Relationship between mohua (*Mohoua ochrocephala*) breeding density and vegetation in a red beech (*Nothofagus fusca*) forest

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Abstract Mohua are endemic to the South Island of New Zealand but they have declined in both range and abundance. The causes of decline include predation from introduced predators and forest clearance. Mohua have survived in reasonable numbers in the Dart Valley in west Otago. In this paper we describe the relationship between the presence of mohua breeding territories and vegetation at a 1 ha scale within low altitude, red beech-dominated forest. The extent of shrub or regeneration was found to have the strongest association with the presence/absence of breeding mohua. Other factors which increase leaf volume, such as forest-edge and broken canopy were also important in explaining the presence of mohua. Milling was found to have a long lasting negative impact (>70 years) on mohua presence. Management which reduces grazing and increases the shrub and regeneration forest component is likely to increase mohua carrying capacity.

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Keywords mohua; *Mohoua ochrocephala*; habitat; density; milling

INTRODUCTION

Mohua or yellowheads (*Mohoua ochrocephala*) are hole-nesting passerines characterised as "tall forest specialists" (Elliott 1992). They are endemic to the South Island of New Zealand. Like many other indigenous New Zealand forest birds, introduced predators (stoats, *Mustela erminea* and ship rats, *Rattus*

rattus) have reduced populations such that mohua are now extinct over much of their former range and threatened over the remainder (O'Donnell 1996; Gaze 1985). Much work has been done in developing effective predator control against stoats (Dilks *et al.* 2003), and considerable resources are now focused on reducing rat predation (Elliott & Suggate 2007). However, forest structure and composition has been modified by introduced herbivores (deer, *Cervus* spp., goats, *Capra hircus*, hares, *Lepus europaeus*, and possums, *Trichosurus vulpecula*) and sawmilling,

Fig. 1. The study area at Lake Sylvan, in the Dart Valley, head of Lake Wakatipu.
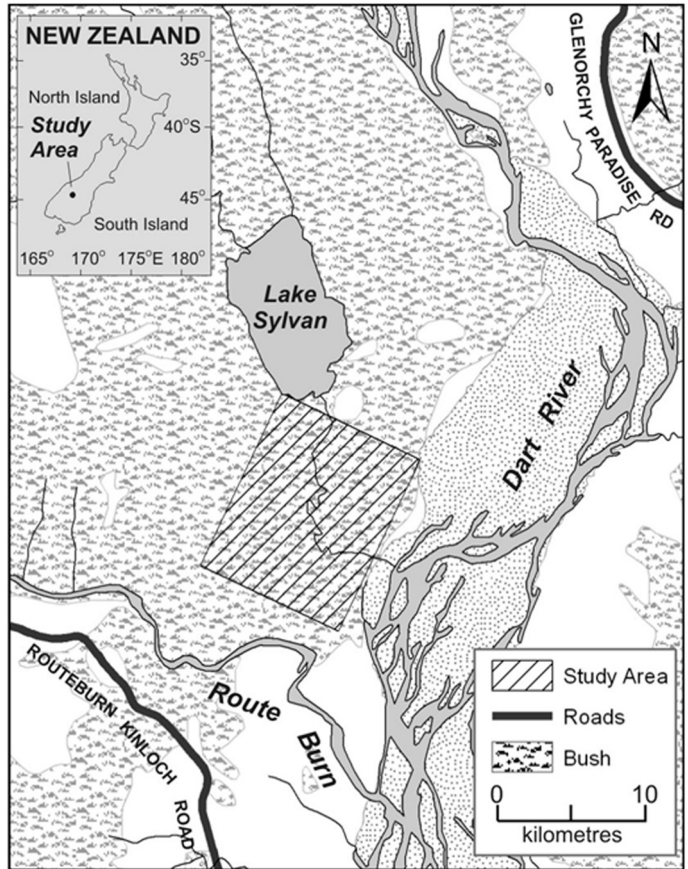
and this may have lowered the carrying capacity for mohua. A lower carrying capacity may make any surviving populations more susceptible to extinction after population collapses from predation.

A previous study of the relationships between mohua distribution and vegetation and topography (Elliott 1992) found that mohua preferred tall, low density forests dominated by red beech near valley floors. Elliott's (1992) study was carried out at a coarse 1 km^2 scale and could not explain the finer-scaled relationships between mohua nesting territories and vegetation structure and composition. In this paper we report on the spatial relationship between frequency of forest use by breeding mohua and vegetation characteristics at a 1 ha scale.

