

# Cornwall Park Kauri Grove enhancement: baseline survey and recommendations for restoration

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**Figure 1.** The peak of kauri forest development – Tāne Mahuta; the largest kauri tree alive today. Waipoua Forest 2011, photo courtesy of Simon Grant.

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## **Executive summary**

### Project and client

Plots were established and surveys carried out in Cornwall Park's kauri areas between December 2017 and February 2018 for the Cornwall Park Trust. The Trust provided funding for a summer student (Grant) to carry out the research under the supervision of Assoc. Prof. Margaret Stanley and Assoc. Prof. Bruce Burns of the University of Auckland.

### Objectives

- Undertake baseline vegetation sampling
- Undertake baseline bird counts and compare with other parts of Cornwall Park
- Undertake baseline soil sampling and analyses
- Establish invertebrate and reptile monitoring stations
- Establish photo points
- Provide recommendations for restoration of the Kauri Grove

### Methods

- Five 20m x 20m permanent vegetation plots were established in kauri stands within Cornwall Park, following standard plot protocols (Hurst & Allen 2007).
- Ten-minute bird counts were conducted at six locations of differing vegetation types across Cornwall Park. All bird counts were repeated five times at regular intervals from December 2017 to February 2018.
- Soil samples were taken from each permanent vegetation plot, and tested for: pH; soil moisture; organic carbon; total nitrogen; phosphorus (Olsen P); and exchangeable bases (Na, Ca, K, Mg).
- Stations were installed in the main Kauri Grove for monitoring of reptiles (onduline covers), and invertebrates (pine slabs and weta motels).

### Results

- The vegetation plots lacked an understory aside from grasses, other ground cover species, and occasional seedlings. Weeds were common amongst ground cover species.
- Tree densities and basal areas of the Cornwall Park Kauri Groves were substantially lower than reported values in natural mature kauri forest.
- Soils within the Cornwall Park Kauri Groves were substantially more fertile than those reported in natural kauri forest.
- A wider range of native bird species and a greater level of native dominance was observed in the Kauri Grove when compared with other areas in the park.

### Discussion/Recommendations

- Remove weeds from Kauri Groves – especially tradescantia (*Tradescantia fluminensis*) and African clubmoss (*Selaginella kraussiana*).
- Consider strategies to lower soil nitrogen availability and pH (e.g. sawdust or sugar additions) in Kauri Groves
- Plant kauri associates in groups throughout the grove – beginning with light gaps.
- Ensure kauri associates are appropriate for the Auckland Region, and include some less common species such as *Halocarpus kirkii*, *Leionema nudum*, *Phyllocladus toatoa*, and *Pittosporum ellipticum*.
- Protect seedlings from browsing - a fence would also prevent people, but costs would need to be considered.

- Prevent any future additions of plant clippings/mulch to Kauri Grove that would increase fertility.
  - Ensure fallen branches (dead wood) are left in place as structure for animal biodiversity.
  - Plant floral (flowering and fleshy-fruited) resources (ensuring they are kauri associates) for nectarivorous and frugivorous birds.
  - Consider a boardwalk where the track currently is, to direct people away from walking through the grove (as another precaution against the spread of kauri dieback).
  - Plant groups of kauri associates close to the boardwalk so people can experience these without leaving the boardwalk.
  - Plant mānuka (*Leptospermum scoparium*) around the edges of the grove to direct people onto the boardwalk, to prevent invasion of weeds, and to reduce environmental edge effects.
  - If the kauri stands are extended, include a small number of a mix of tree species that typify young kauri forest such as tanekaha (*Phyllocladus trichomanoides*), rimu (*Dacrydium cupressinum*), and rewarewa (*Knightia excelsa*), etc. Kauri would still be numerically dominant, however.
- Implement biosecurity surveillance with advice from Auckland Council staff in line with Auckland Council's Regional Pest Management Plan to enable early detection and management of pests.



**Figure 2.** The main Kauri Grove at Cornwall Park, the focal point of this study. February 2018, Oscar Grant.

## Introduction

Cornwall Park is one of the oldest and foremost public parks in Auckland (Cornwall Park Trust Board [CPTB] 2014). It covers 172ha and was gifted to the people of New Zealand by Sir John Logan Campbell in 1903. The Park provides a varied landscape including legacies of past Māori occupation, a working farm, open spaces, and extensive tree plantings as individuals and stands. Amongst these tree plantings, an approximately 1ha stand of kauri (*Agathis australis*), rimu (*Dacrydium cupressinum*), and tōtara (*Podocarpus totara*) (“Kauri Grove”) was planted in 1947 (CPTB 2014). At least two other smaller stands dominated by kauri also occur on Cornwall Park. In 2014, the CPTB published the Cornwall Park Master Plan which provides a vision for the future of Cornwall Park based on a set of guiding principles including (but not limited to) (a) improving the park’s ecological stewardship and resiliency, and (b) reinforcing and strengthening the park’s design and aesthetic (CPTB 2014). One part of the plan to meet these principles seeks to diversify the plant communities present in the Kauri Grove so that it represents a natural kauri forest in composition and structure, and expand the kauri grove to approximately twice its current size.

We were tasked with undertaking a baseline survey and establishing monitoring infrastructure at Cornwall Park’s Kauri Grove and other kauri areas for the Cornwall Park Trust as part of fulfilling the Master Plan. This baseline survey aims to provide a template for future monitoring, which can be replicated to observe changes across a range of parameters over time.

We have undertaken baseline soil, vegetation, and bird sampling, established photo points, and installed invertebrate and reptile monitoring stations for future studies. We have collected data on these parameters to act as a baseline, and most crucially, we have documented the sampling protocols used, allowing for monitoring to be accurately replicated into the future. Lastly, we have made a series of recommendations for the proposed restoration, taking into consideration the restoration plan proposed by the Cornwall Park Trust (CPTB 2014) and communications with the horticulture team at Cornwall Park.

