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# Article 9. Vegetation Ecosystem Studies on both hill and wetland species, Great Barrier Island, New Zealand.

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## Abstract
This field study attempts to identify the community structure by a combination of classification and ordination methods based on the sampling data of vegetation species in Little Windy Hill, Great Barrier Island, New Zealand. Three distinct vegetation community units have been identified. Unit1 mainly includes dense stands of old *Coporosma arborea* species with a mean canopy height of 9m and a mean basal area of 78.95m/ha, while there are mainly four dominated species in unit 2, including *Beilschmiedia tarairi, Coprosma arborea, Dysoxylum spectabile*, and *Rhopalostylis sapida.* Unit 2 has the largest basal area of 90.8m/ha. Unit 3 comprises a large proportion of kanuka (*Kunzea ercoides*) and a few Manuka (*Leptospermum scoparium*) stands with the least basal area of 39.46m/ha and a mean canopy height of 11m. The succession pattern of these vegetation units are from unit 3 → unit 1 → unit 2. The environmental gradients underlying the temporal and spatial dynamics of community succession are associated with slope, topographical unit, aspect, soil conditions as well as historical disturbance, such as fire and grazing activities, which together explain the succession patterns of vegetation community. Another field sampling study has been also conducted in Great Barrier Island, but wetland species are selected to analyze the ecosystem community. This wetland field study examines the community-unit and individualistic concepts by using environmental gradient analysis of vegetation distribution patterns in Kaitoke swamp, Great Barrier Island, New Zealand. Both water depth and transect line are chosen as environmental gradients, along with which the vegetation communities show similar distribution patterns. The boundaries of vegetation species distribution tend to be clustered within some specific intervals of environmental gradient. Nevertheless, no correlation has been found between upper and lower boundaries along both gradients. This conclusion supports neither community-unit nor individualistic conception, which indicates that other hypotheses regarding to community distribution patterns would suit better for the studied ecosystem, e.g. ecological niche which is further discussed in this paper for restoration of wetlands. However, there are some limitations in the sampling accuracy supporting these classic ecological theories.

**Key words: Community Classification; Community Succession; Environmental Gradient Analysis; Community-unit; Individualistic concepts.**

# 新西兰大坝岛山地和湿地植被生态系统研究

**摘要：**此项野外调研旨在应用多元聚类分析方法辨认新西兰大坝岛小风山的植物群落的结构。三个明显的植物群落在研究中被分类出并且确认。群落单元一的建群种主要包括 *Coporosma arborea* 的古树，拥有平均 9m 的树冠层高度和平均 78.95m/ha 的树干面积。单元二主要有四个优势种，分别是 *Beilschmiedia tarairi, Coprosma arborea, Dysoxylum spectabile*, and *Rhopalostylis sapida.*单元二拥有最大的平均树干面积，达到了 90.8m/ha。单元三的优势种群主要是由 kanuka (*Kunzea ercoides*)种群和 Manuka (*Leptospermum scoparium*)种群组成的，平均树干面积只有 39.46m/ha，是三个群落单元中最小的，然而平均树冠层高度则达到了 11 米。决定该植物群落时空演替规律的环境梯度主要与坡度，地型单元，向阳面，土壤条件，历史上人类干扰活动（如火灾和畜牧）等因素相关。群落演替的顺序为从单元三 →单元一 → 单元二。另一项实证型采样研究也在新西兰大坝岛开展，但是选取了湿地植被物种用于群落单元分析。这项实证性研究旨在应用环境梯度分析方法论证两个植物生态理论假设：“群落单元”和“独立单元”假设。采样地点为新西兰大坝岛卡托克沼泽。水深和离岸距离被选取为环境梯度的分析变量。沿着两个环境梯度变量，植被群落显示出了相似的分布形态。植被种类的分布边界趋向于在环境变量的某个特定值域集中。然而，沿着环境梯度变量，植被的上层和下层分布边界之间没有发现显著的相关性。这个结论既不支持“群落单元”假设，也不支持“独立单元”假设。其他关于植物生态分布的理论假设应当更适合于这个被研究的沼泽生态系统, 比如生态位理论在本文得到进一步论述并且应用于湿地修复。然而，采样方法的局限性也很可能使得此项研究的环境梯度分析达不到支持理论假设的精度。

**关键词：群落分类; 群落演替; 环境梯度分析；“群落单元”假设；“独立单元”假设。**

# 1. Introduction

Great Barrier Island, which is the largest off-shore island in the outer Hauraki Gulf, Auckland, New Zealand, occupies a scale of approximately 28 500ha. Little Windy Hill (LWH) is situated at the southeastern end of this island with a scale of around 300ha, reaching a maximum elevation of 361m. This forest is operated as a private conservation and restoration project, under the regulation of the Rosalie Bay Catchment Trust (RBCT) (Bouzaid, 2008).

Fire disturbance has been taken by early Maori, then again by Europeans, which leads LWH to be suffered from a lack of fertility. European farming activities ceased by c .1965 as sheep became less profitable, leading the land to regenerate into native forest. However, there are still a number of these large old forest remnants in some gully sidlings and bottoms. Current landscape is dominated by kanuka, manuka, and silver fern complex mainly on the south east aspect, occupying 35% of the measured sites (Cameron, 2001; Ogden, 2001).

Since 1999, the trust has launched a program to control invasive weeds and mammals, such as rodents and feral cats, which significantly improved the health of native flora and fauna ecosystem. Systems of traps were installed over the forest area in LWH. So far, 27,000 rats were trapped and 300 cats were killed, leading to ideal habitats for the native birds at present. Consequently, successful translocation of robins has been taken in Great Barrier Island (Davy, 2008).

Relatively limited studies have been carried out to identify vegetation community structure using classification and ordination methods in Little Windy Hill. Davy (2008) recognized three types of vegetation communities in LWH, including 'Young' regeneration, 'old' regeneration, and 'mature' forest. Ogden and Perry (2005) distinguished four distinct vegetation units in LWH, and suggested more types of vegetation community should exist, if field sampling could be taken over a larger range. In this study, vegetation data were collected at different points from the above two studies, extending the sampling area of earlier research. Particularly, these sampling sites cover some stations where bird counting was taken at 5 minute interval.

The objective of this hill study is to analyze the vegetation community structure by using both classification and ordination methods based on the field sampling in September in 2008 in Little Windy Hill. Succession patterns will be identified according to the species composition in each vegetation units. The environmental gradient of species composition will be analyzed on the basis of correlation between environmental conditions and forest structure.

For the wetland species in Great Barrier Island, a number of swamp ecosystems, impounded by sand dunes, are located on the exposed eastern side of the island. The Kaitoke swamp system is oriented on the southern central east coast of Great Barrier (36$^o$ 14' S, 175$^o$ 28' E) with a length of 6.5km in the northwest-southeast direction. This swamp contains high level of sediments which are caused by the dune formation and extensive European drainage. According to NZ Map Series (336-02, 1996), freshwater swamp vegetation species on Great Barrier Island include *Typha orientalis*, *Cyperus ustulatus*, *Leptospermum scoparium*, *Baumea spp.*, and *Gleichenia dicarpa*.

In the past, there was a controversial issue regarding to the species competition hypotheses in terms of ecological response curves along with environmental gradient. So far, the broadly-accepted conceptions include community-unit and individualistic theories. Community-unit hypothesis, which was firstly stated by Clements (1916), indicated that competing species excluded each other and developed distinct zones along the environmental gradients with assemblage of species of similar ecological niche in each zone. In comparison, individualistic concept suggested that competition did not lead to the distinct distribution boundaries among species communities and could not produce the well-defined species groups with similar distributions (Gleason, 1935).

Pielou (1975, 1977) interpreted these two theories by using the terms of ‘upper boundaries’ and ‘lower boundaries’ of species distribution along environmental gradient: the individualistic hypothesis stated that both upper and lower boundaries were equally distributed in each interval of the gradient without correlation between them; for the community-unit concept, the upper and lower boundaries should be clustered along environmental gradient and correlated with each other (Pielou, 1975;1977).

The objective of this wetland study is to examine the community-unit and individualistic concepts by using gradient analysis based on the sampling data of vegetation species in Kaitoke swamp. The patterns of species distribution boundaries along the environmental gradient of both water depth and transect line will be compared with the patterns predicted by the hypotheses.

