local board areas (Table 2, Figure 8).

Net changes in comparison to the 2013 canopy cover were considerable: from a net loss of 8% of 2013 canopy area in Ōtara-Papatoetoe, 7% in Howick and 6% in Māngere-Ōtāhuhu to a net gain of 10% in Albert-Eden and 14% in Devonport (Table 2, Figure 9).

Table 2 Tree canopy cover change between 2013 and 2016/18

Local Board	Canopy Cover 2013 (% of LB area)	Canopy Cover 2016/18 (% of LB area)	Net Change (Ha)	Difference in Canopy Cover (%): 2016/18 vs 2013	Net Change Compared to 2013 Canopy Cover Area (%)
Albert-Eden	20	22	55	1.9	10
Devonport-Takapuna	16	18	46	2.2	14
Henderson-Massey	15	15	21	0.4	3
Hibiscus and Bays	25	24	- 125	-1.2	-5
Howick	16	15	- 82	-1.2	-7
Kaipātiki	30	31	35	1.0	3
Māngere-Ōtāhuhu	8	8	- 28	-0.5	-6
Manurewa	12	12	- 8	-0.2	-2
Maungakiekie-Tāmaki	11	12	32	0.9	8
Ōrākei	20	20	18	0.6	3
Ōtara-Papatoetoe	9	9	- 26	-0.7	-8
Papakura	13	13	- 18	-0.4	-3
Puketāpapa	20	21	18	1.0	5
Upper Harbour	27	28	74	1.1	4
Waitematā	19	21	31	1.6	8
Whau	17	18	16	0.6	3
Total (16 local boards)	18	18	60	0.1	0.5

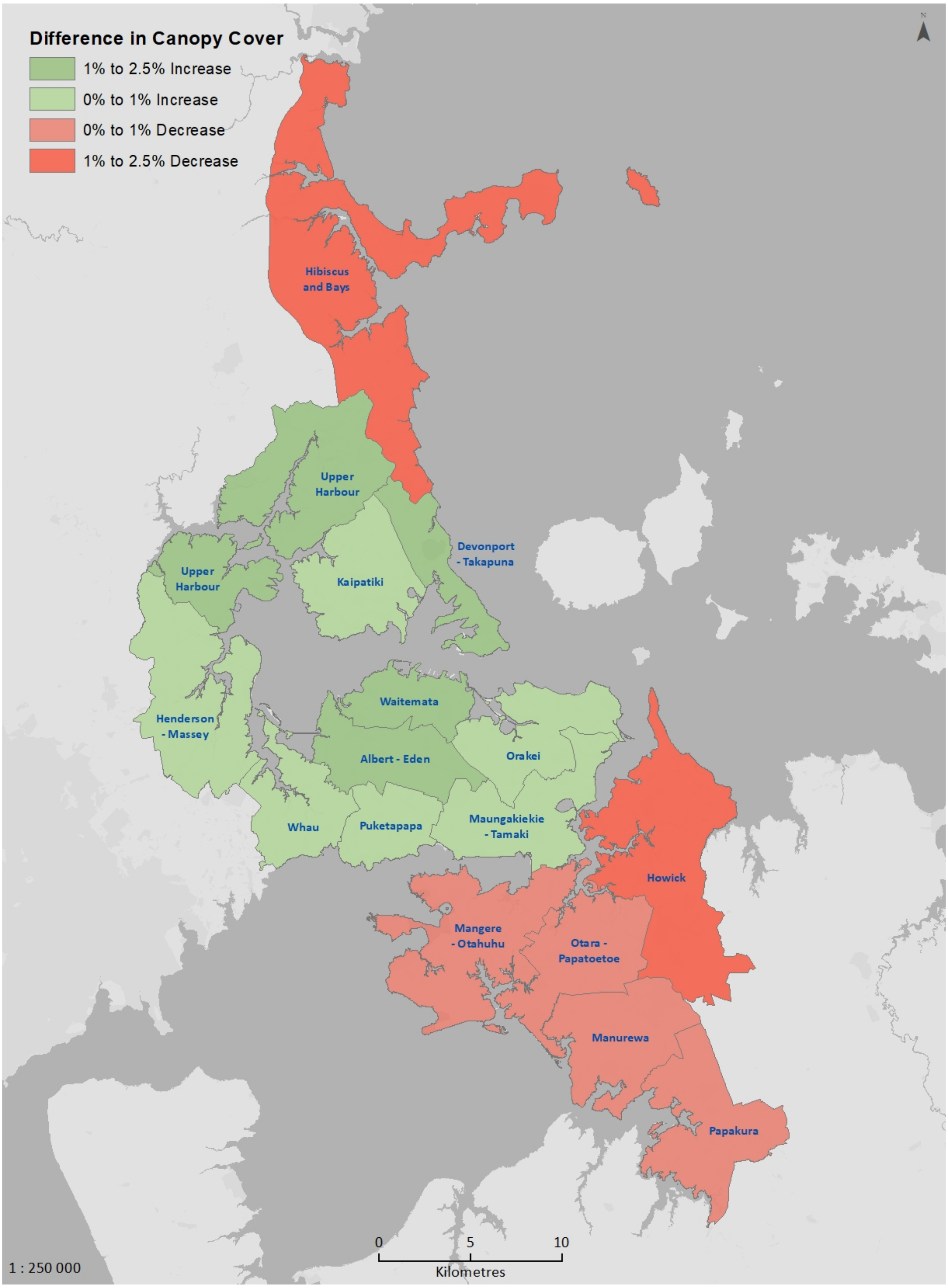

Figure 8 Net change in tree canopy cover (as % of local board area)