METHODS
Study site
Lake Sylvan is located in the Dart Valley in west Otago (Fig. 1). The 120 ha (1000 x 1200 m) study site is immediately south of Lake Sylvan, mainly on a relatively flat river terrace approx 360 m a.s.l., with the western edge of the site rising up the valley wall to 480 m a.s.l. At the north-western end is an area of ~8 ha of moraine hummocks that form the dam which created Lake Sylvan. The average rainfall is 2 m per annum (recorded at Routeburn Station 2 km from the site). The forest is dominated by red beech with a 25 – 30 m high canopy. In the 1930's, 68% of the site was logged (Willoughby 1976). Reasonable numbers of mohua have persisted in this area and an intensive survey of the population has been carried out annually for 9 years from 1993 to 2001.

The vegetation of the rest of the Dart Valley is characterised by red beech-dominated forests on the lower slopes up to 750 - 900 m a.s.l. Above this level red beech becomes less abundant and silver beech (*N. menziesii*) and mountain beech (*N. solandri* var. *cliffortioides*) become more common, with silver beech dominant in the wetter headwaters and mountain beech dominant at higher altitudes (Wardle 1984). *Griselinia littoralis, Pseudopanax simplex, Cardopedetus serratus* and *Podocarpus halli* are commonly found in the sub-canopy. *Myrsine divaricata, Coprosma colensoi, C. astonii, C. parvaflora, Pseudowintera colorata* and *Neomyrtus pendunculata*

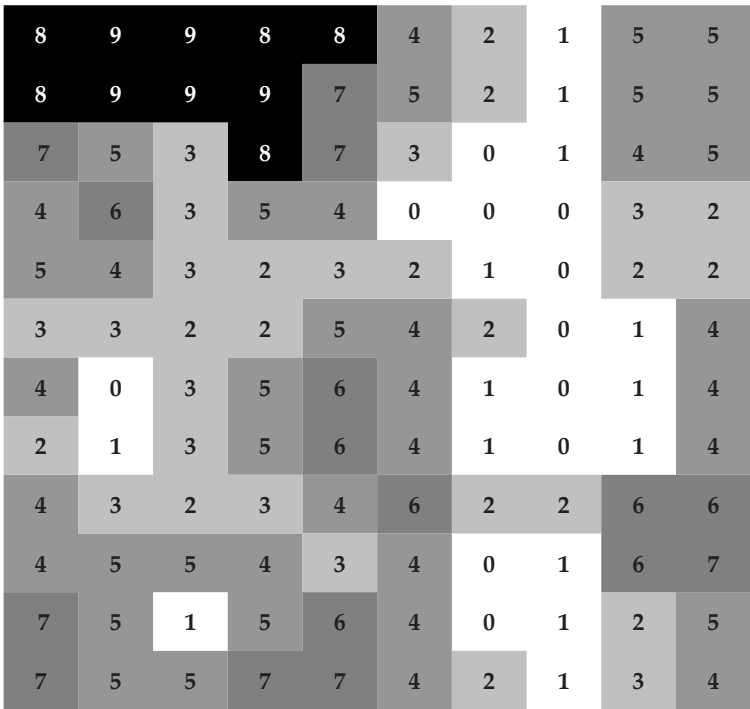| 8	9	9	8	8	4	2	1	5	5
8	9	9	9	7	5	2	1	5	5
7	5	3	8	7	3	0	1	4	5
4	6	3	5	4	0	0	0	3	2
5	4	3	2	3	2	1	0	2	2
3	3	2	2	5	4	2	0	1	4
4	0	3	5	6	4	1	0	1	4
2	1	3	5	6	4	1	0	1	4
4	3	2	3	4	6	2	2	6	6
4	5	5	4	3	4	0	1	6	7
7	5	1	5	6	4	0	1	2	5
7	5	5	7	7	4	2	1	3	4

Fig. 2. The study area showing the number of years breeding mohua were present in each hectare over the 9 year period. The grid intersections where the vegetation data was gathered are at the centre of the squares. Lake Sylvan is at the top and the bush edge is along the right side. Darker shading indicates increasing number of years used by mohua.

are common in the shrub tier. Under-storey plants of the study area are the same as those on similar sites elsewhere in the Dart Valley (Wardle 1984).

