

Habitat use and foraging behaviour of Mohua (*Mohoua ochrocephala*) in the podocarp forest of Ulva Island, New Zealand

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Abstract. The Mohua (*Mohoua ochrocephala*) is an endangered forest passerine endemic to New Zealand. We examined the habitat use and behaviour of Mohua in podocarp forest after their reintroduction to Ulva Island to determine the suitability of this forest type. When in podocarp forest Mohua spent <75% of their time foraging, less than when in beech forest (90%). This suggests that podocarp forest provides more food resources than beech forest and is suitable for Mohua. The birds were frequently observed in the coastal scrub surrounding the island, but this habitat type was not used for foraging. We discovered a seasonal variation in foraging patterns: ripping through bark and epiphytes was predominant in spring, and gleaning in the foliage prevailed in summer. Miro, Rata and Rimu were the preferred foraging trees in the interior forest, and Hall's Totara and Kamahi were consistently avoided in both the forest and along the coast. Variation in the use of tree species throughout the season suggests that a structurally diverse forest community is an important habitat requirement for Mohua, as it provides sufficient resources for all seasons.

Introduction

Like many other endemic forest birds in New Zealand, the Mohua, or Yellowhead (*Mohoua ochrocephala*), has declined in distribution and abundance with the clearing of mature forests and the introduction of mammalian predators to New Zealand (Gaze 1985; O'Donnell 1996; O'Donnell *et al.* 2001). It is a mainly insectivorous bird and generally inhabits mature beech (*Nothofagus* sp.) forests, only in the South Island of New Zealand (Read 1988a; Elliott 1990; Heather and Robertson 1996). Mohua nest and roost in tree cavities, making them very vulnerable to rat (*Rattus* sp.) and stoat (*Mustela erminea*) predation (O'Donnell *et al.* 2001). The decline of Mohua has accelerated dramatically since 1999, with several key populations suffering substantial losses after rat population irruptions (Roberts 2001). Transfers to predator-free islands have been recommended to safeguard the species from extinction (O'Donnell *et al.* 2001).

The success of translocations requires careful planning and proper assessment of the suitability of the release site (Lindenmayer 1995; Saunders 1995; Atkinson 2001). For insectivores, it is crucial that sufficient variety and abundance of invertebrate prey is available and can readily be exploited by the translocated species (Yen 1995). Foraging ecology and habitat use of Mohua have been studied only in beech forests (Read 1988a, 1988b; Elliott 1990). Many of the predator-free islands to which Mohua can be transferred are covered with other forest types, mostly lowland podocarp forest (O'Donnell *et al.* 2001). To assess the suitability of islands without beech forest as Mohua refuges, information is required on how

Mohua use other forest types. In this paper, we present data on habitat use and foraging behaviour of Mohua in a podocarp-dominated rainforest, following their reintroduction to Ulva Island. We assess the suitability of this forest type, and discuss the implications for the future conservation of Mohua.

Study Area

The study was carried out on Ulva Island, 800 m off the coast of Stewart Island, New Zealand (46°56'S, 168°07'E). Mohua were reintroduced to Ulva Island in October 2001. Ulva Island contains two different habitat types, a coastal fringe of stunted scrub and an interior tall forest. The coastal habitat is dominated by Muttonbird Scrub (*Brachyglottis rotundifolia*), Leatherwood (*Olearia colensoi*) and Inaka (*Dracophyllum longifolium*), and covers the exposed places of the island. We combined Muttonbird Scrub and Leatherwood into 'coastal scrub' in all analyses. The scrub is usually less than 10 m tall and extends about 20 m inland from the coast. The interior forest covers most of the island. It is a typical lowland temperate rainforest dominated by Podocarpaceae trees (podocarp forest). The canopy is about 30 m high, and the forest is moderately open with a patchy subcanopy and an understorey mainly comprising treeferns (*Dicksonia squarrosa* and *Cyathea smithii*) and broadleaved species. Rimu (*Dacrydium cupressinum*) makes up most of the canopy, followed by Miro (*Prumnopitys ferrugineus*), Hall's Totara (*Podocarpus hallii*) and Rata (*Metrosideros umbellata*). The subcanopy is dominated by Kamahi (*Weinmannia racemosa*) and Broadleaf (*Griselinia littoralis*). The island was cleared of rats in 1996 and is guarded against reinvasion by a system of traps and bait stations (Beaven 2001).