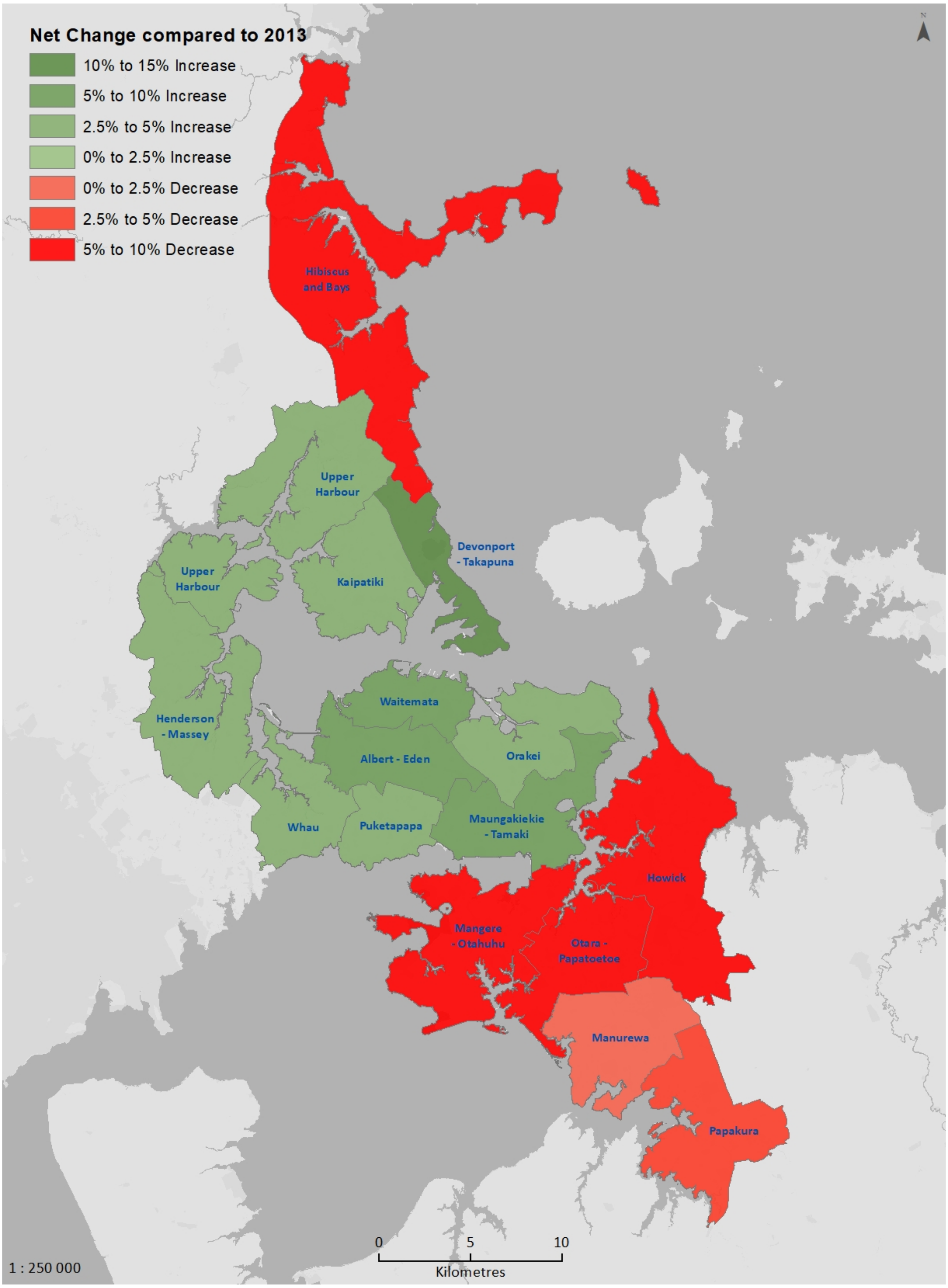

Figure 9 Net change in tree canopy cover (as % of 2013 canopy area)

3.2.3 Tree canopy characteristics: land cover, land use, and tenure

Tree canopy cover varies with land cover, land use, and tenure.

3.2.3.1 Land cover

Across the 16 local boards, 61% of the land cover is urban settlement, according to LCDB v5 (Figure 10, Table 3). Most of the remaining 39% of the area comprises vegetated land cover including urban parkland and open space (10%), high producing grassland (15%), and indigenous forest (4%). Of vegetated land cover, the forest classes have the highest tree canopy cover, from 37% (exotic forest) to 79% (indigenous forest) (Figure 11). In contrast, tree canopy cover in both built-up areas and urban parkland/open space are 13% and 14%, respectively (Figure 11). Other vegetated classes also have higher canopy covers (Figure 11), but each comprise less than 1% of the combined 16 local board area and are omitted from further discussion here (Table 3).

The 2016/18 tree canopy cover is unequally distributed among the land cover classes; those land cover classes with the highest tree canopy covers are least represented across the 16 local boards (Figure 10, Figure 11, Table 3). The distribution of the 2016/18 urban forest canopy differs due to the combination of the presence of each land cover type and its tree cover density. For instance, almost half of the 2016/18 urban forest cover is located in the built-up area (44%) even though the tree canopy cover is only 13% of the urban settlement class itself (Table 3). The next highest proportion of the 16 local boards' tree canopy cover occurs in indigenous forest (17%): although it has a high tree density (79%), indigenous forest occupies only 4% of the study area (Table 3). Moreover, urban parkland/open space hosts the third highest amount of tree canopy (8%) with a similar tree cover to urban settlement (14%) but a smaller area (10% of the study area) (Table 3).

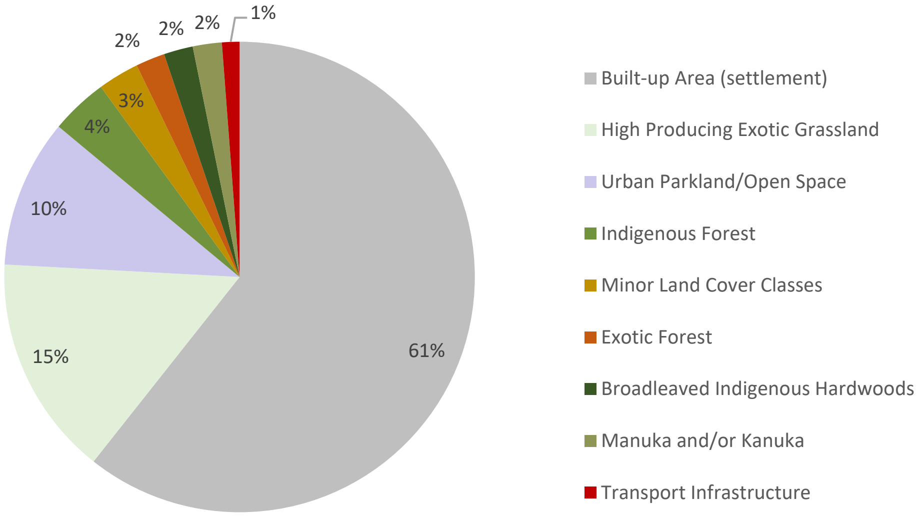

Figure 10 Proportion of land cover class area across the 16 local boards (Source: LCDB v5)