## Background

Kauri (*Agathis australis*) stands are a hallmark feature of forests in northern New Zealand. Not only is kauri arguably New Zealand’s most iconic tree, the plant communities associated with kauri forest are typically unique and diverse (Ogden 1995, Wyse 2013, Wyse et al. 2013). Included in these assemblages are a range of plants that are virtually dependent on kauri for their survival; a number of which are regionally uncommon species (Cranwell 1981, Stanley et al. 2005). An intriguing feature of these communities is that, unlike many unique assemblages that are maintained by abiotic factors, kauri forest communities appear to be facilitated largely by the presence of kauri itself, and the way in which it affects its environment (Wyse 2013). Kauri is in essence an ‘ecosystem engineer’, as it modifies the soil by lowering the pH and availability of nitrogen largely via the breakdown of its leaf litter (Wyse 2013). These effects imposed by kauri, along with other factors such as lower water availability and increased light levels, have been attributed with maintaining the unique communities found beneath a kauri canopy (Wyse 2013). This not only highlights the complexity of kauri ecosystems, but also the necessity to consider soil properties in kauri related restoration projects.

Although the kauri groves currently present at Cornwall Park are relatively young (planted in 1947) and only cover a small area (approx. 1ha), they hold significance in a number of ways. Firstly, if a restoration project such as the one being proposed was pursued, it would be a unique chance to document the success of establishing characteristic plant communities of kauri forest under an existing (planted) kauri canopy. Furthermore, despite these groves being small when



considering the natural range of kauri in New Zealand (Steward & Beveridge 2010), on a regional scale they represent a key opportunity. Remnant patches of kauri forest are now very localised around Auckland City; especially on the Tamaki Isthmus (Singers et al. 2017). Therefore the groves at Cornwall Park also stand as a bastion and with the right insight, restoration could transform them into a rare and authentic example of a forest type that was once much more prominent in the region. Lastly and vitally, the stands of kauri at Cornwall Park provide great opportunities for the public to experience and appreciate kauri forest. Enhancing the diversity of these stands increases the potential for park visitors to develop an interest in these ecosystems, and perhaps feel a deeper connection to the Northland/Auckland Region and Aotearoa.

## **Methodology**

All fieldwork for this study was conducted within the confines of Auckland's Cornwall Park (36° 53' 56" S, 174 ° 47' 12" E). The study predominantly focussed on Cornwall Park's largest kauri stand (36° 53' 53.86" S, 174 ° 47' 11.23" E; approximate area 1ha), though two other smaller stands within the park were also sampled (Fig. 3). Fieldwork was undertaken between December 2017 and February 2018. Separate methodology for each component of the sampling is included.

### Vegetation plots

We established five permanent vegetation plots in the kauri groves at Cornwall Park. The majority of our surveying occurred in the main kauri grove (Fig. 3). We followed the methods of Hurst and Allen (2007) to set up 20m x 20m permanent vegetation plots. Due to area constraints in the kauri stands, placement of plots was largely determined by availability of space rather than random selection. Plots were measured out using 50m tapes and compass bearings to ensure accuracy, and each plot was subdivided into 5m by 5m subplots which were referred to as subplots A-P (Hurst and Allen 2007). Each plot was marked out by inserting 4 corner pegs (A, D, M, and P), however due to the possibility of removal or damage to the pegs GPS coordinates and bearings and distances to nearest tagged trees were also taken (Appendix 1).

Following RECCE (reconnaissance) plot protocols, we gathered metadata parameters (see RECCE plot sheets, Hurst & Allen 2007), and recorded vegetation at the site using three different techniques. Firstly we estimated the cover abundance of each species within set height tiers of the stand (tier 1= >25m; tier 2= 12-25m; tier 3= 5-12m; tier 4= 2-5m; tier 5= 0.3-2m; tier 6= <0.3m; tier 7= epiphytes), using cover classes of 1= <1%; 2= 1-5%; 3= 6-25%; 4= 26-50%; 5= 51-75%; 6= 76-100%. Species were recorded using species codes used in Landcare Research's NVS Databank (<http://nvs.landcareresearch.co.nz/Resources/NVSNames>). All trees with a stem diameter >2.5cm had their diameter measured at breast height (at approximately 1.35m height), and were tagged with a unique identifier (Hurst & Allen 2007). Lastly, seedlings and ground covers were recorded on an understory subplot sheet, recording presence of grasses and groundcover species, and numbers of seedlings within 24 circular subplots in each plot, each with a 49cm radius (Hurst & Allen 2007).

Plots established:

- Three plots in the main kauri stand; Cornwall Park Kauri (CPK) 1-3
- One plot in a small stand of rimu (*Dacrydium cupressinum*) adjacent to the kauri (CPK/R4), for comparison, and as a contingency if restoration plans are also developed for this stand of rimu.
- One plot in a smaller stand of kauri (CPK5).
- A RECCE survey was also conducted in another kauri stand (CPK6), though no permanent plot was installed here because of its small size (Fig. 3).



**Figure 3.** Aerial view of Cornwall Park and Maungakiekie showing bird count sites and the three kauri grove areas, with vegetation plots included (CPK 1, 2, 3, 5, 6, & CPK/R4). Inset in bottom right corner shows enlarged view of the main kauri grove.

### Bird counts

Bird counts were conducted in Cornwall Park's main kauri grove area, and in five other sites around Cornwall Park to compare bird diversity and abundance. A variety of different sites around the park were selected to cover a broad range of different vegetation types (Fig. 3).

These sites included:

- Pohutukawa site: dominated by pohutukawa (*Metrosideros excelsa*) (36° 54' 06.47" S, 174 ° 46' 50.72" E);
- Olive Grove site: a sparse mature olive (*Olea europaea*) grove (36° 53' 54.07" S, 174 ° 46' 49.52" E);
- Kauri site: the interior of the main kauri grove (36° 53' 53.86" S, 174 ° 47' 11.23" E);
- Moreton Bay fig site: two large Moreton Bay figs (*Ficus macrophylla*) (36° 53' 36.77" S, 174 ° 47' 19.85" E);
- Rewarewa site: a young rewarewa (*Knightia excelsa*) grove (36° 53' 39.49" S, 174 ° 47' 20.62" E);
- Recent native planting site: a young mixed native planting with a few mature karaka (*Corynocarpus laevigatus*) trees dominating the canopy (36° 54' 15.08" S, 174 ° 47' 08.49" E).