Methods

Behavioural sampling

Behaviour of Mohua was recorded from October 2001 through January 2002. Instantaneous sampling (Altmann 1974) was used to obtain frequencies of behaviours and habitat characteristics. Mohua flocks were

observed, on average, every second day between 0600 and 2100 hours for up to 60 consecutive minutes in one area. Activity states of all instantly visible birds in a flock were recorded at first sight and every 20 s thereafter using an electronic metronome. Behaviour was recorded in six categories (ripping, gleaning, scanning, flying, calling, other) adapted from Read (1988b) and Elliott (1990). With each behavioural sample the time, habitat type (forest or coast), tree specifics and the bird's position were recorded. Tree specifics included the species of tree, its diameter at breast height (dbh) estimated to 20-cm intervals (0 = 0–10 cm, 1 = 10–30 cm, 2 = 30–50 cm, 3 = 50–70 cm, 4 = 70–90 cm, 5 = 90–110 cm, 6 = >110 cm), and its height estimated to 5-m intervals (0–5 m, 5–10 m, 10–15 m, 15–20 m, 20–25 m, >25 m). The perch site of the bird was recorded in four groups: trunk and large branches (>30 cm diameter), small branches, twigs and foliage, and other (e.g. forest floor).

Vegetation measurements

Vegetation was measured in areas where behavioural sampling of Mohua was carried out. The interior forest was sampled in 40 random plots (0.1 ha) in six areas, and the coast was surveyed in two areas of 0.5 ha each. All self-supporting woody plants and tree ferns higher than 1.5 m were identified to species, and their height and diameter (dbh) were estimated to the same size classes as in the behavioural sampling (see above). Trunk surface, as a measure representing available foraging substrate, was calculated as $(\pi \times \text{dbh} \times \text{height})/2$ (assuming a cone-shaped trunk) (Whittaker *et al.* 1974; Elliott 1990; Bellingham *et al.* 1999). The data were averaged across all plots to give relative abundance of every species per habitat type.

Data analysis

Observations of individual Mohua were lumped into 'flock behaviour' by averaging all records of a flock over a 20-min period in order to assure independence of the data (Morrison 1984; Elliott 1990). A flock sample consisted of 30.01 ± 26.05 (mean \pm s.d.) records taken from 6.07 ± 4.39 birds, and yielded percentages of use for tree species, behaviour, and perch sites, as well as mean values for tree height and dbh. We used Kruskal–Wallis tests to analyse differences in behaviour, tree species use and perch-site use across the four months for both habitat types combined. Mann–Whitney *U*-tests were used to examine differences in behaviour between the two habitat types.

Elliott (1990) concluded that Mohua preferred the largest trees in beech forest. In order to test whether Mohua use larger trees more often than would be expected from their proportion of foraging substrate, we first calculated the total trunk surface for every dbh class within the vegetation plots as a measure of available foraging substrate. We then used Chi-squared analysis to test for differences between the use of tree size classes by Mohua and their availability. Along the coast, tree sizes were uniform and we did not analyse tree-size selection.

Tree species preference was analysed separately for every habitat type by comparing the frequency of tree use by Mohua with the availability of tree species. Availability was defined as the proportion of trunk surface for every tree species, as this yielded the most accurate results in preliminary analysis (Oppel 2002). Compositional analysis was used to rank tree species according to their preference by Mohua (Aebischer *et al.* 1993). This was first carried out for all months combined, but, since habitat preferences might change seasonally (Schooley 1994), we calculated a ranking matrix separately for every month. In compositional analysis, the log-ratio transformation overcomes the unit sum constraint inherent to datasets composed of proportions (Johnson 1980; Aebischer *et al.* 1993). For every Mohua flock sample, the log-ratios of the utilised tree-species composition were compared to the log-ratios of available tree-species composition; if the tree species were used randomly the difference between these two ratios should be zero. One-sample randomisation tests (Manly 1997a)

were applied to test whether log-ratio differences significantly departed from zero.

All analyses were carried out with the statistical package SPSS 11.0™ and RT (Manly 1997b). Results are given as mean \pm standard deviation (s.d.).

Results

Vegetation

Rimu was the dominant tree species in the interior forest, followed by Kamahi and Miro (Table 1). Kamahi contributed many small trees to the understorey, but did not grow large in size. Trees with a dbh of 10–50 cm comprised 58.26% of the trunk surface area, whereas trees that exceeded 70 cm in dbh accounted for only 18.28% of the trunk surface area. Small trees (0–10 cm dbh) and intermediate trees (50–70 cm dbh) contributed 13.11% and 10.35%, respectively, to the total trunk surface area in the interior forest. Along the coast Kamahi and Inaka were the most abundant species. The coastal scrub (Leatherwood and Muttonbird Scrub combined) and Rata provided significantly more vegetation surface along the coast than in the interior forest. Miro and Broadleaf were absent from the coast.