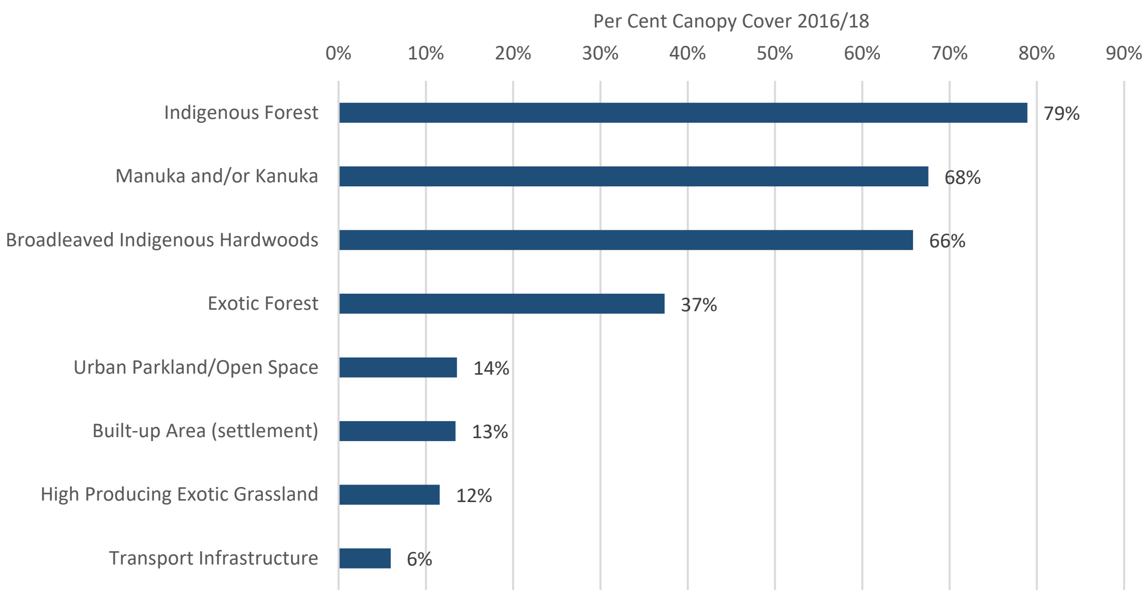

Figure 11 Tree canopy cover (2016/18) of land cover classes across the 16 local boards

Table 3 Tree canopy cover distribution across land cover classes in the 16 local board study area

LCDBv5 land cover class*	Canopy Cover 2016/18 (%)	Canopy Cover as proportion (%) of total 2016/18 tree canopy (%)	Land Cover area as proportion (%) of 16 LB area (%)
Built-up Area (settlement)	13	44	61
High Producing Exotic Grassland	12	10	15
Urban Parkland/Open Space	14	8	10
Indigenous Forest	79	17	4
Exotic Forest	37	4	2
Broadleaved Indigenous Hardwoods	66	7	2
Manuka and/or Kanuka	68	7	2
Transport Infrastructure	6	0.4	1

*Table excludes 16 land-cover classes (short-rotation cropland, lake or pond, mangrove, orchard, vineyard or other perennial crop, surface mind or dump, low producing grassland, deciduous hardwoods, mixed exotic shrubland, estuarine open water, gorse and/or broom, forest-harvested, sand or gravel, herbaceous saline vegetation, herbaceous freshwater vegetation, gravel or rock, river) that individually represent one per cent or less, and collectively less than three per cent, of the total land cover across the 16 local boards.

Across the local boards, there was a net increase in tree canopy cover in built up areas (226 ha) and urban parkland/open space (46 ha) LCDB classes, as well as a small net increase of 4 ha in transport infrastructure. Net decreases of tree canopy cover were highest in exotic forest (190 ha), followed by a decrease of 20 ha in broadleaved indigenous hardwoods and 8 ha in manuka and/or kanuka (Figure 12).

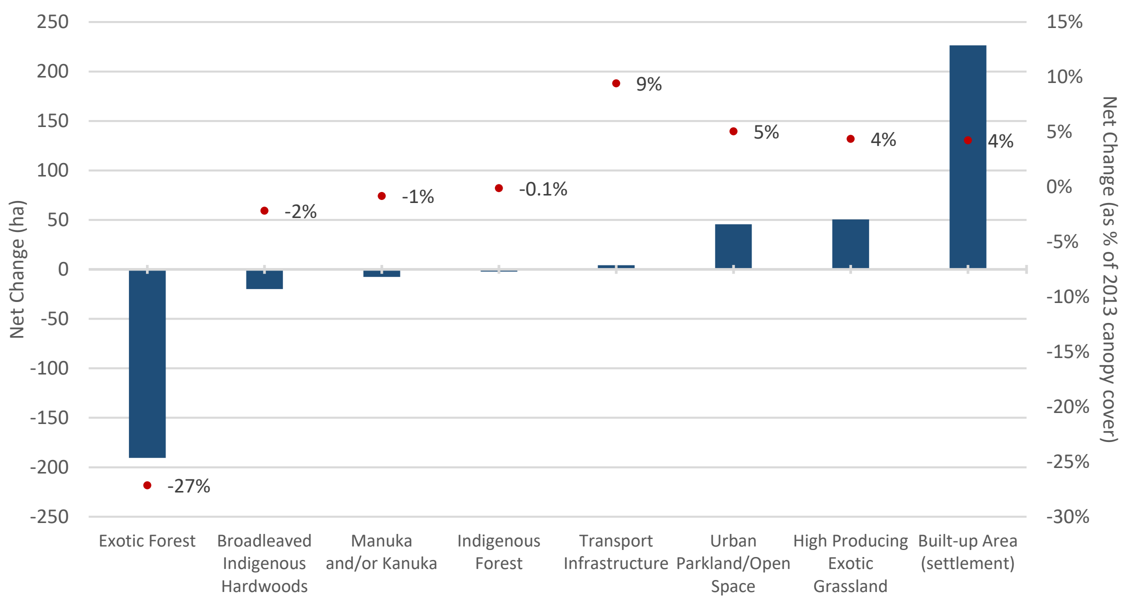

Figure 12 Net change in tree canopy cover between 2013 and 2016/18 across land cover across the 16 local boards [blue bars: net change area (ha) and red dots: net change area as proportion of 2013 canopy cover]

3.2.3.2 Land use

Analysing land use provides more detail about the composition of the built-up area. About half of the 16 local board area is made up of residential land use and another quarter is recreational and lifestyle land uses (Figure 13). Tree canopy varies according to land use, with three distinct groupings: the highest tree canopy cover (30-33%) is in recreational and lifestyle land uses; a moderate level of tree canopy cover (14-17%) in most a mix of land uses including both residential and rural industry; and the lowest canopy covers in (4-6%) in industrial, commercial, and transport land uses (Figure 14).

Across the 16 urban local boards, most of the 2016/18 tree canopy cover is found in residential, recreational, and lifestyle land uses (Table 4). Although residential has a lower canopy cover density (16%) than recreational and lifestyle (33% and 30%, respectively), its dominance across the local board results in the largest proportion of tree cover being located on residential land use (Figure 13, Figure 14, Table 4).