# 2. Methods

### 2.1. Field methods

For the hill vegetation species, field sampling method relied on the point-centred quarter (PCQ), which was a commonly plotless method used for vegetation surveying. At each point, the space was divided into four quadrants in four orientations. Within each quadrant, the nearest tree with its diameter and distance was recorded. Forest density was estimated by the mean point-tree distance in the forest, which was proportional to forest density. Basal area could be calculated using the mean diameter and the species composition was assessed by the summary of identified species. Forest structure was interpreted in terms of the frequency of species, density, or basal area of each species.

The sampling points were chosen along the bait-stations, which were distributed on a 50×50m grid system. Only plants with a stem of more than 5cm diameter at 1m height were considered as ‘trees’. Within each quadrant, the nearest tree was identified, including its diameter and distance from the point. Then the next nearest tree was also identified without measurement of diameter and distance. This contributed to the further identification of species composition. Tree species with the point label was also recorded. In total, there were nine trees identified in each point, including the centre tree, the four nearest, and the four next nearest. In addition, the large tree of the sampling point was also recorded, which the PCQ sampling did not recognize.

The largest tree fern (more than 1m truck height) with a distance of less or equal to the nearest tree was recorded, including its species and height within each quadrant. In this way, up to four tree-fern heights should be measured at each sampling point.

At each point, the canopy height was estimated subjectively, and the slope and aspect were measured using a clinometer and compass. Topography of each sampling point was described using following topographical units: 1, ridge top; 2, upper slope; 3, mid-slope; 4, lower slope; 5, gully, and 6, other.

For the wetland sampling, twelve transects were selected at 100 meter intervals along the traffic road on the southwest of Kaitoke Swamp, starting from the forest end (transect 1) towards the estuary. 5-8 sampling plots were chosen along each transect at north orientation with a distance of 20m between adjacent sampling plots. This makes sure that 12 transects were placed perpendicularly. Seventy nine sampling plots in total were collected in this study. Plant species, relative density of each species, water depth, and soil types were recorded during each sampling. The relative density of vegetation species was scored subjectively, ranging from 1 to 4.

**2.2. Analysis methods**

For the hill vegetation species, the classification of ordination analysis was taken using Primer 5 software package on the basis of Bray-Curtis dissimilarity index. The implementation of ordination attempted to eliminate the 'stress', which indicated the effectiveness of inter-object distances reflecting real similarities/dissimilarities.

Mean density, canopy height, diameter, and basal area were calculated in each vegetation unit. Relative density, relative basal area, and importance (relative density + relative basal area) of dominated species were also calculated. Particularly, species frequency-size relation was analyzed for the identification of succession patterns. Topographical measurement, including Topo units, aspect, slope, was also analyzed for the interpretation of environmental gradient.

For the wetland study, the importance index of each species was measured in terms of the mean scores of species density along environmental gradient. The species frequency was also assessed according to the presence/absence of species in the sampling plots. These numbers were ‘smoothed’ using the following equation: Smoothed value at t = ([value at t-1] + [2 * value at t] + [value at t +1]) / 4. This process helped to analyze the irregular data derived from relatively small sampling units.

In this study, there were two types of environmental gradient used: the water depth and transect line. Distribution boundaries were counted along each gradient based on the methods given by Shipley and Keddy (1987). The recorded water depth ranged from 0 to 70 cm, which was divided into fourteen equal intervals (5 cm water depth per interval). However, the majority of sampling plots were clustered between 0 and 20 cm water depth. Especially, there were no more than 2 sampling plots in the intervals at the water depth of above 25cm, and no sampling plots were found in 45-50, 55-60, and 60-65cm intervals. Consequently, it was cautious to extrapolate the distribution pattern of plant species above 25cm water depth due to small sampling units.

In order to test these hypotheses, Spearman’s Rank Correlation (non-parametric) was used to examine the correlation between upper and lower boundaries of vegetation distribution. However, the effect of environmental gradient intervals on the number of boundaries per interval was estimated subjectively, which examined the ‘clustering’ of distribution boundaries.

# 3.1. Results --- Part A (Hill Vegetation Ecosystem)

### 3.1.1. Classification and ordination

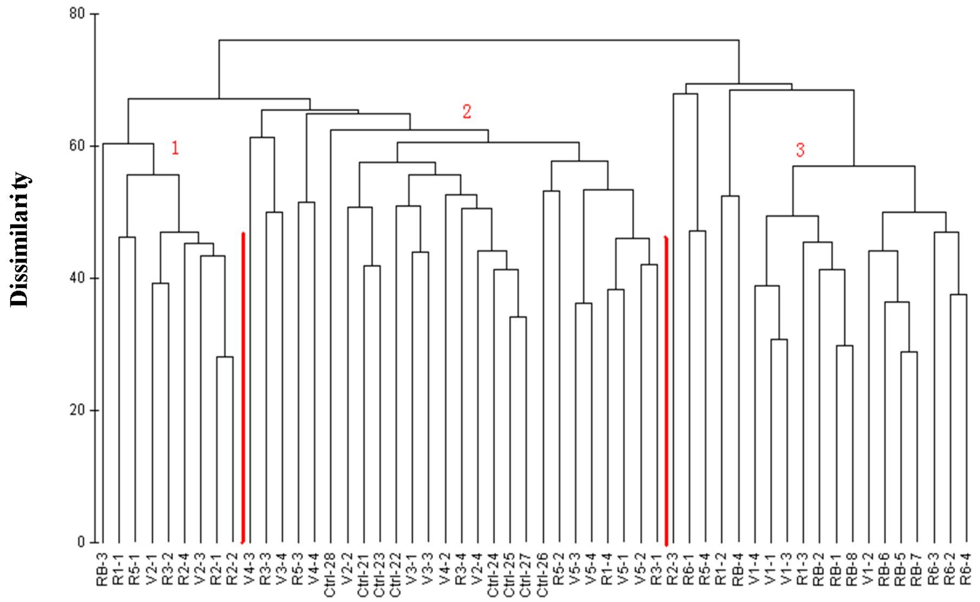


Fig1. Classification dendrogram-showing sites grouped into vegetation unit.

Fig1 shows the dendrogram of grouping sites into vegetation units in LWH. Each sampling point is shown at the bottom (letters indicating the station lines and numbers showing the specific points of the line). These sampling sites are classified according to their dissimilarity (similarity) in species composition. The red lines divide these sites into three vegetation units with different amount of sampling points. Unit 1 mainly comprises sites of upper slope dominated by *Coprosma arborea* species. Vegetation species composition has more diversity in unit 2, where *Beilschmieia tarairir, Coprosma arborea, Dysoxylum spectabile,* and *Rhopalostylis sapida* together become dominated. However, unit 3 is predominantly dominated by *Kunzea ericoides* species with fewer occurrences of *Lepetospermum scoparium* and *Coprosma arborea* species. Generally, there is distinct difference in species composition among these vegetation units.