Mohua use of the site.
Every year from 1993 to 2001 the territories held by breeding mohua in the study area were mapped. Each family of birds was followed for an hour on at least 4 occasions, and their position mapped. From 1995 onwards, a proportion of the population was colour banded, increasing the confidence in our ability to differentiate between groups. This accuracy is less important here, as we are only interested in where birds were 'seen' and 'not seen' each year, rather than territory boundaries. The number of years in which mohua were recorded within the hectare around each grid intersection of the study area is shown in Figure 2.
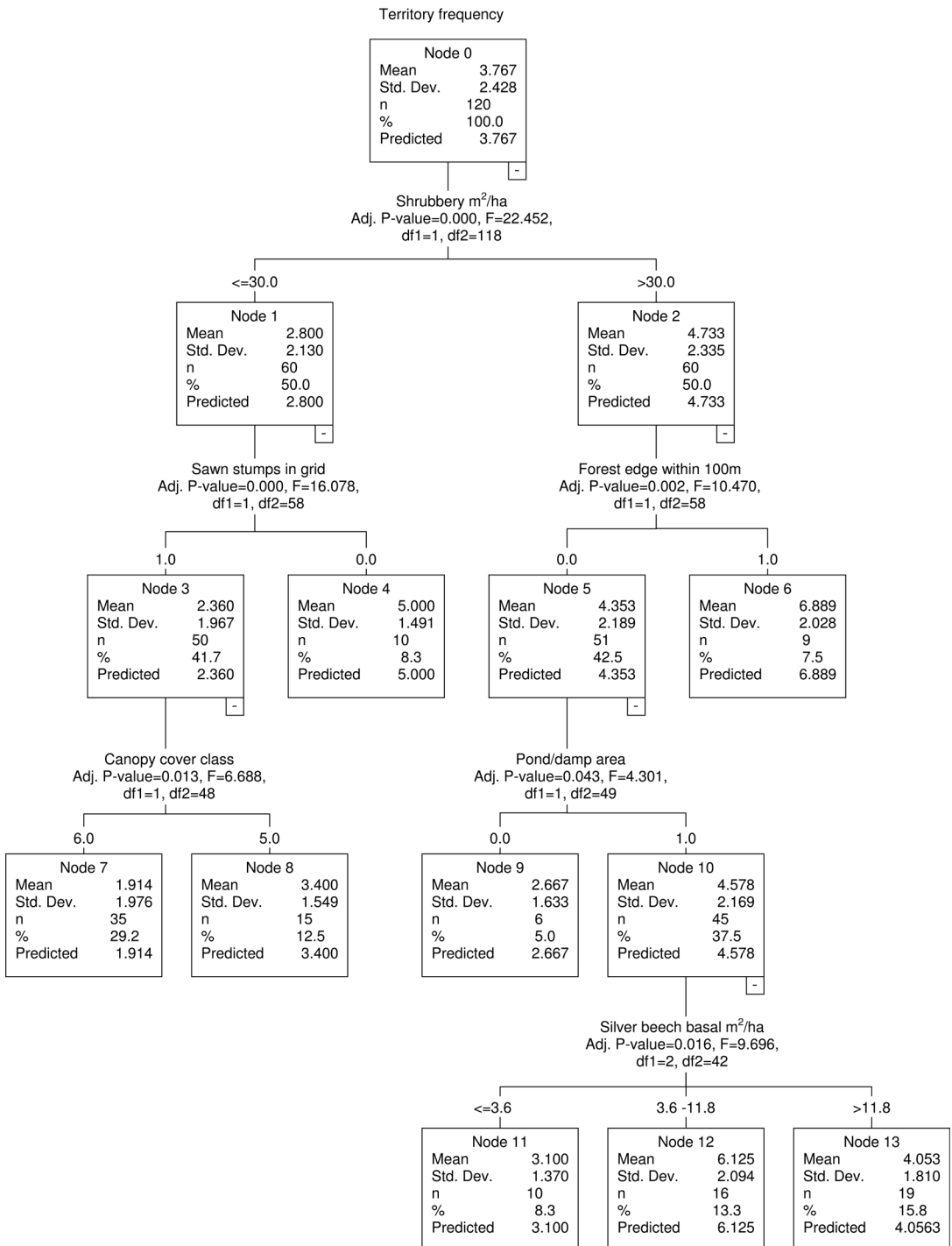
Vegetation characterisation
Vegetation data was collected at each grid intersection. At each grid intersection ($n = 120$), the percentage cover of the canopy (>5 m), shrub (0.3-5 m) and ground (0-0.3 m) tiers was estimated on a 6 point scale. A variable area plot was then set up at each grid intersection (Batchelor & Craib 1985). The radius of the variable plot was recorded, the radius varying to include ~30 stems reaching the canopy tier (5 m). Each canopy stem was counted and the species and diameter at breast height (dbh) recorded.