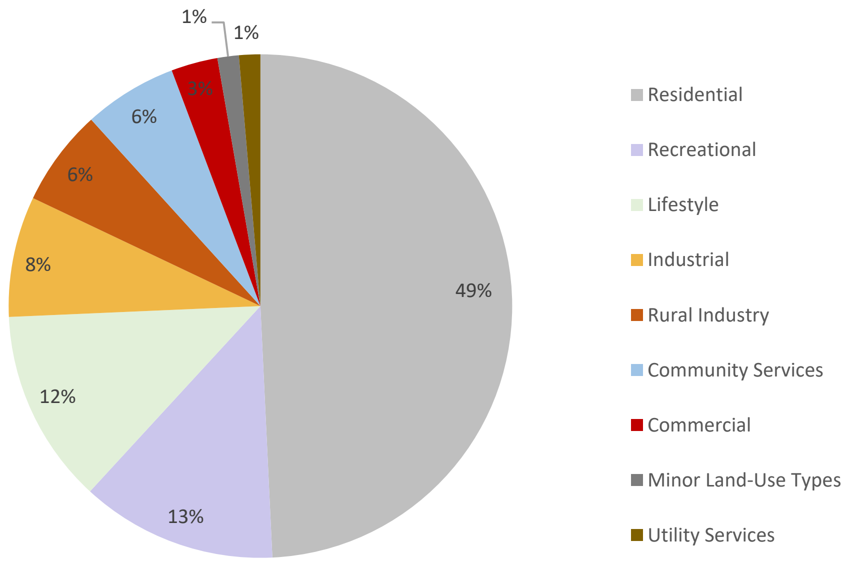

Figure 13 Proportion of land use area across the 16 urban local boards

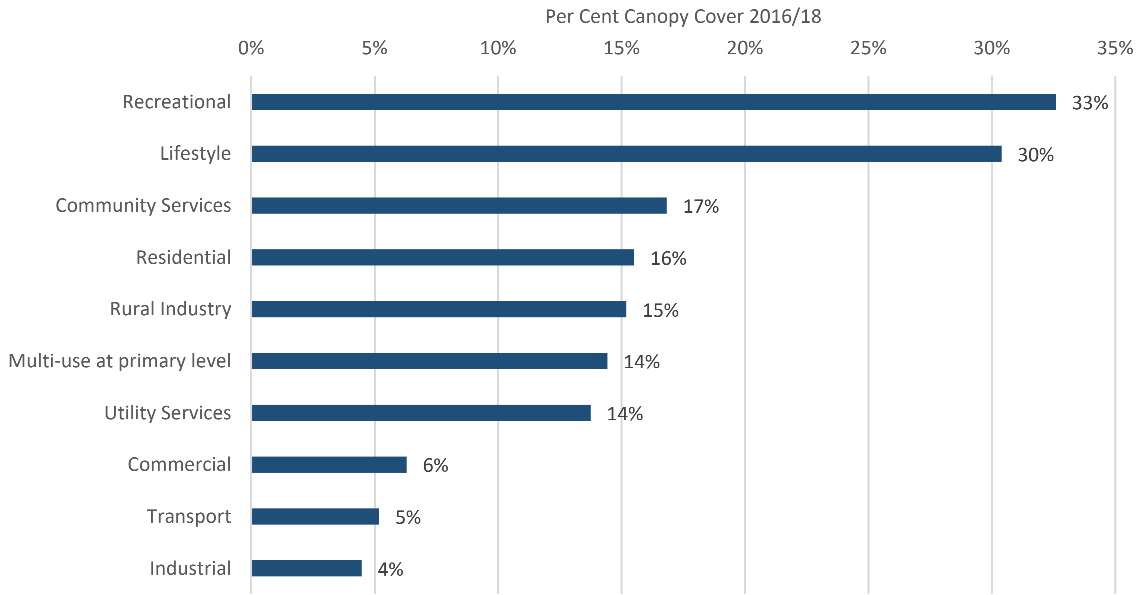

Figure 14 Tree canopy cover (2016/18) of land uses across the 16 local boards

Table 4 Tree canopy cover distribution across land-use type in the 16 local board study area

Land Use*	Canopy Cover 2016/18 (%)	Canopy Cover as proportion (%) of total 2016/18 tree canopy (%)	Land Use area as proportion (%) of 16 LB area
Recreational	33	22	13
Lifestyle	30	21	12
Community Services	17	6	6
Residential	16	42	49
Rural Industry	15	5	6
Multi-use at primary level	14	0.01	0.02
Utility Services	14	1	1
Commercial	6	1	3
Transport	5	0.4	1
Industrial	4	2	8

*Grouped by actual primary land use types

There were net losses of canopy cover in the rural industry land-use group (predominantly forestry) of 155 ha (-21% since 2013 and -4% of the land use area) and 1 ha in the residential land use group (-0.01% of land use area), whereas net increases occurred in both the recreational (61 ha) and community services (15 ha) land-use groups (both 3% net gain since 2013, increasing canopy coverage of each land use +1% and +0.4%, respectively) (Figure 15). Other noticeable gains in canopy cover were in utility services (5 ha) and commercial (5 ha) (Figure 15).

Various dynamics played out within some land-use groups. For example, in the residential subclasses the largest net loss was in vacant residential (-56 ha), largely balanced by net gains in single unit residential (50 ha), and multi-unit residential (1 ha). But for lifestyle land uses, the net gain of 34 ha in the single unit and multi-unit lifestyle classes was mostly balanced by a net loss of 33 ha in the vacant lifestyle one. There were net gains in six of seven recreational subclasses. The highest areas of net gain in the community services category were in educational, multi-use, and cemeteries/crematoria land uses. In commercial land uses, net gains in retail, offices, and multi-use were balanced by a net loss in vacant commercial.

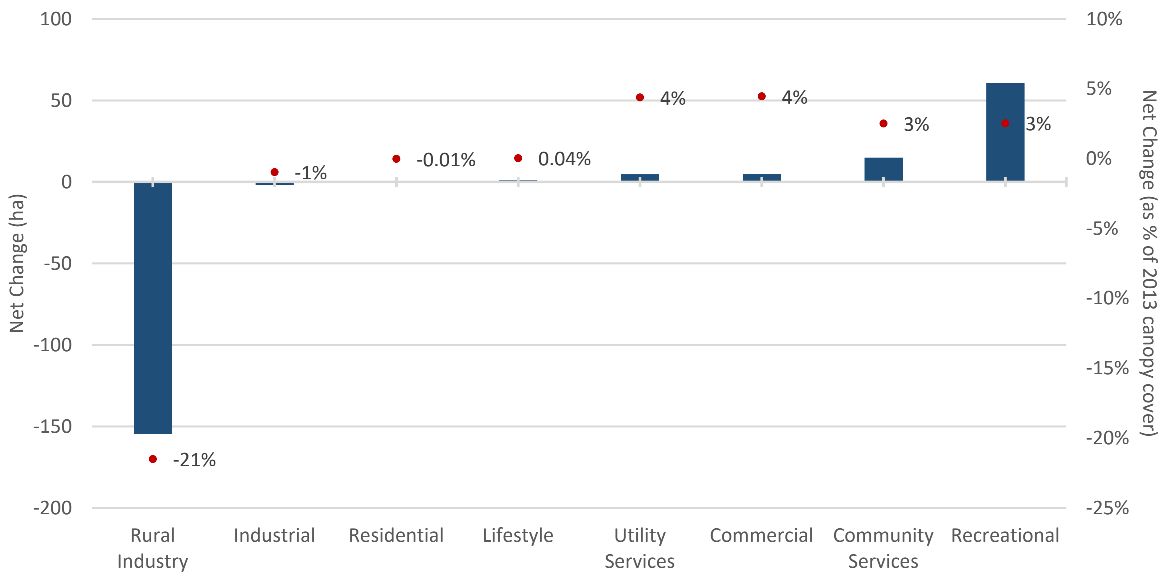

Figure 15 Net change in tree canopy cover between 2013 and 2016/18 in land uses across the 16 urban local boards. [blue bars: net change area (ha) and red dots: net change area as proportion of 2013 canopy cover]