Tree sizes along the coast were very uniform: 5–10 m tall and with dbh of 10–30 cm. Due to the limited availability of tree sizes we did not analyse tree-size selection by Mohua in the coastal habitat.

Behavioural sampling

Foraging behaviour (ripping and gleaning) was recorded in $52.7\% \pm 26.8$ of all samples, and was highest in October ($59.5\% \pm 31.9$). 'Scanning' made up 25% of all observations between November and January. Scanning was rare in October ($11.9\% \pm 13.5$), but did not change significantly ($P > 0.05$) in the later season (Fig. 1).

Foraging techniques changed significantly from October to January, with 'ripping' being dominant in October ($38.4\% \pm 34.9$), and 'gleaning' being the most frequent activity in January ($41.4\% \pm 22.3$). This coincided with a seasonal change of perch sites (Fig. 2). The main trunk and large

Table 1. Floristic composition of Mohua sampling units on Ulva Island, New Zealand, as calculated from diameter at breast height (dbh) and tree height

Tree species	Interior forest (% trunk surface)	Coastal habitat (% trunk surface)
Rimu	25.5	2.0
Rata	5.2	12.2
Kamahi	24.4	33.0
Miro	10.8	0.0
Hall's Totara	8.1	2.5
Broadleaf	2.2	0.0
Inaka	1.3	28.4
Coastal Scrub	1.4	16.7
Other	21.1	5.2

Preference rankings varied between months. In October, Rimu and Miro were equally preferred, and both were significantly more preferred than Rata ($P < 0.01$). In December and January, Rimu was significantly preferred over Miro and Rata, which did not differ between each other.

Mohua used trees with a dbh of 30–90 cm significantly more than would be expected from their trunk surface area in the interior forest ($\chi^2 = 21.3$, d.f. = 3, $P < 0.001$). Trees with a dbh smaller than 30 cm were used less than expected from their available trunk surface ($\chi^2 = 6.96$, d.f. = 1, $P < 0.01$). The largest trees, with dbh exceeding 90 cm, were used approximately in proportion to their available trunk surface area ($\chi^2 = 0.89$, d.f. = 1, $P > 0.05$). The tree size preferences were consistent throughout all four months of the study period.

In coastal habitat, compositional analysis ranked the tree species in the following order: coastal scrub > Rimu = other > Rata > Kamahi = Inaka > Hall's Totara (Table 3). This ranking did not change between November and January, and could not be calculated for October due to small sample size ($n = 1$).

Discussion

Foraging behaviour

Mohua in podocarp forest spent little more than half of their time foraging and another quarter of their time scanning (Fig. 1). This is considerably less than has been reported from beech forests, where non-breeding Mohua spent 90% of their time, on average, foraging and scanning (Read 1988b; Elliott 1990). During November and December, Mohua spent much time in coastal habitat, where scanning was unrelated to foraging. This behaviour might have been a consequence of the recent translocation. However, the higher proportion of energy-consuming behaviour suggests that food resources were abundant on the island. Moeed and Meads (1984, 1986) compared the insect abundance of

podocarp and beech forests, and found that podocarp forest supported significantly higher numbers of aerial and litter-inhabiting invertebrates. This might enable a higher foraging efficiency, resulting in Mohua spending less time foraging.

Temporal variation in resource use has been linked to arthropod distribution and abundance of several insectivorous bird species (Hejl and Verner 1990; Miles 1990; Keane and Morrison 1999), including Mohua in beech forests (Read 1988b; Elliott 1990). We confirmed that Mohua exhibit seasonal differences in foraging substrate use in podocarp forest. Elliott (1990) stated that during winter, when insect numbers in the foliage are low, Mohua resort to ripping larvae from the trunk. This might account for Mohua foraging mainly on the trunks and large branches of Rimu and Miro in spring, while gleaning in the foliage during summer. Moeed and Meads (1983) found strong seasonal differences of invertebrate numbers on the trunks of four lowland rainforest tree species. They explained higher numbers in summer with increased movements of adult invertebrates heading towards the canopy (Moeed and Meads 1983). This suggests that numbers of invertebrates in the foliage increase significantly in summer, which might explain the increasing usage of this substrate by Mohua in summer.