Five separate bird counts were conducted at each site between December 2017 and early February 2018. All counts took place in the early – mid morning (between 7am and 9.30am), as bird activity has been shown to decrease after the first 3 hours of sunrise by 60% (Lynch 1995). At each site, birds were counted if they were present within a 50m radius (approximately) of the central point of the site. Birds flying overhead were not recorded, and similarly bird calls were only deemed acceptable to count if they were clearly associated with a bird in the direct vicinity of the site. Effectively we (O.G.) did a ten minute bird count at each site, though this was broken into two five minute counts. While five minute bird counts are the most typical bird count carried out in New Zealand (Dawson & Bull 1975), detection of species is increased by extending the time to ten minutes (Heggie-Gracie 2016). The observer (O.G.) was careful, however, not to include individual birds in the second five minute count that had been recorded in the first, therefore limiting the usefulness of the separate five minute counts as replicates. Hence, we have used the totals for the cumulative ten minute counts in analysis.

### Soil sampling

Soil samples were taken from each permanent vegetation plot (CPK 1, 2, 3, 5, & CPK/R4), and from the small Kauri Grove 'CPK6' (36° 53' 49.03" S, 174 ° 47' 10.14" E). We collected soil samples using a 2 cm diameter soil corer set to a depth of 10cm, with each sample consisting of approximately six cores. Two separate samples were taken from each plot (except for CPK6 with one sample), approximately from diagonally opposite edges of the plot, giving a total of 11 soil samples. Samples were kept in plastic bags, and sent to the Environmental Laboratory at Manaaki Whenua - Landcare Research in Palmerston North for analysis. We requested that the soil samples be tested for: pH; soil moisture factor; organic carbon; total nitrogen; phosphorus (Olsen P); and exchangeable bases (Na, Ca, K, Mg).

### Invertebrate and reptile monitoring

For future monitoring of invertebrates and reptiles we placed onduline covers (ground reptiles) and pine slabs (invertebrates) in the main Kauri Grove, and also installed 'weta motels' (Appendix 2). Untreated pine slabs (300mm by 300mm by 25mm thick) (Fig. 4B) were placed on the ground as a proxy for coarse woody debris (dead wood), which provide habitat structures



(refuges) for invertebrates and other animals (Bowie and Frampton 2004, Richardson et al. 2009). Three of these pine slabs were installed in the main Kauri Grove (in CPK 1, 2, & 3), allowing for rapid monitoring of invertebrates by simply lifting the slab and recording the presence/absence (or counts for larger invertebrates) of species underneath. Two handmade weta motels were also installed in the main Kauri Grove (CPK1 & 3), which consist of pieces of treated pine (approx.. 250mm by 100mm by 50mm) which have been drilled into from the top (20mm drill-bit diameter), and chiselled out for weta and potentially other large invertebrates to inhabit (Figs. 4A & 5A). These have been attached to the kauri trees via a small nail (Fig. 4A). Lastly, onduline covers were placed in the main Kauri Grove for ground reptile monitoring (Figs. 4A & 5B). Black onduline was used, cut to pieces of 400mm by 316mm. Stacks of three pieces of onduline separated by 10mm doweling wood were placed in the field, and lightly covered by leaf litter to make them less conspicuous.