3.2.3.3 Unitary Plan zoning

Tree canopy cover varies greatly across the Unitary Plan zones (Auckland Council 2016a). Approximately one-third of the land zoned as rural and public open space across the 16 local boards is forested (Figure 16). And, to a slightly lesser degree, the same is true for the coastal zone. In contrast, there is moderate cover on land in the general zones (roads and strategic transport corridors) (12%) and the new growth zone (13%), and both business and special purpose zones have relatively little tree canopy cover (6-8%) (Figure 17).

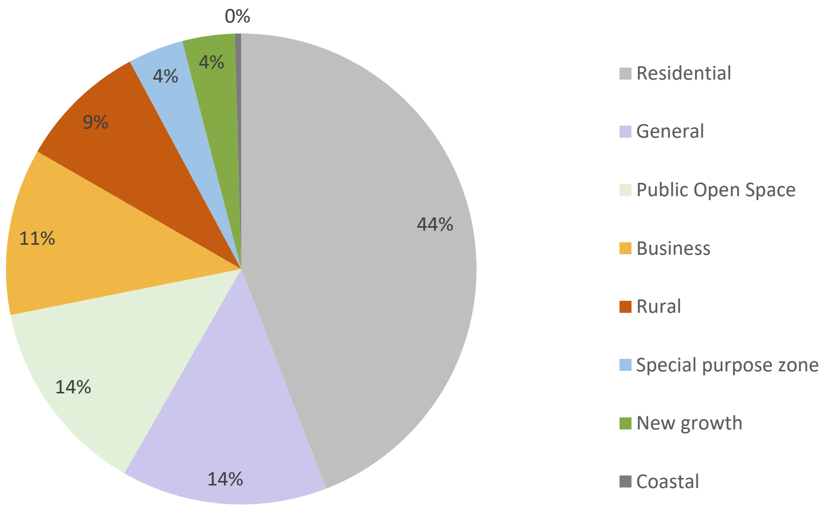

Figure 16 Proportion of unitary plan zone areas across the 16 urban local boards

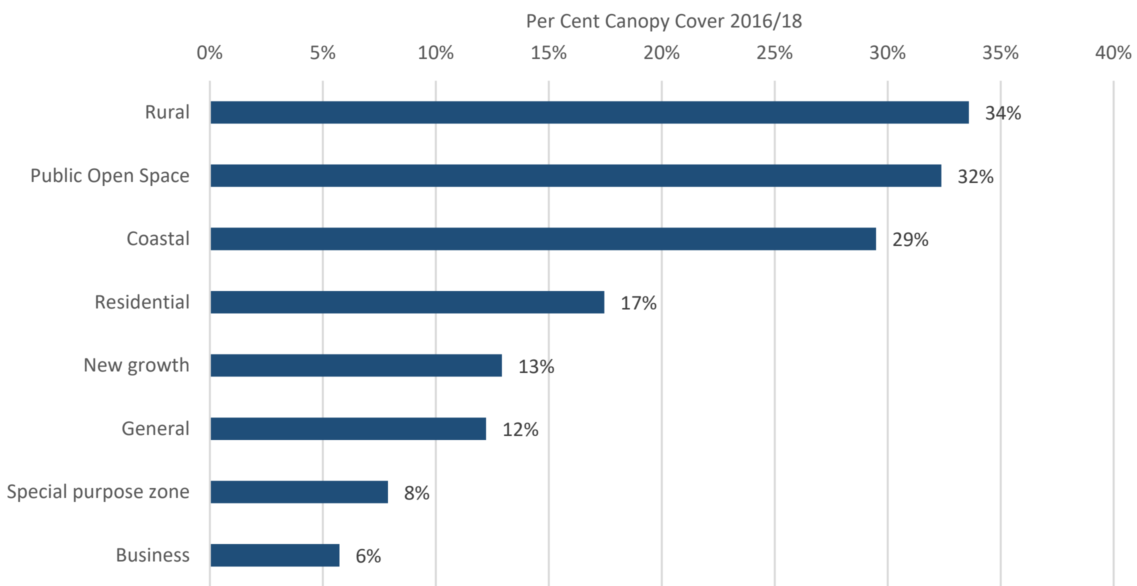

Figure 17 Tree canopy cover (2016/18) of Unitary Plan zones across the 16 local boards

Over 40% of the 2016/18 tree canopy cover is located in the residential zone, which occupies 44% of the combined 16 local board area (Table 5). Public open space has the second highest share of tree canopy cover (24%). Only 16% of the 2016/18 tree canopy cover is in the rural zone, which occupies less than 9% of the combined local board area (Table 5).

Table 5 Tree canopy cover distribution across Unitary Plan Zones in the 16 local board study area

Unitary Plan Zones	Canopy Cover 2016/18 (%)	Canopy Cover as proportion (%) of total 2016/18 tree canopy	UP Zone area as proportion (%) of 16 LB area
Rural	34	16	9
Public Open Space	32	24	14
Coastal	29	1	0.4
Residential	17	42	44
New growth	13	3	4
General	12	9	14
Special purpose zone	8	2	4
Business	6	4	11

Between 2013 and 2016/18, net gains occurred in the general (156 ha, or 14% since 2013) and public open space (56 ha or 2% since 2013) zones, about 2% of their total areas in both instances (Figure 18). A net canopy loss of 164 ha in the rural zone occurred, 7% net loss since 2013 and 3% of the zone's area across the 16 local boards.