From this data canopy stem density and basal area for each species was calculated. Within each plot the number of fallen dead trees was recorded. The presence of ponds/damp depressions, sawn stumps (indicating which parts of the site had been milled), and size of patches of regeneration or shrubs within 50 m of the grid intersection were also recorded. This last character provided a measure of understorey vegetation volume and no differentiation was made between low regenerating beech and other low stature shrubs.

Analysis
Relationships between mohua use during the breeding season and predictor variables were examined using a regression tree (Answer Tree software SPSS Inc.) to determine which of the available explanatory variables best explained variation in occupancy. The method used to build the tree was 'Exhaustive CHAID' (exhaustive Chi-square Automatic Interaction Detector; Biggs *et al.* 1991). The tree explains variation of the response variable (mohua use during the breeding season) by defining a split in the data based on the predictor variable that gives the most significant association with the response variable, using an *F*-statistic criterion. This is then repeated for each group of data created by the split, in an iterative process until there is no significant association to report. While other statistical approaches could be

Fig. 3. Analysis of mohua habitat use with a regression tree (Answer Tree SSPS Inc., Chicago). This method selects the variable with the most explanatory power of mean use in the breeding season to determine the splits. Each branch of the tree ends when no further variable is significant. The 'mean' ('Territory frequency') refers to the average years of mohua use during breeding for the sites in that category or 'node'.

taken, the tree gives a clearer understanding of the inter-relationships of the predictor variables. This approach takes no account of any possible spatial autocorrelation and there may be other explanatory variables that we have not tested.

RESULTS

Mohua use in the breeding season

The use mohua made of hectare grid squares varied considerably (see Fig. 2). Twenty two percent of the grid squares were occupied for 6 or more years of the study and 45% of the squares were occupied for 3 years or less. The highest occupancy was in the area closest to the lake, with the lowest occupancy on a low terrace nearer the Dart River, but excluding the forest edge.

Vegetation characteristics associated with high breeding season

Red beech was the dominant canopy species across 77% the study area, with mountain beech dominant over 17 % and silver beech over 6%. Shrubbery or regeneration was present in 70 of the 120 grids.

Regression Tree analysis found that the most significant predictor variable of mohua use during breeding was the area of shrubbery or regeneration (Fig. 3). There was a significant difference in mohua use of sites with more than 30 m^2/ha of shrubbery or regeneration (used on average 4.7 of 9 years) and sites with less than 30 m^2/ha of shrubbery or regeneration (used on average 2.8 of 9 years).

In the portion of the study area where shrubbery or regeneration was less than 30 m^2/ha, past milling (presence of sawn stumps) was the next best predictor of mohua, with milled areas being used on average 2.3 of 9 years compared with unmilled areas which were used 5 of 9 years. In the milled area where the canopy was broken (canopy cover class 5), mohua occupancy was greater (3.4 of 9 years) than where the canopy was closed (canopy cover class 6; mohua occupancy 1.9 of 9 years). A more closed canopy reflects 80 years of regeneration after milling.

In the portion of the study area where shrubbery or regeneration was >30 m^2/ha, the next best predictor of mohua use was forest edge, with average use of edge being 6.9 of 9 years compared with 4.3 of 9 years away from the forest edge. In areas with shrubbery or regeneration present and away from forest edge the best predictor of mohua use was damp areas. Within these damper sites (38% of the study area) moderate basal area of silver beech (10-20% of the canopy) was associated with greater use by mohua.

Variables which were included in the analysis but did not contribute significant explanatory power were ground cover, understorey cover, stem densities of red, mountain and silver beech, total stem density, basal area of red and mountain beech, total basal area, number of canopy species, number of dead standing trees, and the number of dead fallen trees.

Milling and nest trees for mohua

Mohua are hole-nesting birds and most nest holes are found in large trees. Elliott *et al.* (1996) found that 70% of mohua nests were in trees with a girth >700 mm dbh. We compared the density of red beech trees of this size in milled and unmilled areas, and found no significant difference in the large tree density (35/ha unmilled, 29/ha milled; Mann-Whitney U: *P* = 0.3). This reflects the style of milling, which left old trees as they were unsuitable for milling.

DISCUSSION

Vegetation characters associated with high use by mohua during breeding season

The study was undertaken wholly within a red beech-dominated forest and the relationships we found may not occur in silver beech-dominated forests (*e.g.*, Catlins, Blue Mountains and Western Fiordland forests).