Selective tree use

In podocarp forest Mohua used bigger trees than would be expected from their relative proportion of surface area, which is consistent with Elliott's (1990) study in beech forest. Larger trees might have a greater variety and abundance of foraging substrates and microhabitats, supporting more prey (Read 1988a; Elliott 1990). Prey abundance related to tree size has been shown to influence the tree-use patterns of several bird species (Woinarski and Wykes 1983; Mariani and Manuwal 1990; Flemming *et al.* 1999; Wilson and Recher 2001; Luck 2002). It is likely that Mohua prefer larger trees due to the availability of higher prey numbers and larger prey diversity.

Insectivorous birds are also known to choose certain tree species that provide higher prey abundance (Holmes and Robinson 1981; Wilson and Recher 2001). Mohua displayed a strong preference for Rimu, Miro and Rata in the interior forest of Ulva Island. Miro was mainly used in spring, when ripping on the trunk was the dominant foraging strategy. Miro supports abundant epiphytic mosses, ferns and lichens, amongst which Mohua often forage. This is similar to Silver Beech (*Nothofagus menziesii*), which Elliott (1990) found to be preferred by Mohua in beech forests. Miro might be an important winter foraging substrate for Mohua in podocarp forest. Rimu was the most important foraging tree species in summer, but since Rimu were the largest trees in this podocarp forest, it is not clear whether Mohua's preference is for the species itself, or rather for the tree size, as suggested by Elliott (1990). Rata was mainly used later in the season

Table 3. Simplified ranking matrix of Mohua tree species preference along the coast of Ulva Island, New Zealand, during the 2001/2002 summer

Symbols in the matrix represent direction and level of significance of differences: + indicates that the column category is preferred more than the row category, – indicates that the column category is preferred less than the row category. 0, n.s.; + or –, $P < 0.05$; ++, $P < 0.01$. Ri = Rimu, Ra = Rata, Ka = Kamahi, To = Hall's Totara, Cs = coastal scrub, In = Inaka, O = other

	Ri	Ra	Ka	To	Cs	In	O	Rank
Ri		0	0	–	++	0	0	2
Ra	0		0	0	++	0	0	4
Ka	0	0		0	++	0	0	5
To	++	0	0		++	0	++	7
Cs	–	–	–	–		–	–	1
In	0	0	0	0	++		0	5
O	0	0	0	–	++	0		2

(Fig. 3), when the appearance of its flowers might attract more insects. Flowers were often searched for food by Mohua, and might therefore account for the preferential use of Rata. Flower phenology is known to increase the usage of a tree species by insect-gleaning birds (Keane and Morrison 1999).

Some species were used less than their abundance would suggest, which might, in the case of Kamahi, be related to its size. However, Hall's Totara were of equal size to Rimu and Miro, yet they seemed to be avoided in both habitat types (Tables 2, 3). Leaf arrangement and the prickly nature of Hall's Totara leaves might impede the birds' movements on its branches, rendering foraging inefficient in these trees (Holmes and Robinson 1981). Low perch quality might also explain the low usage of Hall's Totara along the coast, where foraging decisions did not seem to affect tree selection. Alternatively, it is possible that both Kamahi and Hall's Totara do not support prey quantities equal to those of other trees.

Birds select their habitat at different spatial scales (Bergin 1992; Rolstad *et al.* 2000; Esely and Bollinger 2001; Luck 2002). Larger-scale site selectivity of Mohua in the forest might have influenced tree species availability, as defined in this study. The areas in which Mohua were observed, and where vegetation was sampled, differed significantly from random vegetation plots (Department of Conservation, unpublished) in having much lower relative abundance of Hall's Totara, and higher proportions of Rimu. This suggests that Mohua do not only prefer certain trees, they also choose particular sites where those trees are more abundant than in other areas.

Implications for conservation and future research

Podocarp forest appears to provide sufficient resources for Mohua, and islands with a Rimu- and Miro-dominated forest are probably suitable habitat for further translocations. Seasonal differences in use of foraging substrate and behaviour suggest that some structural diversity might be required to provide year-round food. The use of coastal habitat suggests that Mohua can utilise more diverse habitat than just tall forest. The study was carried out over the summer months and Mohua did not breed on Ulva Island during this time. Further research is required to determine potential limiting factors for Mohua breeding or wintering in podocarp forest. The ultimate indicator of the suitability of Ulva Island's forests for Mohua will be the successful breeding and establishment of a viable Mohua population.

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