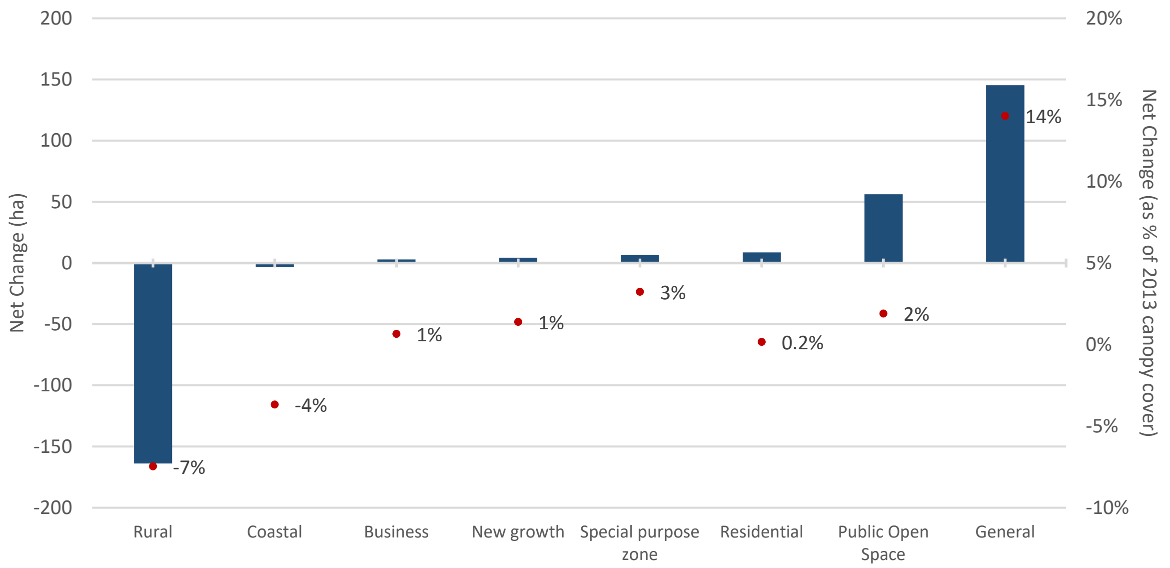

Figure 18 Net change in tree canopy cover between 2013 and 2016/18 in Unitary Plan zones across the 16 urban local boards. [blue bars: net change area (ha) and red dots: net change area as proportion of 2013 canopy cover]

3.2.3.4 Tenure

Across the 16 local boards, almost two-thirds (64%) of land is under private tenure, with the remainder split among roads (13%), public open space (13%), and other public land (10%) (Figure 19). Of these, public open space has the highest tree canopy cover (33%), followed by private land (18%) (Figure 20). This translates to more than half of tree canopy cover located on private land and almost a quarter on public open space (Table 6).

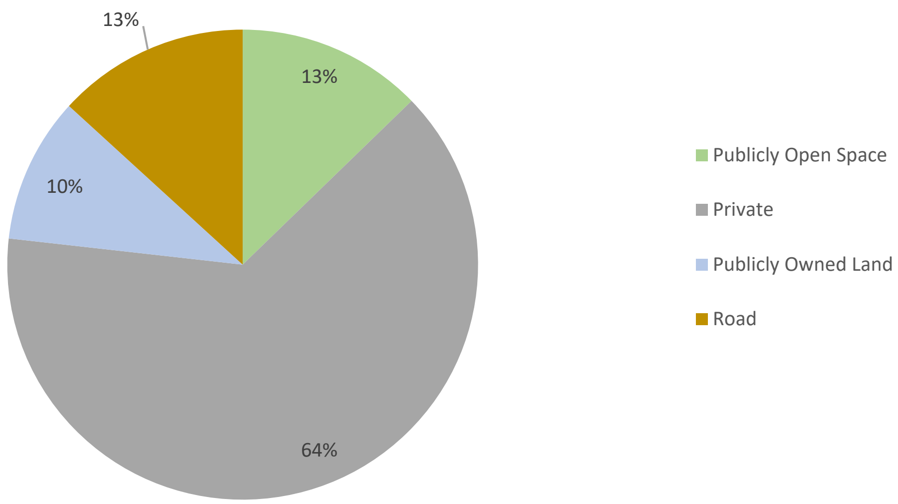

Figure 19 Proportion of tenure class across the 16 urban local boards

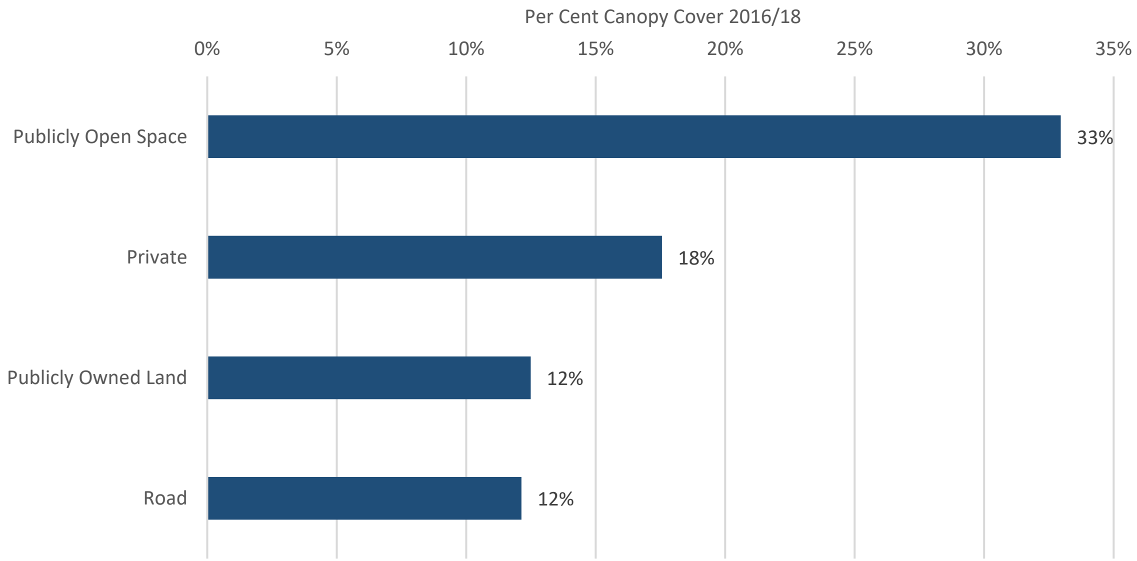

Figure 20 Tree canopy cover (2016/18) on tenure types across the 16 local boards

Table 6 Tree canopy cover distribution by tenure classes across the 16 local boards

Tenure	Canopy Cover 2016/18 (%)	Canopy Cover as proportion (%) of total 2016/18 tree canopy	Tenure Area as proportion (%) of 16 LB area
Public Open Space	33	23	13
Private	18	61	64
Publicly Owned Land	12	7	10
Road	12	9	13

For the tenure class areas across the 16 urban local boards, distinct differences emerge in canopy change dynamics between 2013 and 2016/18. In road parcels, there was a net increase of 142 ha of canopy cover (2% of the road corridor area), amounting to a 15% increase on the 2013 canopy cover. Public land also increased in comparison to 2013: by 2% (47 ha) for public open space and by 4% (30 ha) for other public land. On the other hand, there was a net decrease of 2% (159 ha) on private land compared to 2013 canopy cover.