Mohua may favour areas with shrubbery or regeneration because they contain a greater abundance and diversity of invertebrate prey. A high proportion of insects are host specific (Patrick & Dugdale 2000), so if a habitat has more species of plants more species of invertebrate are expected. The abundance of those invertebrates will, amongst other things, depend on their host plant abundance. Different species of invertebrate cycle in abundance at different times, with the amplitude of the cycle driven by environmental variables. Thus, an area with a greater diversity of plants/insects has a higher chance that at least one invertebrate food source is available at any point in time. More importantly, in the breeding season the abundance of each invertebrate species is likely to be cumulative (*i.e.*, more invertebrates on shrubs does not mean less invertebrates on beech), increasing mohua prey in an area. During nesting, mohua may avoid areas where there is an insufficient quantity of food to meet the increased demands of egg and chick production. At Lake Sylvan there is abundant beech but a sparse and patchy shrub presence.

Shrubbery or regeneration most often occurs in lightwells or forest gaps. The other predictors of mohua presence we found were forest edge, unmilled forest and a slightly open canopy. All these predictors are indicative of a greater volume of canopy. For example, old forest at Sylvan typically has broken canopy with effective canopy depths of between 15 and 20 m, whereas the 80 year old regenerating forest with unbroken canopy has

canopy depths of only 3-4 m. Increased canopy depth probably means there is a greater volume of leaf and thus caterpillar food (especially in the spring; BL, *pers. obs*.). Greater volumes of leaves also means that foraging habitat is more concentrated and foraging time could be significantly lower (Gill 1995). Volume or density of vegetation has been shown to affect bird densities, with invertebrate abundance the suggested link (McShea & Rappole 2000; Mills *et al*. 1991). Because of their potentially high leaf volumes, broken canopies, gaps and forest edge might also have high litter volumes and abundant litter invertebrates (Fitzgerald *et al.* 1996), a good proportion of which become arboreal (*i.e.*, mohua prey) in later instars (*e.g.,* Geometrid Lepidoptera; Dugdale 1996).

Long term effects of milling
We found that shrubbery or regeneration was less abundant in milled areas and these areas have lower use by mohua during breeding. This is likely to be a function of the closed post-milling canopy. As regenerating red beech reaches final canopy height at ~100 years (Wardle 1984), it is likely that at least a similar period will elapse before the canopy matures and starts to break up, allowing light to penetrate, deepening the canopy and providing more favourable conditions for shrub development. Conversely, initial seral vegetation can support high breeding densities of mohua if it is adjacent to mature forest stands (as at Surveyors Flat 10 km north of the study site; B. Lawrence, *unpubl. data*). One of the criticisms of logging forest is that it reduces the available holes for nesting. This does not seem to be important at our study site probably because the type of logging undertaken left considerable numbers of old trees which are suitable for nesting mohua.

Comparison with earlier studies
In a large scale habitat suitability study, Elliott (1992) found that mohua preferred forests near valley floors dominated by red beech, and in a smaller scale habitat use study (Elliott 1990), he found they preferentially foraged in large trees and silver beech trees. Our findings are consistent with Elliott's (1992) large-scale findings as our entire study occurred within the type of forest that Elliott found mohua preferred. If we combined the findings of Elliott's (1990) with our study, we conclude that although mohua spend a disproportionate amount of time in large trees and silver beech trees (see nodes 11-13, Fig. 3), the presence of shrubbery or regeneration is nonetheless important. This leads us to the conclusion that the best forests for mohua are valley floor red beech-dominated forests with significant amounts of silver beech and shrubbery or regeneration.

Conservation implications
Habitat loss due to milling has in the past been a major cause of the contraction of mohua range. Even when enough old trees are left for nesting and the forest is allowed to regenerate, artefacts of milling, such as a closed canopy and consequent lack of shrub understorey are associated with mohua avoiding the habitat 80 years on. This artefact and the avoidance of mohua is likely to remain for a considerable period.

Deer are known to reduce the abundance of shrubs and regeneration in New Zealand forests (Husheer *et al.* 2003) and this study has shown that mohua are less abundant where shrubbery or regeneration is lacking. In North America, McShea and Rappole (2000) found a negative relationship between deer density and both small passerine bird density and shrub density. Maintaining deer at levels which allows an increase in shrubbery and regeneration is likely to lead to an increase in mohua carrying capacity. Increased mohua carrying capacity will, in turn, reduce the chances of local extinctions and increase the rate of recovery after events such as periodic predator irruptions.

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