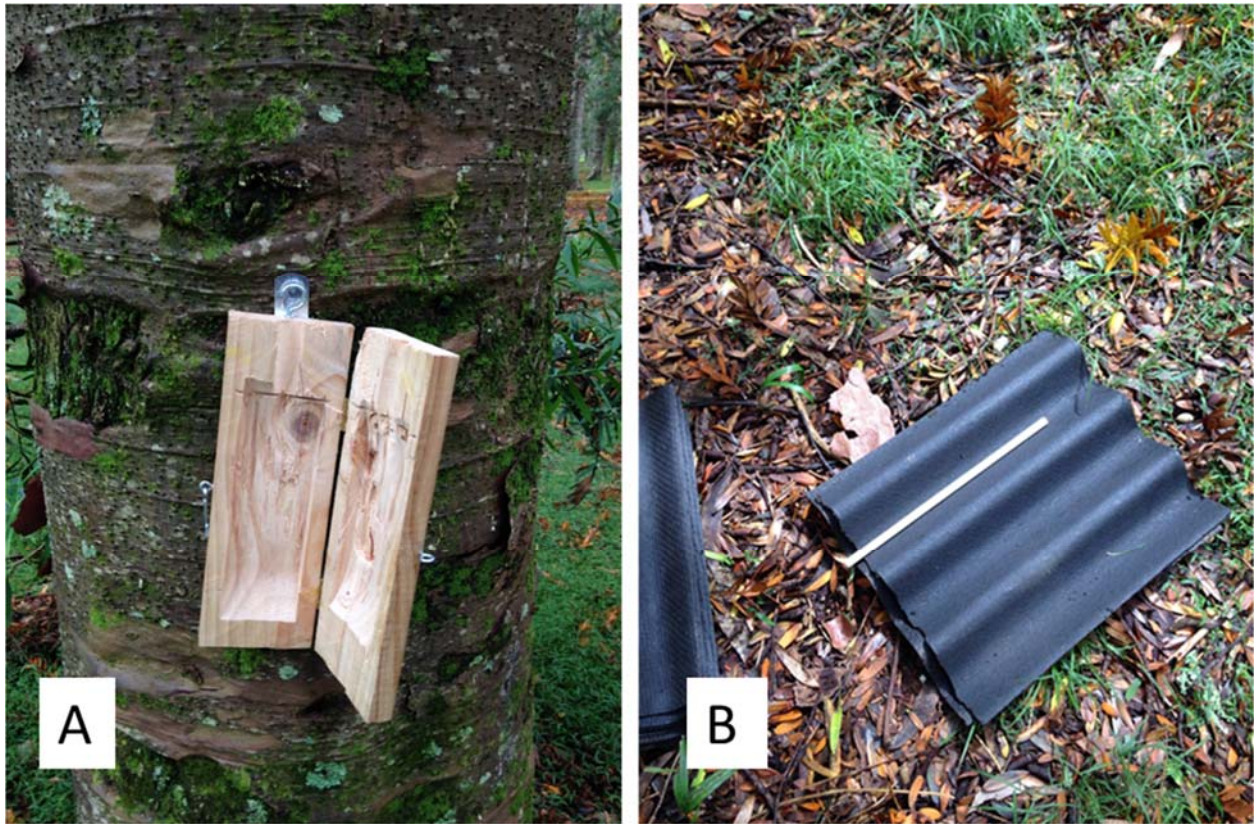


**Figure 4.** Onduline covers for reptile monitoring and weta motel in-situ at Cornwall Park (A). Pine slab for invertebrate monitoring under kauri litter (B).

#### Photo points

Photo points were established at each corner peg of the vegetation plots (points A, D, M, & P in CPK 1, 2, 3, 5 and CPK/R 4). Photos were taken from a distance of approximately 2m behind each peg, using a mobile phone camera. Additional photo points were also established outside each kauri grove to give a broader perspective of the groves as a whole, and any changes that occur overtime. Images from each photo point have been lodged electronically with Cornwall Park Trust, and corresponding GPS coordinates can be found in Appendix 3.





**Figure 5.** Handmade weta motel *in-situ* and open, displaying the design (A), and stacked onduline covers with doweling shown (B).

## Results

All data from baseline monitoring have been lodged electronically with Cornwall Park Trust. The following is a brief analysis of some key points, particularly relevant to consideration of future surveys and monitoring.

### Vegetation plots

As can be easily observed from a visit to the Kauri Grove areas, the vegetation plots were very homogenous and lacked any real understory. The original planting scheme of rows is still very much intact, with some clearly visible spaces where trees have died and been removed. The average DBH for kauri trees was 48cm. When comparing these groves with typical mature kauri forest, the density, basal area, and tree height are substantially lower in the Cornwall Park stands than mature natural stands (Table 1) (Ahmed & Ogden 1987). Growth rates, however, indicate that kauri in the Cornwall Park stands are growing between 2.5-3 times faster than kauri in natural mature stands, with an average radial growth rate of 3.4mm per year (Cornwall Park), as opposed to 1.15mm per year in natural stands (Table 1).

**Table 1.** Comparison of the kauri (*Agathis australis*) groves at Cornwall Park to data obtained from 25 mature kauri forest plots spanning the latitudinal range of the species (Ahmed & Ogden 1987). Figures given are means  $\pm$  standard deviations, or ranges in parentheses.

| Forest structural variable                    | Natural kauri forest | Cornwall Park kauri stands |
|---|----------------------|----------------------------|
| Basal area (m <sup>2</sup> ha <sup>-1</sup> ) | 84 $\pm$ 33          | 62 $\pm$ 8                 |
| Height (m)                                    | (30-40)              | (18-25)                    |
| Density (trees ha <sup>-1</sup> )             | 579 $\pm$ 242        | 325 $\pm$ 35               |
| Average radial growth rate (mm/year)          | 1.15 (n=352)         | 3.4 (n=51)                 |

Very few saplings were recorded in any of the plots, with the majority of large canopy species only being recorded as seedlings (typically <30cm tall), including *Beilschmiedia tarairi*, *Vitex lucens*, and *Podocarpus totara*. No kauri seedlings or saplings were recorded, although cones were seen developing on some of the trees suggesting kauri in Cornwall Park do produce seed. Some of the plots were moderately covered by ground-cover species and grasses, of which the natives *Oplismenus hirtellus* subsp. *imbecillis*, *Microlaena stipoides*, and *Carex dissita* (in damper patches) were particularly prevalent. The exotic and invasive sedge *Carex divulsa* was also common. Patches of the invasive weeds *Tradescantia fluminensis* and *Selaginella kraussiana* had taken hold in places.

### Bird counts

In comparison with other areas in Cornwall Park, the Kauri Grove was notable for having a more diverse range of native species and a higher level of native bird dominance. Every native species recorded in the study was observed or heard in the Kauri Grove, with grey warbler (*Gerygone igata*) and shining cuckoo (*Chrysococcyx lucidus*) not recorded elsewhere (see bird count raw data). Although both tui (*Prothemadera novaeseelandiae*) and silvereye (*Zosterops lateralis*) had the highest average abundances in the Kauri Grove, eastern rosella (*Platycercus eximius*) was also relatively abundant (Table 2). The eucalyptus stand directly adjacent to the Kauri Grove may, however, have had a somewhat confounding effect on our counts, as some bird species, including the eastern rosellas, seemed to be more associated with the eucalypts than the kauri.