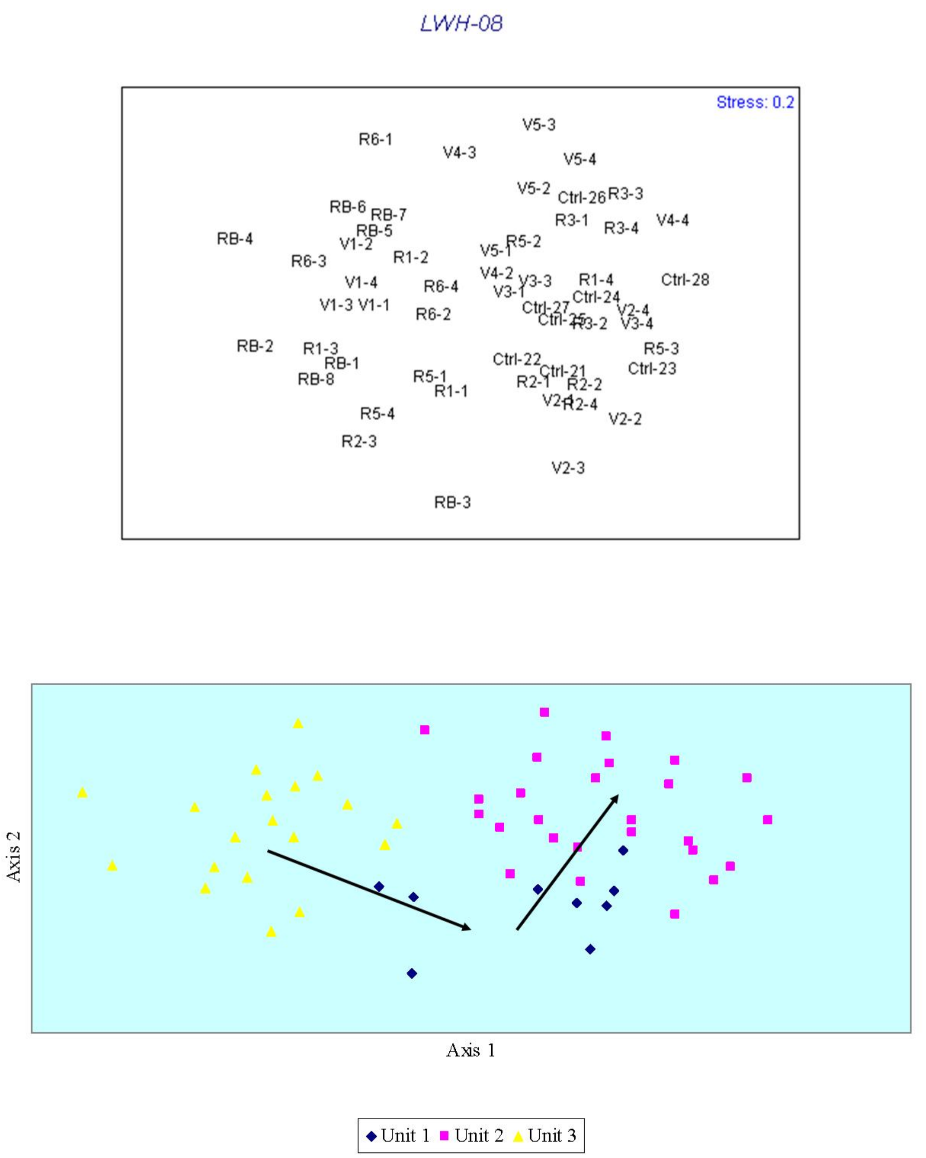


Fig 2. Ordination gram showing site distribution in two dimensions.

Fig 2 illustrates the interrelations among these sampling sites in terms of species composition in two dimensions. The nMDS Stress value is 0.2, which means that this diagram effectively represents the similarity of matrix. The below chart of Fig2 indicates the classification units superimposed on the ordination graph without overlap. Unit 1 is located at the middle bottom of this diagram, while unit 2 and unit 3 are at the upper right and left, respectively. The succession patterns of these vegetation units are from unit 3 → unit 1 → unit 2.

### 3.1.2. Forest structure and species composition

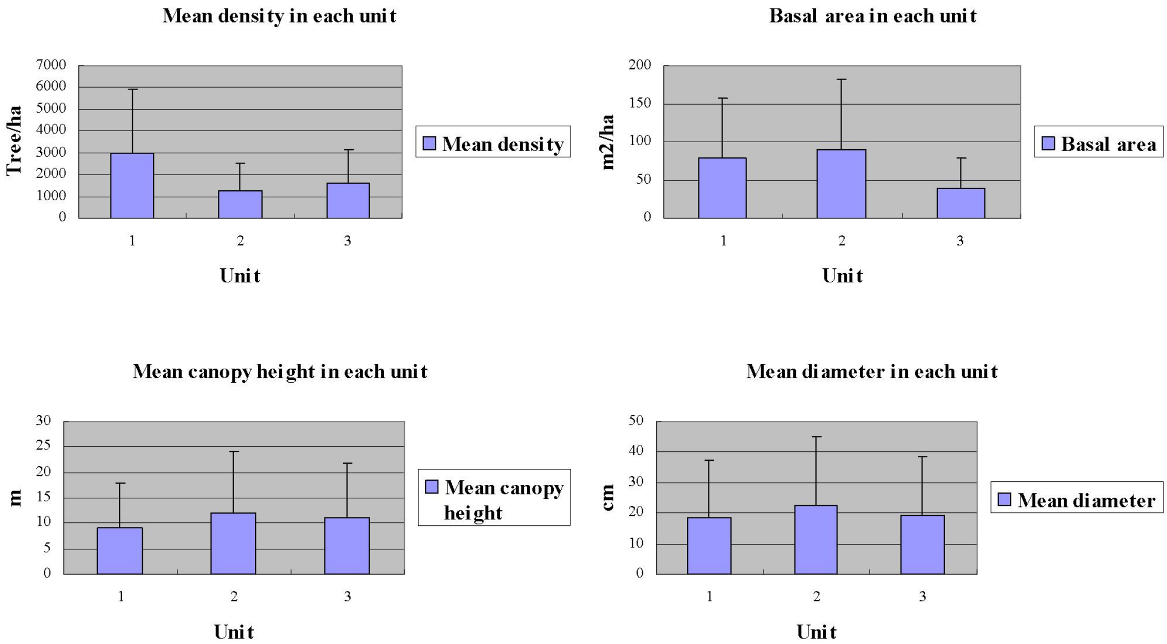


Fig 3. Forest structure in each vegetation unit.

Fig 3 illustrates the forest structure in terms of mean density, basal area, canopy height, and diameter in each unit. Unit 1 has the highest mean density of trees (2966 trees/ha) among three units. Mean basal area ranges from 39.46 $m^2$/ha in unit 3 to 90.8 $m^2$/ha in unit 2. There are fewer variations in mean canopy height and diameter among these units, ranging from 9 to 12 m and from 18.6 to 22.5 cm, respectively. The mean tree fern height is 2.5, 3.56, and 2.07m in unit 1, unit 2, and unit 3, respectively (not list in figure).

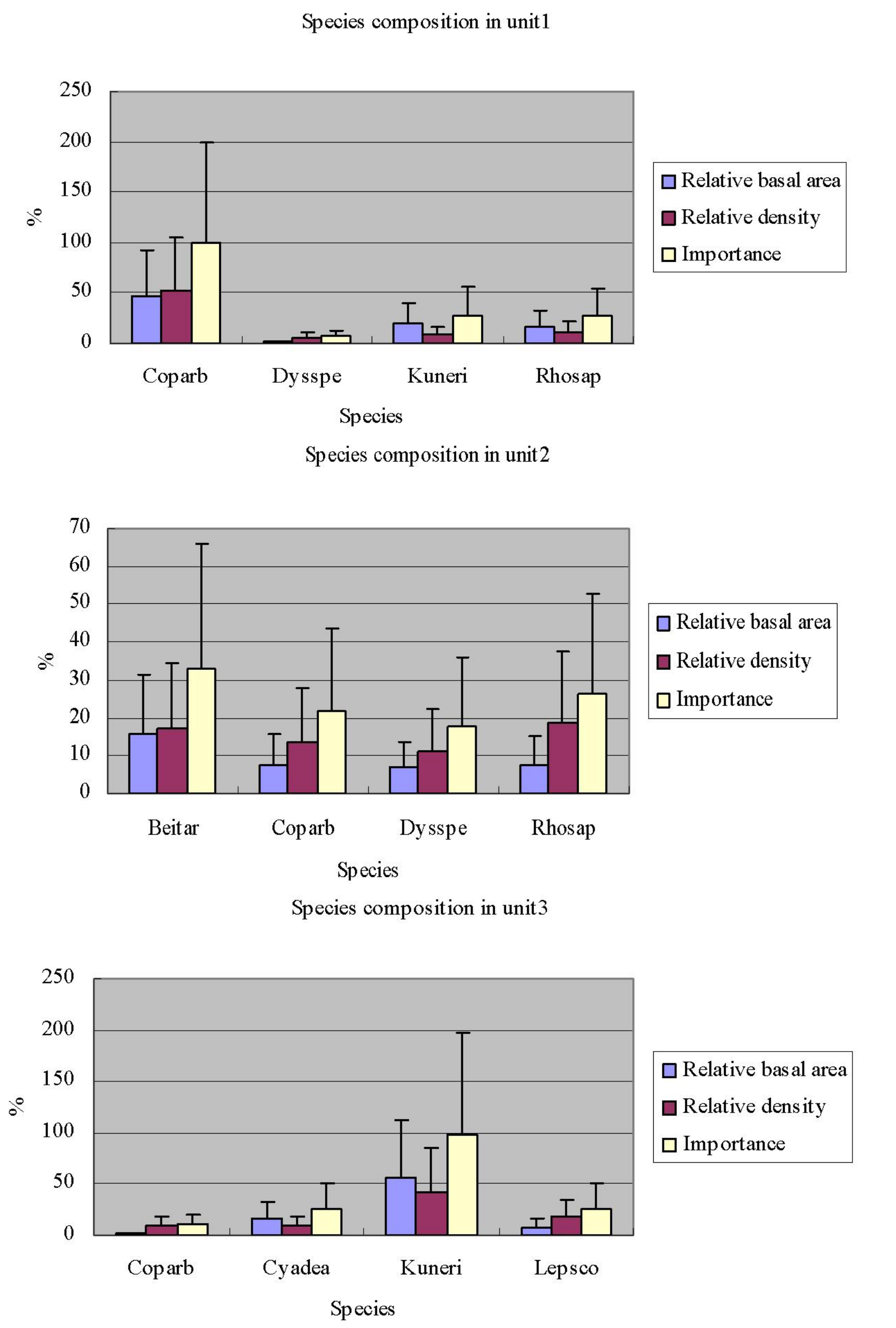


Fig 4. Species composition in each vegetation unit.