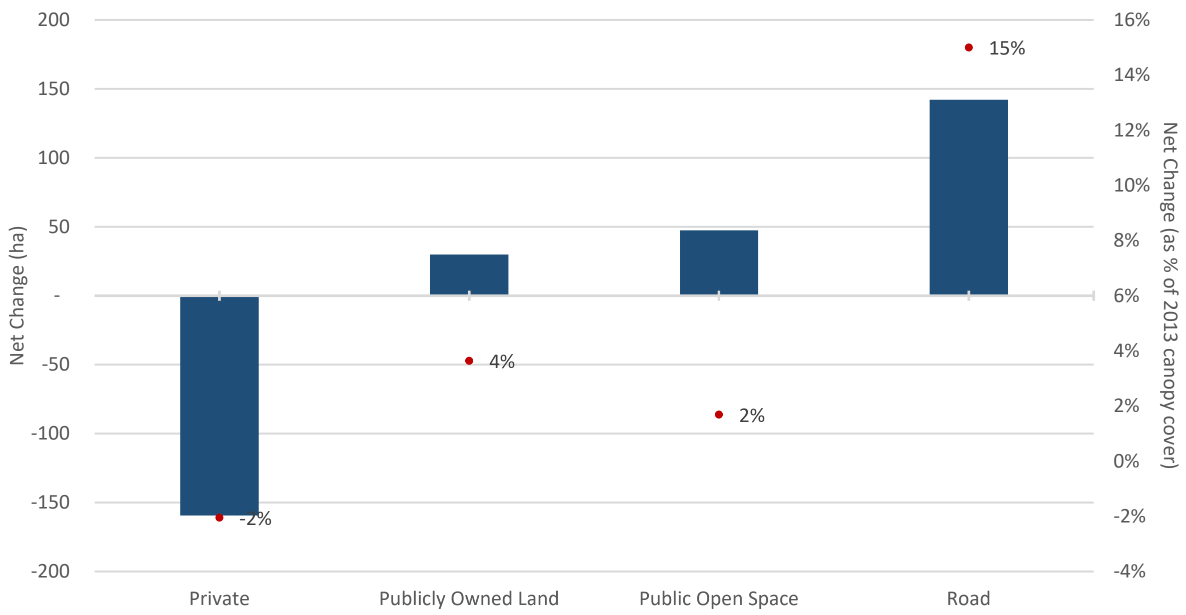

Figure 21 Net change in tree canopy cover between 2013 and 2016/18 in across tenures within the 16 urban local boards. [blue bars: net change area (ha) and red dots: net change area as proportion of total area in each tenure class]

4.0 Discussion

4.1 Auckland's urban tree canopy cover

The Auckland region encompasses rural and urban terrain comprised of different land-covers, and hosts diverse land uses that are under a variety of tenures and management. It is the combination of the tree canopy density in any particular land cover or land use and the presence of that land use or land cover on the landscape that results in the total tree canopy cover for the particular area. The density of tree canopy varies among different land covers and land uses, from 60-70% in indigenous forested areas to 14-18% in residential areas. Across the 16 urban local boards, residential land use is predominant, resulting in an overall tree canopy of 18%, although there are patches of highly vegetated land covers with high canopy covers within these areas.

Tree canopy cover in local boards fell into three groups: on target, moderate, and low. Of the 16 urban local boards, only one local board, Kaipātiki, meets the Urban Ngahere Strategy's target average canopy cover of 30% (Auckland Council 2019a) with one other, Upper Harbour, close at 28%. While 11 of the 16 local boards meet the minimum of 15% canopy cover, the five south Auckland local boards in this study are under the 15% minimum threshold for tree canopy cover: Māngere-Ōtāhuhu, Manurewa, Ōtara-Papatoetoe, Maungakiekie-Tāmaki, and Papakura. This distribution of canopy cover across local boards remains consistent with that measured in the 2013 tree canopy cover (Bishop and Lawrence 2017). Low tree canopy cover in south Auckland has been a long-term issue, and those local boards under the minimum threshold may present priority areas for the 'growing' phase of the Urban Ngahere Strategy.

The local board tree canopy coverage figures are useful for summarising variability within the Auckland region but do not tell the full story. As with any ecological issue (Peterson and Parker 1998), the question of tree canopy is essentially one of scale: coverage depends on the area under consideration. That is, while regional canopy cover is 18%, local board canopy cover ranges from 8-31% across the 16 urban local boards. Context is also important. The composition of land cover and/or land use, and whether one dominates, in the particular boundary area (from parcel through suburb and local board to region) will influence the aggregate tree cover. For instance, taking tenure into consideration, public open space across the 16 local boards already meets the Urban Ngahere Strategy's stated target of 30% canopy cover. Road corridors and other public land, however, remain at less than half of this target coverage.

Through the various lenses of land cover, land use, and management, the overarching finding that emerges is that the majority of 2016/18 tree canopy occurs in private residential and public open space land; the former has relatively low canopy cover density, whereas the latter hosts higher tree canopy covers.

4.2 Short-term change in Auckland's urban forests

During the 3-5 years (2013 and 2016/18) between urban forest measurements, the net change in the tree canopy above a 3 m height across the 16 central, urban local boards was slightly positive: 0.5% of 2013 forest area, or 0.1% of local board area. Gains in canopy cover largely consisted of biomass growth of existing vegetation throughout the entire tree canopy – small but ubiquitous instances of tree growth and crown expansion – in addition to existing tree canopy crossing the 3 m minimum height threshold and any new plantings that also met the height threshold (Figure 22). On the other hand, tree canopy losses were a combination of small, ubiquitous instances (e.g., from maintenance such as pruning and trimming) and discrete events, usually larger in area than the dispersed new growth (Figure 22). Similar change dynamics have been documented over five-year periods in other cities, such as Los Angeles (Locke et al. 2017).