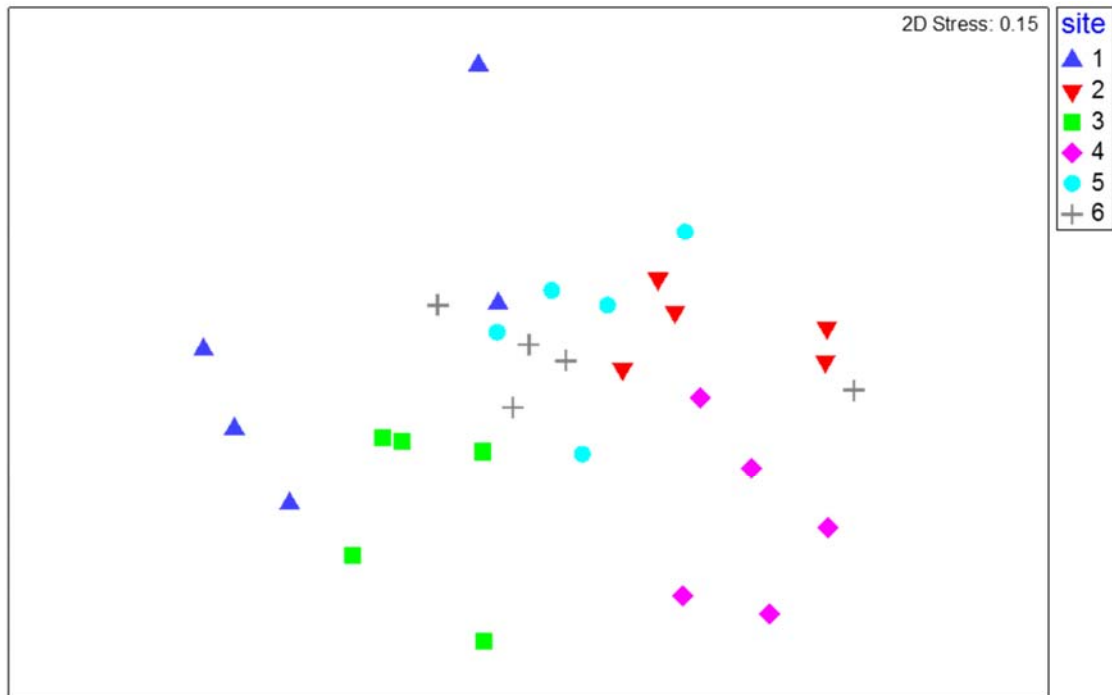
Other interesting patterns outside of the Kauri Grove included a short period of activity at the pohutukawa dominated site when high tui counts were observed. These seemed to be directly correlated with pohutukawa flowering which the tui were clearly feeding off. Conspicuous feeding by blackbirds (*Turdus merula*) on Moreton Bay fig fruits was also observed at the Moreton Bay fig site at all counts (Table 2).

**Table 2.** Three most abundant bird species for each bird count site based on averages per 10 minute count, with sites demonstrating highest levels of native bird dominance listed first.

|                              | Site                    | Species                                      | Average recorded per 10 minute count |
|------------------------------|-------------------------|--|--------------------------------------|
| <b>Native bird dominated</b> | <b>Kauri Grove</b>      | <i>Prothemadera novaeseelandiae</i> (tui)    | 4                                    |
|                              |                         | <i>Zosterops lateralis</i> (silveryeye)      | 4                                    |
|                              |                         | <i>Platycercus eximius</i> (eastern rosella) | 3.8                                  |
|                              | <b>Pohutukawa</b>       | <i>Prothemadera novaeseelandiae</i> (tui)    | 5                                    |
|                              |                         | <i>Zosterops lateralis</i> (silveryeye)      | 4.4                                  |
|                              |                         | <i>Platycercus eximius</i> (eastern rosella) | 1.4                                  |
| <b>Exotic bird dominated</b> | <b>Native planting</b>  | <i>Zosterops lateralis</i> (silveryeye)      | 3.6                                  |
|                              |                         | <i>Turdus merula</i> (blackbird)             | 3.6                                  |
|                              |                         | <i>Passer domesticus</i> (sparrow)           | 1.8                                  |
|                              | <b>Rewarewa stand</b>   | <i>Passer domesticus</i> (sparrow)           | 2.6                                  |
|                              |                         | <i>Zosterops lateralis</i> (silveryeye)      | 2.4                                  |
|                              |                         | <i>Turdus merula</i> (blackbird)             | 2.4                                  |
|                              | <b>Moreton Bay figs</b> | <i>Turdus merula</i> (blackbird)             | 16.6                                 |
|                              |                         | <i>Passer domesticus</i> (sparrow)           | 1.8                                  |
|                              |                         | <i>Prothemadera novaeseelandiae</i> (tui)    | 1.2                                  |
|                              | <b>Olive Grove</b>      | <i>Turdus merula</i> (blackbird)             | 4                                    |
|                              |                         | <i>Passer domesticus</i> (sparrow)           | 2                                    |
|                              |                         | <i>Sturnus vulgaris</i> (starling)           | 1.6                                  |

To analyse whether bird community compositions observed among the sites were significantly different, we performed an ordination (nMDS) on square-root transformed abundance data using a Bray-Curtis similarity coefficient. From this we were able to deduce that there was no temporal variation, but significant spatial variation in bird community composition (Fig. 6). While the bird community composition was similar among most sites, the Kauri Grove counts separated out from the other sites (had a different bird community), as did the site dominated by large Moreton Bay fig trees (Fig. 6). As well, bird communities associated with native tree dominated sites generally occurred on the left hand side of the ordination diagram, while those associated with exotic tree dominated sites generally occurred on the right hand side of the diagram (Fig. 6). This was supported by an ANOSIM analysis, which gave a value of  $P = 0.001$ , indicating that the difference among sites was statistically significant.





**Figure 6.** nMDS ordination plot showing similarity between bird counts at sites 1 to 6 (1=pohutukawa; 2=Olive Grove; 3= Kauri Grove; 4= Moreton Bay figs; 5= rewarewa; 6= young native planting). Points closer together have bird communities that are more similar than those points further apart. Five bird counts were carried out at each site between December 2017 and February 2018.

#### Soil sampling

Soils of the Kauri Groves in Cornwall Park were strongly different from the soils found in a stand of natural kauri forest at Mangatangi in the Hunua Ranges (Table 3). All soil variables except for organic C and Na were much lower in the Mangatangi soils indicating that the Cornwall Park soils were much more fertile. The Cornwall Park soils were substantially higher in pH, Total N, Olsen P, Ca, Mg, K, CEC, and base saturation, and much lower in CN ratio than soils within natural kauri stands at Mangatangi (Table 3).