Fig 4 shows the composition of the most four significant vegetation species in terms of relative basal area, relative density, and importance in each unit. In unit 1, *Coporosma arborea* species has the highest importance of 99.34, indicating its dominance in this unit. In comparison, unit 3 is predominantly dominated by *Kunzea ericoides* species with the highest importance of 98.68. However, in unit 2, *Beilschmiedia tarairi, Coprosma arborea, Dysoxylum spectabile*, and *Rhopalostylis sapida* have similar value of importance, ranging from 17.91 to 33.03. This reveals that more diverse composition of vegetation species exists in unit 2. In addition, all the control sites are located in unit 2.

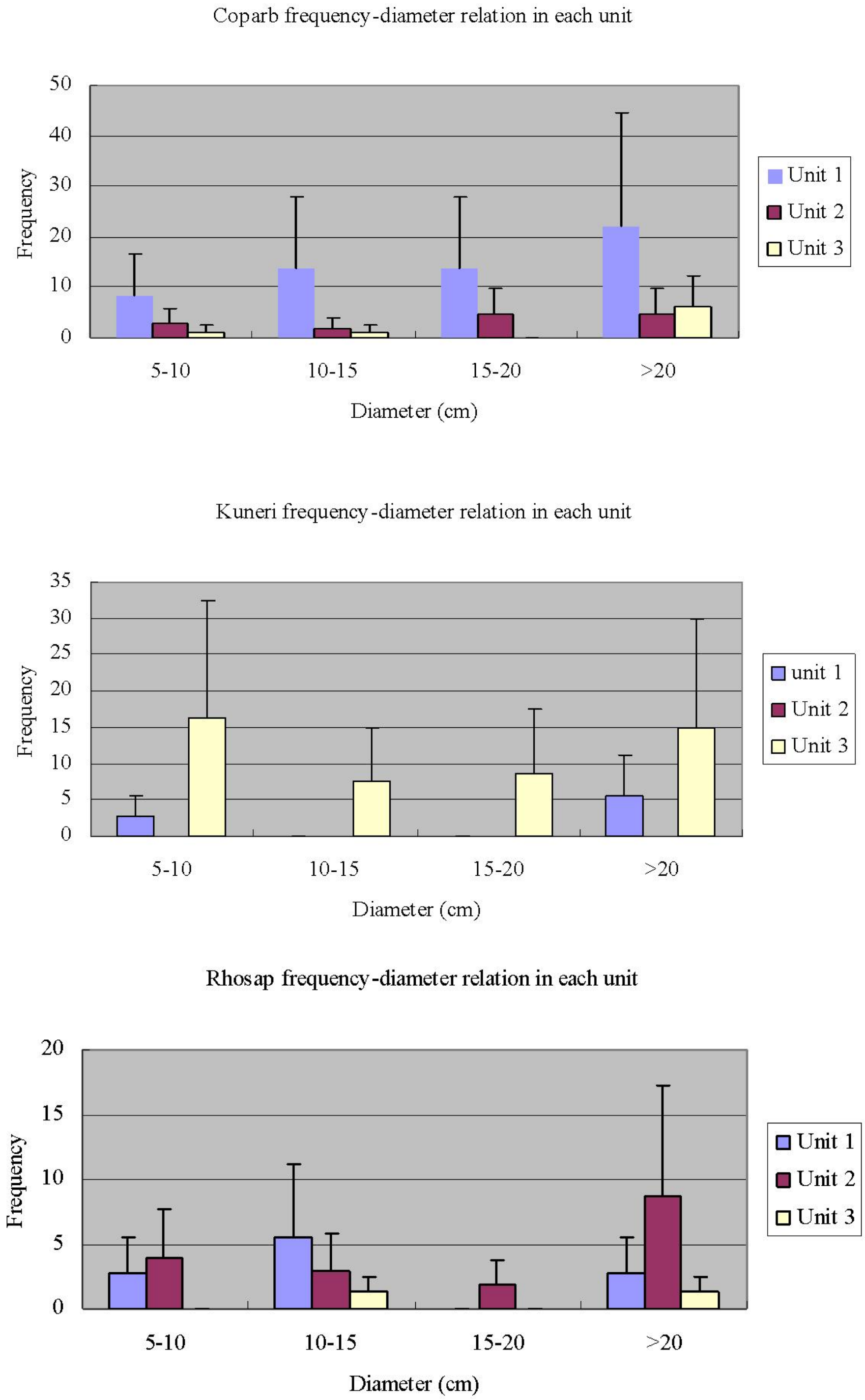


Fig 5. Species frequency-size relation in each units

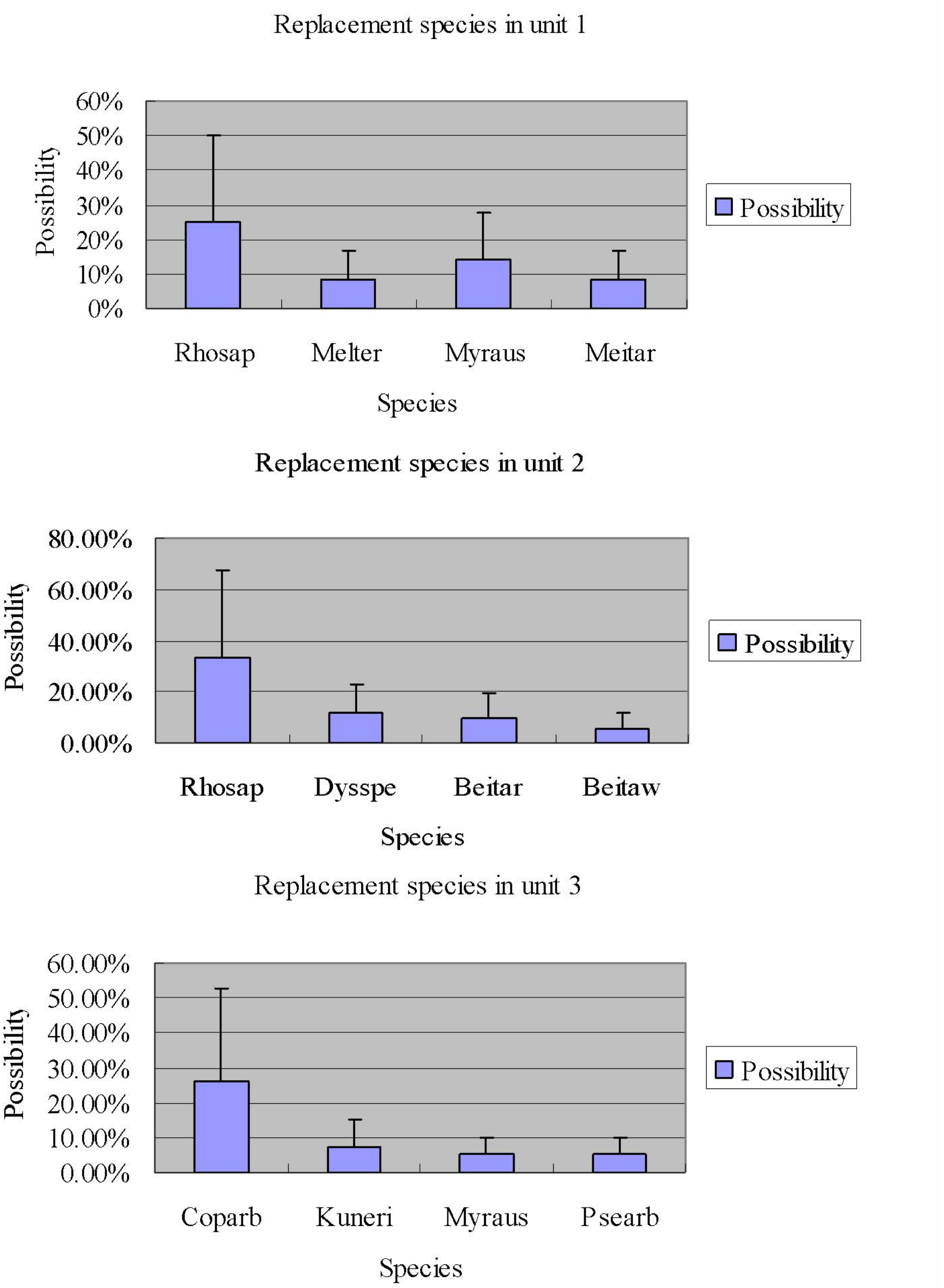


Fig 6. Replacement species in each vegetation unit.