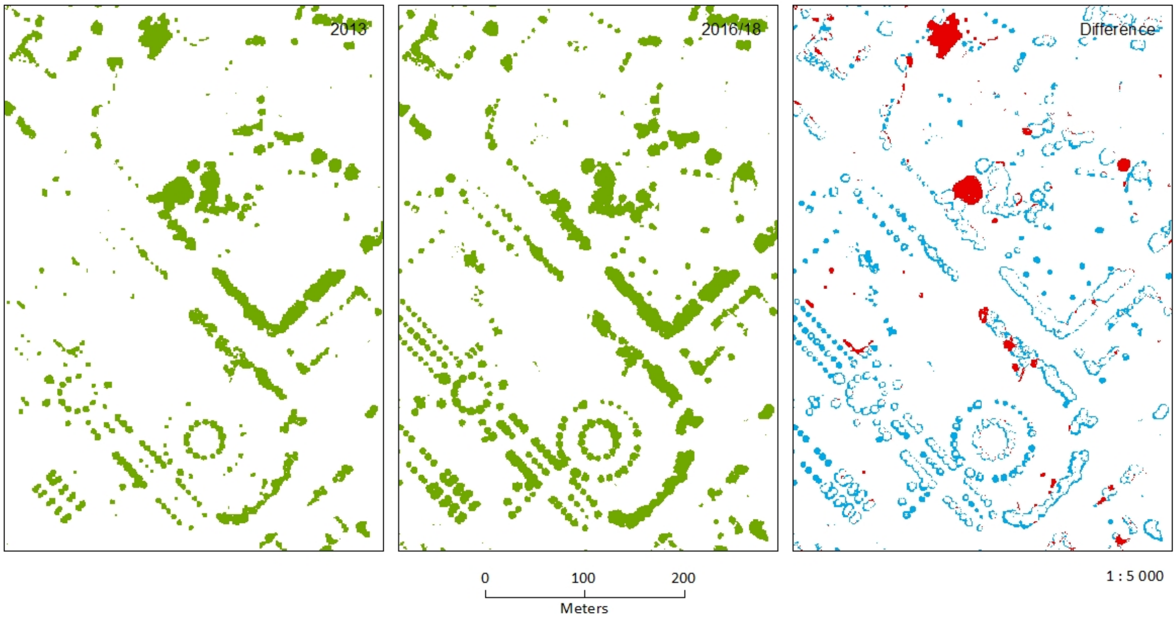

Figure 22 Change Detection: (a) 2013 Canopy Cover; (b) 2016/2018 Canopy Cover; (c) gains-new vegetation > 3m detected in 2016/18 [blue] and losses – 2013 vegetation no longer detected in 2016/18 [red]

Across Auckland's 16 urban local boards, these gains and losses largely balance each other on an area basis for a net change close to null[3]. Here again, scale is important, as is the baseline of comparison. Whereas the net change across all local boards ranged between -1% and 2% based on their area, the proportional changes were markedly different when based on the starting point, the 2013 canopy cover. The tree canopy cover in four local boards (Hibiscus and Bays, Māngere-Ōtāhuhu, Howick, and Ōtara-Papatoetoe) decreased 5-8% compared to the 2013 canopy. In contrast, in Waitematā, Albert-Eden, and Devonport-Takapuna, the 2016/18 tree canopy covers increased 8%, 10%, and 14%, respectively, in comparison to 2013 tree canopy area. Both trajectories reflect well-known dynamics in urban ecosystems, where land development and other activities can lead to the loss of biomass (Drummond and Loveland 2010) at the same time that landscape management and afforestation can make cities carbon hotspots (Golubiewski 2006, Golubiewski and Wessman 2012). Further investigation about the underlying reasons for the different trajectories in Auckland is warranted.

Tree canopy loss at the parcel level will be more keenly observed and felt than at aggregate geographies of the suburb, local board, or region. Overall, canopy cover dynamics consist of fine-grain biomass accrual and somewhat coarser-scale loss. These dynamics not only matter for the net change that occurs, but, more importantly, influence changes at the locations of the gain or loss. Their characteristics differ, with discrete loss events far more noticeable and ecologically, functionally different, than small, dispersed growth. Thus, canopy cover, and its changes, have different meanings for ecology and management, depending on whether the region, local board, neighbourhood, or even parcel, is the area of interest.

The ecosystem services, the benefits humans derive from nature, are well documented for urban forests (Nowak 1994, Schwendenmann and Mitchell 2014, Livesley et al. 2016, Bishop and Lawrence 2017), including carbon storage, water regulation, and habitat. Auckland's urban forests have been studied for their habitat provision in particular (Watts and Larivière 2004, Nottingham et al. 2019). Harvests and tree removals cut down, partially or completely, individual or groups of trees of various sizes. Tall trees are more likely to be removed than planted. Large additions of biomass to the urban forest from the planting of big trees would be rare (due to both cost and the difficulty of transplanting large specimens). It is logical to consider that the ecosystem services lost or gained are correlated with the size of the loss and gain events, though ecosystem service dynamics are also complex and non-linear, and

[3] pending an accuracy assessment, which will permit the calculation of uncertainty associated with estimates of gains, losses, and net change.

further specification of this is beyond the scope of this project. The verification and quantification of alterations to ecosystem services corresponding to urban forest change dynamics is another area requiring more research.

Given that loss events often are associated with the felling of large trees and gains are often due to plantings of smaller trees in lower height classes, structural differences in the tree canopy are noticeable. In Auckland, a change in the height of the canopy surface area between 2013 and 2016/18 was detected with a reduction in the canopy surface area above 15 m and an increase in surface area in the 3-5 m height class in each of the 16 local boards. Preliminary analysis of the canopy surface area data shows that the majority of the loss area in the 30 m height class occurred in exotic forestry land covers. As noted previously, however, the work in this report only considers canopy surface area overall; it does not yet account for individual trees (nor individual loss/gain events), so only canopy area is under consideration here, not trees themselves. This is an important point of clarification, as previously, information about the 2013 height distribution in Waitematā, specifically, and height data generated from LiDAR more generally, has been misinterpreted as the urban forest's height class structure (Bishop and Lawrence 2017). Although the change statistics are indicative of the loss of some larger trees, the specifics of how the size structure of the urban forest has shifted will not be known until further investigation of the tree distribution and crown structure that comprises the urban forest canopy. This is an active area of interest for further work.

4.3 Summary and recommendations

This study presents the first findings of a comprehensive assessment of Auckland's urban forests and its change over a three to five-year period. For the 16 central, urban local boards, a wide range of canopy cover exists, from 8% to 31%. A slight increase (0.5%) in urban forest cover was detected across all the local boards, but the changes ranged from -8% to +14% at the local board level.

Further work can be undertaken in order to more fully investigate the dynamics of Auckland's tree canopy cover. These include:

- Completion of the 2016/18 tree canopy cover for the remaining five, rural local boards (Waitākere Ranges, Rodney, Franklin, Waiheke, and Aotea/Great Barrier). In order to complete a change detection of these local boards, further data collection (e.g., of satellite imagery) will be required, as the 2013 LiDAR survey only captured parts of some of these local boards.
- An accuracy assessment to quantify the degree of uncertainty in the 2013 and 2016/18 tree canopy cover rasters produced from the classified LiDAR data.
- More detailed analyses of local boards, informed by the results of the accuracy assessment.

To understand the trends of forest canopy cover across Auckland, a longer time series will have to be developed: change can be detected from two points in time, but a trend requires three or more time periods. To support this, a structured monitoring programme with appropriate financial support to periodically assess the region's tree canopy cover, from which trends and dynamics can be detected, would significantly enhance the ability to map and report on changing forest canopy cover. No ongoing (nor long-term) data collection programme exists.

Although Auckland's Urban Ngahere (Forest) Strategy – Te Rautaki Ngahere ā-Tāone o Tāmaki Makaurau specifies a "3 yearly LiDAR survey", LiDAR is not the same as a tree canopy cover; rather, it is the raw data from which a tree canopy cover can be developed. LiDAR is also not the only data source from which tree canopy cover information can be compiled; other sources, such as satellite imagery, offer potential opportunities with various price points, complexity of data collection and analysis, and data resolutions.

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