**Table 3.** Comparisons of mean  $\pm$  SE soil parameters in Cornwall Park Kauri Groves (n= 11) and kauri forest at Mangatangi (n= 8) (B. Burns, unpubl. data).

| Soil variable       | Cornwall Park   | Mangatangi      | t-test             |
|---------------------|-----------------|-----------------|--------------------|
| pH                  | 5.9 $\pm$ 0.1   | 4.1 $\pm$ 0.1   | t = 17.7, P<0.001  |
| Organic C (%)       | 10.7 $\pm$ 1.0  | 10.5 $\pm$ 1.1  | t = 0.1, NS        |
| Total N (%)         | 0.64 $\pm$ 0.05 | 0.36 $\pm$ 0.03 | t = 4.3, P<0.001   |
| CN ratio            | 16.5 $\pm$ 0.7  | 28.9 $\pm$ 0.9  | t = -11.8, P<0.001 |
| Olsen P (mg/kg)     | 61.0 $\pm$ 5.7  | 4.6 $\pm$ 0.7   | t = 8.4, P<0.001   |
| Ca (cmol+)/kg)      | 20.6 $\pm$ 1.8  | 0.6 $\pm$ 0.1   | t = 9.4, P<0.001   |
| Mg (cmol+)/kg)      | 8.0 $\pm$ 0.4   | 1.6 $\pm$ 0.3   | t = 11.4, P<0.001  |
| K (cmol+)/kg)       | 1.7 $\pm$ 0.1   | 0.4 $\pm$ 0.04  | t = 10.0, P<0.001  |
| Na (cmol+)/kg)      | 0.39 $\pm$ 0.04 | 0.29 $\pm$ 0.04 | t = 1.8, NS        |
| CEC (cmol+)/kg)     | 44.1 $\pm$ 2.2  | 23.0 $\pm$ 1.9  | t = 6.9, P<0.001   |
| Base saturation (%) | 69.3 $\pm$ 2.5  | 11.9 $\pm$ 1.2  | t = 17.7, P<0.001  |

## Discussion

### Soil environment

It is now widely recognised that one of the most unique properties of kauri forest is its soil (Wyse 2013). Since kauri engineer the soil in ways that eventually favour a select range of ‘associate’ species, the state of the soil environment is crucial to consider when undertaking a restoration project of this type of community. The recalcitrant (i.e. slow to decompose) leaf litter of kauri have been shown to immobilize nitrogen in the soil and lower the soil pH, affecting the understory communities markedly (Wyse 2013). Among other things, these unique conditions have been shown to affect germination rates, with seeds of plants not typically associated with kauri generally having less germination success than kauri associated species (Wyse 2013). In a natural situation, soils under a kauri canopy are likely to gradually become more acidic and less fertile, as more leaf litter is deposited and the kauri podsol develops. However, with a revegetation project that aims to create a diverse kauri associate understory in a short space of time, issues regarding the soil conditions need to be considered. This is not only to increase the survival chances of the species planted, but also to ensure this type of community will be able to maintain itself, and not be constantly invaded by weed species (Perry et al. 2010) or other non-kauri associate species.

Currently the Cornwall Park Kauri Grove soils are much more fertile than found in natural kauri stands, and management options should be considered to decrease this dissimilarity. Firstly, plant clippings from other parts of the park should not be added into the Kauri Grove areas, as this practice is likely to increase soil fertility, hindering the formation of soils compatible with kauri communities. Other options involve direct inputs with the intention of limiting nitrogen availability. Of the methods which have been tested, the most realistic in this situation would involve increasing soil carbon, through the addition of substances such as sugar and or sawdust (Perry et al. 2010). In essence, adding these to the Kauri Grove would accelerate

microbial activity (increasing their N uptake), and in turn lowering available N present in the soil (Perry et al. 2010). A range of studies have demonstrated the positive effects of such methods on decreasing invasion and facilitating the growth of favoured plant communities (Perry et al. 2010). However, the logistics of such additions need to be considered, as even adding only 1 kg m<sup>-2</sup> of sugar to 1ha would require 10,000kgs of sugar, and sawdust additions should ideally be incorporated into the soil through mixing, which could be a task within itself (Perry et al. 2010). Furthermore, the length of time such additions will take to have their desired effect varies greatly among different environments, meaning it is not straightforward to predict whether reapplication would need to be relatively regular (i.e. multiple times a year), or much less frequent (Perry et al. 2010).

### Planting Strategy

In terms of the planting itself, protection of seedlings and palatable plant species from pests such as rabbits and possums (CPTB 2014) is an important consideration. Pest control will be vital to reduce damage to seedlings. Fencing may also be a useful way to achieve rabbit control, and it may have the added bonus of deterring people from exploring off the path to prevent the spread of kauri dieback. As the main Kauri Grove represents a substantial area to plant, we support the plan proposed by the horticulture team to stagger the planting, perhaps starting with a trial planting in the more modest area of CPK6. Within the larger Kauri Grove a similar approach could be taken too, focussing initial plantings around areas such as light gaps where kauri trees have already been lost (which may also lessen the likelihood of further weed invasions). Removal of the invasive weeds that are currently present before plantings should be a priority, particularly *Tradescantia fluminensis* and *Selaginella kraussiana*, and perhaps *Carex divulsa*.

If the kauri stands were to be extended, we would recommend including a small number of a mix of other tree species rather than planting a kauri monoculture. Other tree species such as tanekaha (*Phyllocladus trichomanoides*), rimu, and rewarewa could be planted so that the composition would be more typical of a young natural stand. Kauri would still be numerically dominant in the stand however. This added diversity would also provide a more diverse range of wildlife resources. We would also recommend planting more densely, mimicking a typical kauri ricker stand in which natural thinning is an important process. Edge plantings of species such as mānuka and kānuka (*Kunzea robusta*) to keep people out and act as a natural buffer may also be worth investing in, as might a boardwalk through the Kauri Grove to better protect the vulnerable kauri roots.