Fig 5 shows the frequency-size relation of vegetation species in each unit, which explains the stand age and succession patterns among three vegetation units (this calculation excluded the dead trees). Generally, the age structure of three main species varies among different vegetation units. The *Coprosma arborea* species comprise more densely old stands (>20cm) than young trees (5-10cm) in both unit 1 and unit3, indicating that there is decreasing trend in *Coprosma arborea* development in these two units. However, *Kunzea ericoides* species is evenly distributed in each interval of size in unit 3 with few or no distribution in unit 1 and unit 2. For *Rhopalostylis sapida* species, there are more old stands in unit 2, but more young trees in unit 1.

In Fig6, the dominated species *Coprosma arborea* becomes less possible to replace existing canopy in unit 1, further indicating that this species tends to decrease in this unit. The most likely replacement species is *Rhopalostylis sapida* in both unit 1 and unit 2. Nevertheless, *Coprosma arborea* has the highest possibility of replacement in unit 3, whereas the dominated species *Kunzea ericoides* becomes less significant in terms of replacement species in this unit. This indicates a decreasing trend in *Kunzea ericoides* species in unit 3.

### 3.1.3. Correlation between vegetation unit and environmental measurement

**Table 1. The mean aspect and slope angle of each vegetation unit.**

| | Unit1 | Unit2 | Unit3 |
|---|---|---|---|
| Mean aspect (º) | 189 | 206 | 144 |
| Mean slope (º) | 18 | 16 | 18 |
| Median Topo unit | 3 | 3 | 3 |

**Table 2. Proportion of points in each topography unit within each vegetation unit.**

| | Unit1 | Unit2 | Unit3 |
|---|---|---|---|
| Topo1 | 11.11% | 3.85% | 5% |
| Topo2 | 55.56% | 15.38% | 35% |
| Topo3 | 11.11% | 30.77% | 15% |
| Topo4 | 11.11% | 30.77% | 20% |
| Topo5 | 11.11% | 19.23% | 25% |

**Table 3. Proportion of points in each orientation within each vegetation unit.**

| | Unit 1 | Unit 2 | Unit 3 |
|---|---|---|---|
| North | 11.11% | 11.54% | 35% |
| East | 22.22% | 11.54% | 15% |
| South | 22.22% | 26.92% | 10% |
| West | 22.22% | 50% | 40% |

The mean aspect and slope are shown in table 1. Three vegetation units have similar mean slope angle (16-18º). The majority of sampling sites in unit 1 falls in topography unit 2. This means that unit 2 is closer to the ridge side of hills. The median topography unit in vegetation unit 2 and 3 is Topo3. Nevertheless, sampling points in each vegetation unit cover all the topography units. In unit 1, points are evenly distributed over all the orientations. There is predominantly southwesterly aspect in unit 2, while unit 3 mainly has northwesterly aspect.

# 3.2. Results --- Part B (Wetland Vegetation Ecosystem)

## 3.2.1. Dominant plant species in wetlands

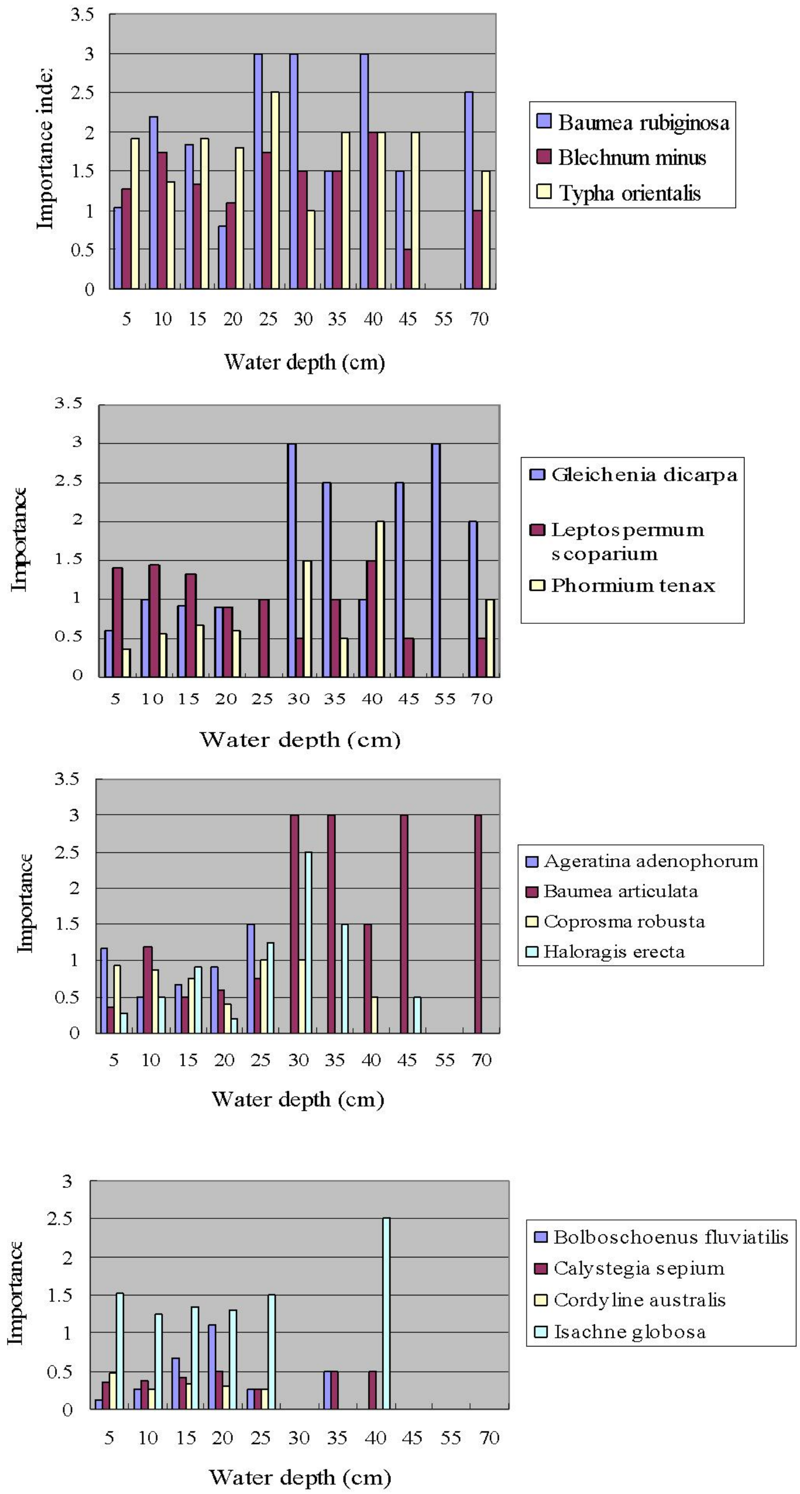


Fig1. Importance of significant species in water depth interval.

Figure 1 showed the importance index of 14 plant species in terms of mean density scores in each water depth interval in Kaitoke swamp. The density scores of these 14 plant species accounted for 77.8% of total vegetation density scores, which hence should be considered as dominated vegetation species in this wetland ecosystem. Among these species, *Baumea rubiginosa, Typha orientalis, Gleichenia dicarpa,* *Baumea articulate* occupied 12.4%, 11.0%, 10.6%, and 10.3% of total density scores, respectively. These results were consistent with the observation recorded by Rutherford (1998) and NZ Map Series (336-02, 1996).

The distribution zones of these vegetation species varied along water depth gradient. *Baumea rubiginosa, Blechnum minus, Typha orientalis, and Isachne globosa* dominated over the whole gradient of water depth (0-70cm). In comparison, *Leptospermum scoparium* and *Ageratina adennophorum* tended to be clustered in the shallow water depth (0-25cm), whereas *Gleichenia dicarpa, Phormium tenax, Baumea articulata,* and *Haloragis erecta* were more frequently found in the intervals of above 30 cm water depth (Fig1). Nevertheless, the majority of these dominated species were distributed over the entire water depth gradient in this study.

**3.2.2. Distribution pattern of plant species along environmental gradients**

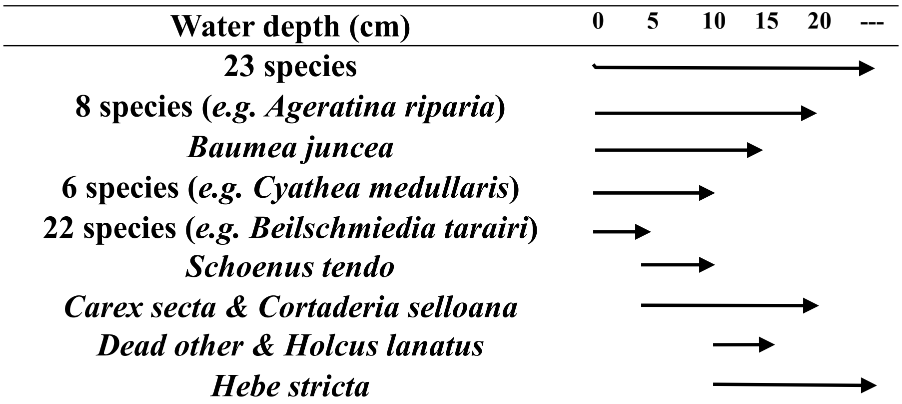


**Fig 2. Plant species distribution along water depth gradient in Kaitoke swamp.**

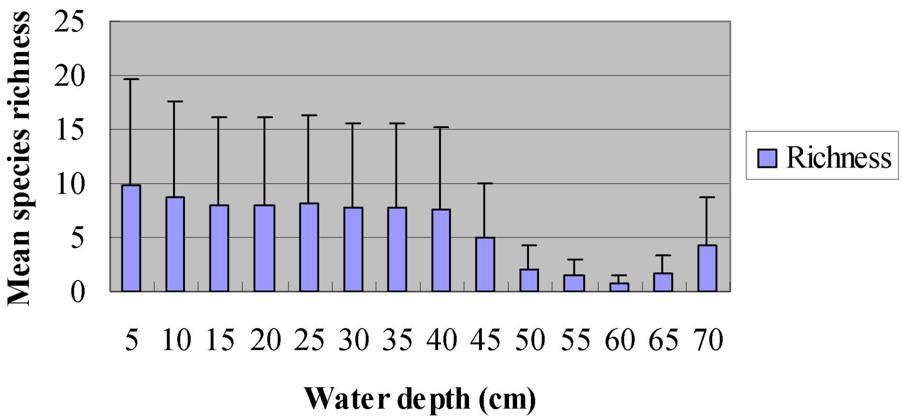


**Fig3. The mean species richness in each 5 cm water depth interval.**

Fig 2 listed the distribution patterns of all the vegetation species along water depth gradient in Kaitoke swamp. Since there were seldom sampling units above 25 cm water depth, the distribution boundaries of plant species could be determined only between 0 and 20 cm water depth gradient. Among the total 66 species, the distribution of most species started in the water depth interval between 0 and 5 cm. However, there are some exceptions: *Schoenus tendo, Carex secta,* and *Cortaderia* *selloana* started its distribution in the 5-10 cm interval, while the upper distribution boundaries of *Dead other, Holcus lanatus,* and *Hebe stricta* were found between 10 and 15 cm water depth. Compared with the dominated plant species, a large proportion of infrequent species could only survive in the shallow water, e.g. *Beilschmiedia taraire* can only be found in 0-5 water depth interval. Nevertheless, the overall distribution pattern of vegetation species did not form ecological zones which were distinctly separated. Further more, there was no correlation between upper and lower boundaries, which could not support the concept of community-unit. However, the majority of species were clustered in lower boundaries (both 5-10cm and 15-20cm) water depth intervals, which was not consistent with the individualistic hypothesis as well. There was not significant difference in species richness among the intervals of below 40cm water depth (Fig3). However, species richness decreased in the deep water (above 40cm).

**Fig 4. Plant species distribution along transect gradient in Kaitoke swamp.**

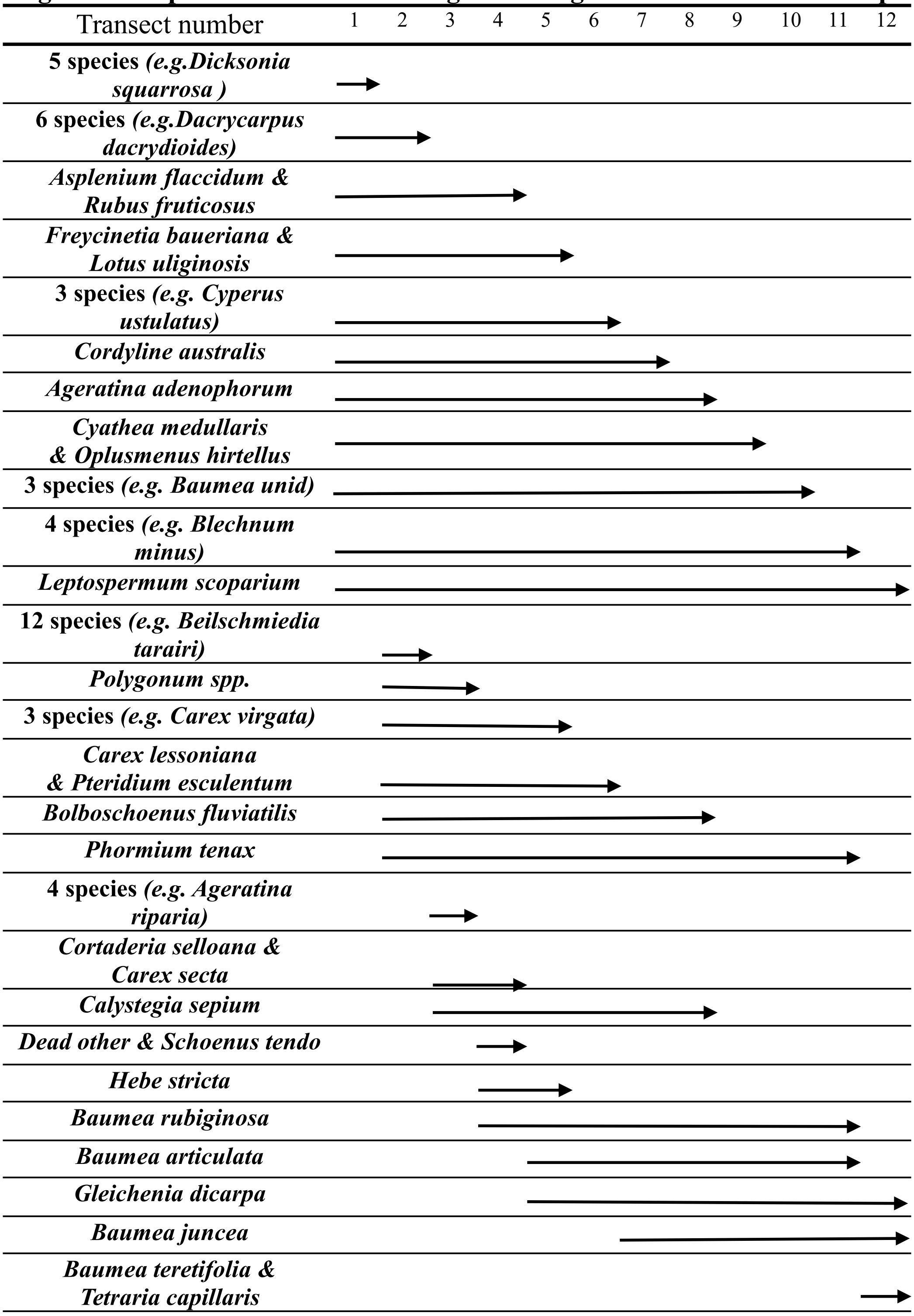


Fig4 showed the distribution patterns of plant species along the transect gradient. *Dacrycarpus dacrydioides, Hedycarya arborea, Hoheria populnea, Melicytus ramiflorus, Metrosideros perforate,* and *Microsorum pustulatum* reached their lower distribution boundaries in transect 2, while other 8 species (from *Polygonum spp.* to *Phormium tenax*) started distribution at this transect. In transect 3, the upper boundaries of another species group (from *Ageratina riparia* to *Calystegia sepium*) were found, but there were no lower distribution boundaries in this transect. Particularly, a large number of lower boundaries were found between transect 4 and 11, while relatively fewer boundaries of upper distribution existed within this range. This disconcordant distribution pattern of upper and lower boundaries led to no correlation between them ($R = 0.1182$, $P <= 0.7589$) (Fig 5), which did not support community-unit concept.