### Fauna

Increasing the size of the Kauri Grove is also likely to have positive effects on wildlife, as there will be more interior habitat and less of an edge effect. This is particularly likely to increase native bird dominance (Heggie-Gracie 2016), as the comparatively large size of the current Kauri Grove within Cornwall Park may be an important factor in explaining the greater proportions of native bird species observed here, with exotic birds being more edge specialists. A greater diversity of plants will decrease the homogeneity of the habitat, offering more floral (flowers and fruit) resources and structural complexity for a wider range of animal species, including invertebrates and reptiles. For example, edge plantings of mānuka will have the added benefit of being highly attractive to fauna. Currently the Kauri Grove lacks floral and fruit resources for birds, with birds in the Kauri Grove likely to be feeding on invertebrates, or simply using the grove for perching or roosting. The bird communities within sites dominated by exotic tree species also had lower insectivore numbers, which reflects general patterns that



exotic trees have lower invertebrate diversity, hence the need for more invertebrate rich understorey plant species. Some animal species however are hindered from reaching the Kauri Grove by dispersal constraints (such as the majority of native reptiles), as there are too few suitable areas of habitat nearby from which they could disperse. However, the urban context of Cornwall Park means that the Kauri Grove is at risk of invasion from species such as the plague skink (*Lampropholis delicata*) and other pest animal species. Biosecurity surveillance should be implemented in line with Auckland Council's Regional Pest Management Plan and with advice from Auckland Council.

### Understorey species

Understorey plantings and more complex forest structure are critical for both flora and fauna. Plants suitable for planting in the kauri understory include quite a wide range, although this is considerably lessened by availability of plants in cultivation. Ideally plants should be obtained from nurseries growing locally sourced (Auckland region), seed grown material. Focussing on plants more typical of kauri forests in the Auckland region (rather than Northland kauri forest) seems like the most authentic approach, with plants such as *Astelia trinervia*, *Gahnia xanthocarpa*, *G. pauciflora*, *Gahnia setifolia*, *Corokia buddleioides*, *Coprosma spathulata*, *C. arborea*, *C. lucida*, *Alseuosmia macrophylla*, *Brachyglottis kirkii* var. *angustior*, and *Toronia toru* all being worthy choices (Wyse 2013). We would also suggest focussing some planting around the path, enriching visitor experiences by allowing people to get a good opportunity to see some unusual kauri species. This could also be a good opportunity to plant a few slightly more unusual kauri associate species found in the Auckland region such as *Halocarpus kirkii*, *Pittosporum ellipticum*, *Phyllocladus toatoa*, *Libocedrus plumosa*, and *Leionema nudum* (Cranwell 1981). Not only does this raise the profile somewhat of these less commonly seen and potentially at risk species, but it also adds further opportunity for interest to be sparked in Auckland citizens and visitors from further afield, for the wonders of a very special forest type in this part of the country.

### **Recommendations:**

- Remove weeds from Kauri Groves – especially tradescantia (*Tradescantia fluminensis*) and African clubmoss (*Selaginella kraussiana*)
- Adopt strategies to lower soil nitrogen availability and pH (e.g. sawdust or sugar additions) in Kauri Groves.
- Plant kauri associates in groups throughout the grove – beginning with light gaps.
- Ensure kauri associates are appropriate for the Auckland Region, and include some less common species such as *Halocarpus kirkii*, *Leionema nudum*, *Phyllocladus toatoa*, and *Pittosporum ellipticum*.
- Protect seedlings from browsing - a fence would also prevent people, but costs would need to be considered.
- Prevent any future additions of plant clippings/mulch to Kauri Grove that would increase fertility.
- Ensure fallen branches (dead wood) are left in place as structure for animal biodiversity.
- Plant floral (flowering and fleshy-fruited) resources (ensuring they are kauri associates) for nectarivorous and frugivorous birds.
- Consider a boardwalk where the track currently is, to direct people away from walking through the grove (as another precaution against the spread of kauri dieback).
- Plant groups of kauri associates close to the boardwalk so people can experience these without leaving the boardwalk.

- Plant mānuka (*Leptospermum scoparium*) around the edges of the grove to direct people onto the boardwalk, to prevent invasion of weeds, and to reduce environmental edge effects.
- If the kauri stands are extended, include a small number of a mix of tree species that typify young kauri forest such as tanekaha (*Phyllocladus trichomanoides*), rimu (*Dacrydium cupressinum*), and rewarewa (*Knightia excelsa*), etc. Kauri would still be numerically dominant, however.  
Implement biosecurity surveillance with advice from Auckland Council staff in line with Auckland Council's Regional Pest Management Plan to enable early detection and management of pests.

## Acknowledgements

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## **Appendices**

Note: Most appendices consist of raw data or GPS points, and have been lodged with Cornwall Park Trust as electronic files

**Appendix 1: Cornwall Park Kauri Grove – Permanent vegetation plot locations**

**Appendix 2: Invertebrate and reptile monitoring station locations**

**Appendix 3: Photo points Cornwall Park Kauri Grove enhancement baseline survey**

**Appendix 4: Soil data from Cornwall Park Kauri Groves**

## **Appendix 1: Cornwall Park Kauri Grove – Permanent vegetation plot locations**

GPS coordinates for the 'A peg' of each plot, and bearings and distances of pegs from nearest tagged tree are given. Note, bearings are taken from the nearest tagged tree to the peg (not the other way around).

\*missing data represents pegs that had already been damaged/removed when these measurements were taken (and hence need reinstatement for when the plots are re-measured).

CPK1: Point A: 36° 53' 52.9" S, 174 ° 47' 11.6" E

Bearings and distances:

- Peg A: Tagged tree: CPK1 01; distance: 2.9m; bearing: 336°
- Peg D: Tagged tree: CPK1 04; distance: 3.6m; bearing: 65°
- Peg M: -
- Peg P: Tagged tree: CPK1 13; distance: 2.8m; bearing: 236°

CPK2: Point A: 36° 53' 52.8" S, 174 ° 47' 11.2" E

Bearings and distances:

- Peg A: -
- Peg D: Tagged tree: CPK2 03; distance: 2.74m; bearing: 56°
- Peg M: Tagged tree: CPK2 09; distance: 3.25m; bearing: 188°
- Peg P: -

CPK3: Point A: 36° 53' 54.2" S, 174 ° 47' 10.1" E

Bearings and distances:

- Peg A: Tagged tree: CPK3 01; distance: 2.8m; bearing: 338°
- Peg D: Tagged tree: CPK3 03; distance: 4.22m; bearing: 40°
- Peg M: Tagged tree: CPK3 11; distance: 2.84m; bearing: 136°
- Peg P: Tagged tree: CPK3 13; distance: 2.44m; bearing: 238°

CPK/R4: Point A: 36° 53' 55.1" S, 174 ° 47' 10.2" E

Bearings and distances:

- Peg A: Tagged tree: CPK/R4 02; distance: 6.15m; bearing: 328°
- Peg D: Tagged tree: CPK/R4 01; distance: 3.1m; bearing: 16°
- Peg M: Tagged tree: CPK/R4 05; distance: 2.95m; bearing: 90°
- Peg P: Tagged tree: CPK/R4 07; distance: 3.17m; bearing: 237°

CPK5: Point A: 36° 54' 11.6" S, 174 ° 47' 09.2" E

Bearings and distances:

- Peg A: Tagged tree: CPK5 01; distance: 5.3m; bearing: 99°
- Peg D: Tagged tree: CPK5 03; distance: 9.1m; bearing: 209°
- Peg M: Tagged tree: CPK3 08; distance: 2.84m; bearing: 136°
- Peg P: Tagged tree: CPK5 10; distance: 4.25m; bearing: 26°

## **Appendix 2: Invertebrate and reptile monitoring station locations**

### Onduline covers:

- CPK1: base of CPK1 01
- CPK2: base of CPK2 03
- CPK2: base of CPK2 05
- CPK3: base of CPK3 01
- CPK3: base of CPK3 09
- Between CPK1 'peg P' and CPK2 'peg D': 290° bearing from 'peg D' (CPK2)

### Invertebrate pine slabs:

- CPK1: base of CPK1 13
- CPK2: base of CPK2 02
- CPK3: base of CPK3 13

### Weta motels:

- CPK1: hanging on tag attachment nail of CPK1 01
- CPK3: hanging on tag attachment nail of CPK3 09

### **Appendix 3: Photo points Cornwall Park Kauri Grove enhancement baseline surveys**

Photos were taken from roughly 2 meters behind each peg (A,D,M,P) in each vegetation plot (CPK1,2,3,5, & CPK/R4). Locations of each plot and peg can be found in the vegetation plots folder. See electronic folders for actual image files.

Additional photos were also taken of each of the three kauri groves from a point outside to give a wider perspective on the grove. Coordinates for these points are as follows:

**Main kauri grove perspective photo point:** photo taken from base of grand stone steps to the west of the grove. 36° 53' 52.95" S, 174 ° 47' 09.18" E

**Small kauri grove (CPK6) perspective photo point:** photo taken from base of large puriri (*Vitex lucens*) directly adjacent to the west of the grove. 36° 53' 48.59" S, 174 ° 47' 09.23" E

**CPK5 perspective photo point:** photo taken from the base of a lone kauri tree standing in the grass to the north east of the grove, approximately 20m from the grove. 36° 54' 10.89" S, 174 ° 47' 09.75" E

#### Appendix 4: Soil chemistry data from Cornwall Park kauri groves

| Sample<br><br>ID | pH<br>(2:5<br>Water)<br>(method<br>106(ii)) | Organic<br><br>C<br><br>(method 114)<br><br>(%) | Total<br><br>N<br><br>(method<br>114)<br><br>(%) | C/N<br><br>ratio<br><br>(calculation)* | Olsen<br><br>P<br><br>(method<br>124)<br><br>(mg/kg) | Exchangeable                      |      |      |      | CEC<br><br><br>(method<br>144(ii))*<br><br>(cmol(+)/kg) | Base<br><br><br>Saturation<br><br>(calculation)*<br><br>(%) |
|------------------|---|---|--|--|--|-----------------------------------|------|------|------|---|---|
|                  |   |   |  |  |  | Ca                                | Mg   | K    | Na   |   |   |
|                  |   |   |  |  |  | (method 140(ii))*<br>(cmol(+)/kg) |      |      |      |   |   |
| CPK 1.1          | 6.10  | 9.42  | 0.62   | 15                                     | 49   | 20.3                              | 8.39 | 1.96 | 0.30 | 42  | 74  |
| CPK 1.2          | 5.97  | 9.07  | 0.59   | 15                                     | 68   | 18.8                              | 7.58 | 1.93 | 0.29 | 41  | 70  |
| CPK 2.1          | 5.88  | 9.33  | 0.60   | 15                                     | 55   | 18.6                              | 7.99 | 1.55 | 0.34 | 41  | 70  |
| CPK 2.2          | 5.93  | 10.5  | 0.66   | 16                                     | 45   | 17.9                              | 8.11 | 1.27 | 0.33 | 41  | 67  |
| CPK 3.1          | 6.04  | 5.49  | 0.40   | 14                                     | 62   | 15.3                              | 6.41 | 1.17 | 0.30 | 34  | 69  |
| CPK 3.2          | 6.11  | 5.52  | 0.38   | 15                                     | 69   | 16.0                              | 6.45 | 1.70 | 0.30 | 35  | 71  |
| CPK/R 4.1        | 5.75  | 13.2  | 0.65   | 20                                     | 92   | 27.8                              | 8.97 | 1.34 | 0.57 | 53  | 73  |
| CPK/R 4.2        | 5.89  | 12.3  | 0.62   | 20                                     | 93   | 29.1                              | 10.1 | 1.52 | 0.49 | 55  | 75  |
| CPK 5.1          | 5.51  | 14.5  | 0.90   | 16                                     | 45   | 18.0                              | 7.42 | 1.94 | 0.41 | 48  | 58  |
| CPK 5.2          | 5.44  | 13.1  | 0.84   | 16                                     | 59   | 13.6                              | 6.11 | 1.72 | 0.30 | 41  | 52  |
| CPK 6            | 6.22  | 15.1  | 0.78   | 19                                     | 34   | 31.3                              | 9.99 | 2.35 | 0.68 | 54  | 83  |