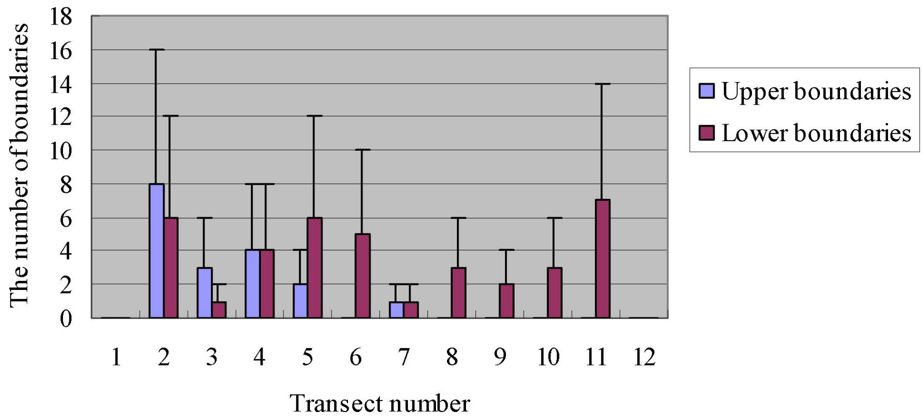


**Fig5. The number of boundaries in each transect in Kaitoke swamp.**

The upper boundaries of species distribution could be only found in transect 2, 3, 4, 5, and 7 (Fig 5), which indicated that they tended to be clustered along the transect gradient (this pattern might also exist in lower boundaries). Hence, the individualistic concept should be also rejected. The representative species distributions are shown in Fig 6. There was no clear similarity to the patterns demonstrating community-unit and individualistic concept.

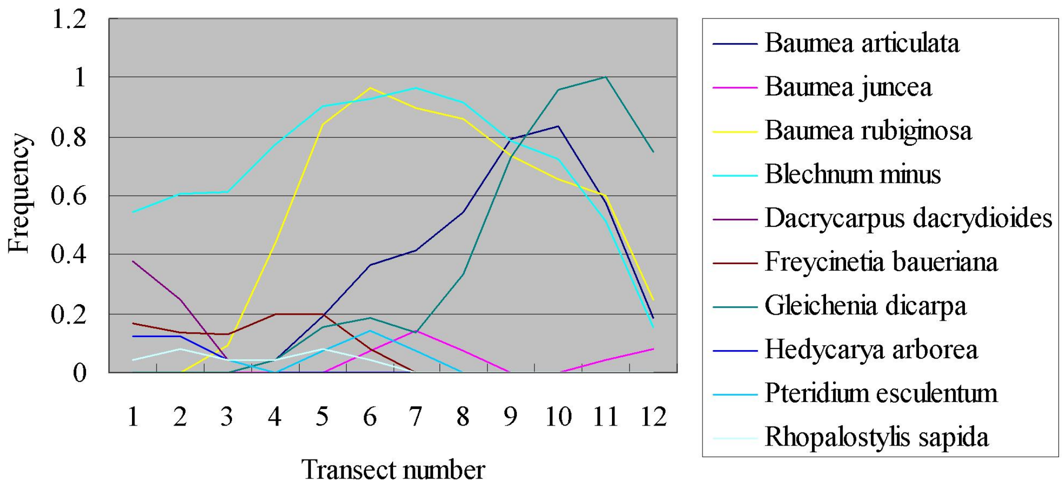


**Fig 6. Frequency distribution of plant species along transects in Kaitoke swamp.**

### 3.2.3. Water table and soil type

Water table recorded ranged from 0 to 70cm with an average of 13.97cm in Kaitoke swamp, which was relatively shallow. Soil types were predominantly organic with infrequent occurrence of coarse, or clay soil scattered between transect 2 and 3.

# 4. Discussion

## 4.1. Hill Vegetation Ecosystem

The classification results can be supported by the distinct difference in stand composition. Three vegetation units have been identified in Little Windy Hill. The majority of sampling points in Unit 1 are closer to ridges and dominated by denser, older stands of Mamangi (*Coporosma arborea*), which have a mean canopy height of 9m and a mean basal area of 78.95m. Unit 3 comprises a large proportion of kanuka (*Kunzea ercoides*) and a few manuka (*Leptospermum scoparium*) on lower slope*,* with the smallest basal area of 39.46m and a mean canopy height of 11m. The relatively small stands reveal that most of this forest is relatively young with low biomass. There are mainly four dominated species in unit 2, *Beilschmiedia tarairi, Coprosma arborea, Dysoxylum spectabile*, and *Rhopalostylis sapida.* The abundance of tree fern species (*Cyathea dealbata*) is highest in unit 2. This unit has the fewest stem density of 1262.64 tree/ha but the largest basal area of 90.8m/ha, indicating an older forest. In addition, we found a 'Rata' stand with a diameter of 109 cm as well as other large stands in unit 2 (not list in results), further supporting the older age of this forest. This vegetation unit also has more diverse composition of vegetation species.

It is suggested that the environmental gradients of species composition are associated with altitude, topography, fire/clearance history. It is also necessary to combine the topographical gradient with the temporal succession, because the effect of past disturbances on top-soil and nutrient loss varies at different topographical locations, which leads to different regeneration and growth rate among these vegetation units (Ogden & Perry, 2005). For example, there were two cycles of fire existing in GBI, including the maori and subsequent pakeha. Fire caused more degradation of soil nutrient on the ridge topography, which led to slower succession rates on ridge areas. This subsequently reduced the species richness and increased the incidence of weed invasion, especially in the mature forests (Ogden, 2006).

In this study, the older *Coporosma arborea* stands tend to grow on the upper slope of hill with drier and thinner soil conditions, showing a decrease trend (situated at the lower middle of dendrogram), while the *Kunzea ercoides* dominates on the mid- and lower topography predominantly with northwesterly aspect (located at the left of dendrogram). *Beilschmiedia tarairi, Coprosma arborea, Dysoxylum spectabile*, and *Rhopalostylis sapida* together dominate unit 2 on the topography with mid- and lower slope and southwesterly aspects (located on the right of dendrogram), which are damper and shadier with deeper topsoil. The consistence between environmental conditions and forest structure may further support the fact that the forests in LWH are recovering from former grazing activities or fires.

As can be seen in Fig5, unit 2 contains more old stands of *Rhopalostylis sapida.* In comparison, there are more young stands of *Rhopalostylis sapida* in unit 1, which is also the most likely replacement species in this unit (Fig6). This reveals that the developmental pathway is from unit 1 to unit 2. *Coporosma arborea* in unit 1 is predominantly old stands, which shows a decrease trend. However, in unit 3, *Coporosma arborea* has the highest probability to become the replacement species, which indicates unit 3 contains a high density of young *Coporosma arborea* stands. Consequently, the overall succession patterns should be from unit 3 → unit 1 → unit 2.

In unit 2, there are relatively abundant vegetation species providing suitable habitats for native birds, which include *Beilschmiedia taraire, Beilschmiedia tawa, Dysoxlum spectabile, Coprosma arborea,* and *Vitex lucens*. Hence this unit should be considered as better choice for the re-introduction of native birds. All the control sites are located in unit2. However, no significant differences were found between control and management points within this vegetation unit in terms of vegetation species composition.

There are also other types of vegetation communities existing in Little Windy Hill. Ogden and Perry (2005) found four intergrading but distinct units in LWH, which included dense manuka stands on upper slopes and ridges, younger dense kanuka on mid- and upper slopes, older stands of kanuka on lower and mid- slopes, and broadleaf forest on gullies (Ogden & Perry, 2005). Particularly, no west-facing points were sampled in Ogden and Perry (2005) study, while there were a large number of sampling plots facing west orientation in our study, which further supports the topography gradient of species compositions in Little Windy Hill. Recently, Davy (2008) identified three forest types in LWH, comprising of 'Young kanuka', 'Mature forest', and 'Old kanuka' regenerating types.

*Rhopalostylis sapida* is the replacement species of highest possibility in both unit 1 and unit 2. Other significant replacement species include *Myrsine australis* and *Beilschmiedia taraire* (Fig6). The high possibility of these replacement species indicates that their relative densities tend to increase in the future in LWH. These findings were consistent with the prediction made by Davy (2008), who reported a positively proportional change in these species. On the other hand, he predicted a negative trend in proportion change of *Coporosma arborea* and *Kunzea ercoides* species, which can also be supported by this study. These two species have less possibility to replace existing canopy, leading to a decrease trend in stand density (Fig 5 and Fig 6).

**4.2. Wetland Vegetation Ecosystem**

Rutherford (1998) identified seven broad vegetation types distributed in different water levels in Kaitoke wetland. Typha orientalis usually grows in deep water (Rutherford, 1998), which can be found over the whole water depth gradient (0-70cm) in this study. Gleichenia dicarpa dominates sedge community, while cabbage tree (Cordyline australis) and flax (Phormium tenax) are common in permanent shallow water over sedge. Manuka (Leptospermum scoparium) usually dominate gumland (dry forest) and distribute over wet meadow (Rutherford, 1998). Nevertheless, these four species were recorded over the whole water table (0-70cm). For some dry forest species, such as *Beilschmiedia tarairi* and *Dicksonia squarrosa*, they could be only found between transect 1 and 2 without distribution towards estuary. Particularly, *Ageratina adenophorum* which is exotic, invasive species grows between 1 and 8 transects, which are closer to the forest end. The underlying mechanisms of different species distribution patterns include the interaction of abiotic growth factors and both inter- and intra- species competition (Simberloff, 1982).

In the past century, studies on the nature of community organization have been taken sporadically (Shipley & Keddy, 1987), which led to relatively few evidence supporting the patterns of either community-unit or individualistic concept. In this study, the distribution patterns did not show distinctly separated zones along both environmental gradients. Elsewhere Whittaker (1975) suggested that their field observations agreed with the individualistic concept, which revealed that 'most communities intergraded continuously along environmental gradients rather than forming distinct, clearly separated zones.' By contrast, Clarkson (1984) reported that species distribution zones could be clearly distinguished among forest land, shrubland, and sedge-fernland areas. However, these two field observations did not employ the direct gradient analysis to interpret their results.

In this study, the boundaries of vegetation species were clustered along both types of environmental gradient, but did not coincide with the correlated patterns predicted by community-unit concept. This result was consistent with the observation made by Shipley and Keddy in Breckenridge Marsh (1987), which revealed that both upper and lower boundaries of vegetation species were clustered along gradient of relative water height, but no correlation were found between them. Similarly, Pielou and Routledge (1978) found 'clustered' boundaries of salt marsh vegetation along latitudinal gradient. Keddy (1983) indicated the clustering boundaries in a lakeshore plant community. Elsewhere Dale (1984) reported a contiguity of upslope and downslope boundaries in a zoned community. In comparison, Underwood (1978) found 'clustered' lower boundaries but a random distribution of upper boundaries. However, the conservative methods used by Underwood might cause that it failed to detect the non-random patterns (Shipley & Keddy, 1987).

In addition to the community-unit and individualistic concepts, there are other community patterns possibly existing in the ecosystem, which means that the two concepts can not cover all the possibilities of distribution patterns (Shipley & Keddy, 1987). In this case, the result of this study might provide evidence supporting other theories.

This study applied two types of environmental gradient to analyze the distribution patterns. Nevertheless, Shipley and Keddy (1987) argued that the individualistic concept was unfalsifiable when using pattern analysis, because distribution pattern could be concurrently influenced by multiple causal mechanisms, which together explained the 'clustering' of boundaries along one environmental gradient (Shipley & Keddy, 1987). Further more, the statistic methodology which was used to deduce distribution pattern was also questioned. In this study, if the interval of water depth gradient is changed from 5cm into 10cm, then the boundaries no longer show 'clustering' pattern. This means that the selection of environmental gradient interval also potentially affect the conclusion of inferential statistic analysis.

There were no distinct distribution zones found along environmental gradients in this study, but it is still possible to identify the clear vegetation units of sampling plots on the basis of similarity in species composition in Kaitoke swamp, which can be achieved by multivariate cluster analysis methods. This classification method of vegetation communities can be explained by the same mechanisms of environmental gradient, but gives better understanding of vegetation structure and dynamics.

However, there were some limitations in this study. Firstly, the gradient of transect lines used in this study was less advantageous, because the distance between transect lines could not significantly influence the vegetation growth. Consequently, the gradient of water depth should be a better choice for the analysis of distribution pattern. Nevertheless, swamp water level varied significantly over seasons. The water depth measured was relatively shallow during that sampling day, which led to small sampling units at deep water (above 30cm). When the water level rises, the protrusive, dry plots will be inundated, which potentially changes the proportion of sampling units in each interval of water depth. In order to overcome this, data collection should be better taken during wet season and more sampling units should be selected in the deep water.

The 'ecological niche' theory would be better to analyze the vegetation ecosystem in the future. There are three steps in applying 'ecological niche' theory on the ecological restoration, taking wetland sampling data as an example: Firstly, identification of specific ecological niche along environmental gradient is conducted. In the sampling, species *Baumea rubiginosa, Gleichenia dicarpa, Baumea articulate* and *Isachne globosa* dominate in the deeper water depth regions, which consequently grow in the similar ecological niche along the environmental gradient measured by water depth; Secondly, it is to identify the association between different species so that the competition or dependent relationship would be identified. In this sampling, species *Baumea rubiginosa, Gleichenia dicarpa, Baumea articulate* and *Isachne globosa* would become competition species with each other, which can be seen from the phenomenon that these species can be hardly found concurrently in the same sampling plots (Results---Part B, Fig1). In comparison, Species *Baumea rubiginosa* is usually associated with species *Blechnum minus,* and *Gleichenia dicarpa* is usually associated with *Leptospermum scoparium,* which means that they may rely on each other to grow in their specific ecological niche; Thirdly, it is to further confirm if these species distribution is indigenous and natural. If it is yes, this distribution pattern becomes the important indicator to select species for the ecological restoration in the specific ecological niche along environmental gradient.

# 5. Conclusion and implication for landscape management

Three distinct vegetation units have been identified by both classification and ordination methods in Little Windy Hill, Great Bay Island. Unit1 is mainly the dense stands of old *Coporosma arborea* species on the upper slope. Unit 2 has four dominated species of equal importance on middle, southwesterly topography, including *Beilschmiedia tarairi, Coprosma arborea, Dysoxylum spectabile*, and *Rhopalostylis sapida*. *Kunzea ercoides* dominates unit 3 on middle slope with northwesterly aspect. Among three vegetation units, unit 3 has the smallest basal area indicating a young forest. Succession pattern of these units is from unit 3 → unit 1 → unit 2. Topographical gradient of species composition has been identified, associated with aspect, slope, soil depth, moisture, and available nutrient. However, the past disturbance such as fire also plays important role in explaining the difference in community structure.

Fully understanding of community structure difference is essential for the identification of vegetation succession pattern in landscape, which provides useful information for both fauna and flora conservation. The distribution of rare or endangered vegetation species can be predicted according to the understanding of species composition dynamics, helping to decide the necessary measures taken for conservation. Especially, the re-introduction of native fauna species, such as native birds, should rely on the identification of suitable habitats which provide enough fruit, nectar, and shelters. This is also based on the understanding of vegetation community structure. Consequently, it is expected that more classification and ordination research should be taken to better understand the community structure in the future in Great Barrier Island. In addition, control of invasive mammals and weeds should also be effectively maintained to improve the health of ecosystem.

This study shows a model of ‘clustering’ vegetation distribution boundaries along environmental gradient without correlation between upper and lower boundaries in Kaitoke swamp, Great Barrier Island, New Zealand. This result coincides with neither community-unit nor individualistic concept, which may indicate the existence of other types of hypotheses regarding to the distribution patterns. This conclusion reveals that community-unit or individualistic concept may influence the species distributions in a ecosystem community, but there are other multiple factors jointly affecting the distribution pattern.

Further more, the methodology of environmental gradient analysis also has limitations. It is better to identify the vegetation units of these sampling plots by multivariate cluster analysis in Kaitoke swamp. Then the mechanism of environmental gradients and ecological niche can also be employed to explain the difference in community composition, which are more applicable on the restoration by species selection and plantation.

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