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Distribution of sympatric orange-fronted (*Cyanoramphus malherbi*) and yellow-crowned parakeets (*C. auriceps*) in the South Branch Hurunui, New Zealand, prior to a catastrophic population crash

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Abstract The valley of the South Branch of the Hurunui River, prior to 2001, held a dense population of the orange-fronted parakeet (*Cyanoramphus malherbi*). However, a rat plague in 2001 reduced this population by ~85%. In preparation for a restoration program of this species in the Hurunui valley, I analysed the distribution of sightings of orange-fronted parakeets, as well as the congeneric, yellow-crowned parakeet (*C. auriceps*) prior to the population collapse. My objective was to identify the areas and types of habitats used by each species. A vegetation survey showed significant differences between different parts of the valley floor study site, and this appeared to be reflected in the distribution of orange-fronted parakeets. Both species had significantly different distributions, and orange-fronted parakeets were recorded most frequently within forests growing on the river fan, an area characterised by mature red beech (*Nothofagus fusca*) and areas of dense regenerating mountain beech (*N. solandri* var. *cliffortioides*). While the valley has been subject to anthropogenic modification since the 1850's, it still contains a relatively intact beech forest. My observations on the historic distribution of orange-fronted parakeets suggest this valley is still capable of supporting a large population of the species. However, the success of any re-introduction program is likely to depend upon continued preventative and reactive predator control, as well as a release programme that introduces enough individuals to prevent severe bottlenecks.

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Keywords parakeet; distribution; vegetation; *Cyanoramphus*; reintroduction

INTRODUCTION

Ensuring the survival of an endangered species requires a comprehensive knowledge of its ecology. Unfortunately, many species reach an endangered state before being systematically studied (*e.g.*, black robin [*Petroica traversi*]; Kennedy 2013). The critically endangered orange-fronted parakeet (*Cyanoramphus malherbi*) is a typical example of this problem, which was further compounded by the fact that it was not confirmed as a distinct species nor received protection until 1999 (Boon *et al*. 2001; Kearvell *et al*. 2003; Kearvell 2013.). Prior to this point there had been little interest in the species, and no attempt to study its ecology or biology. After Taylor (1986) concluded it was not a distinct species, but merely a colour-morph of the congeneric yellow-crowned parakeet (*C. auriceps*), its imminent demise as an ornithological curio seemed assured.

The orange-fronted parakeet currently survives only in one small meta-population (Kearvell & Steeves 2015) centred on 3 valleys in the Canterbury

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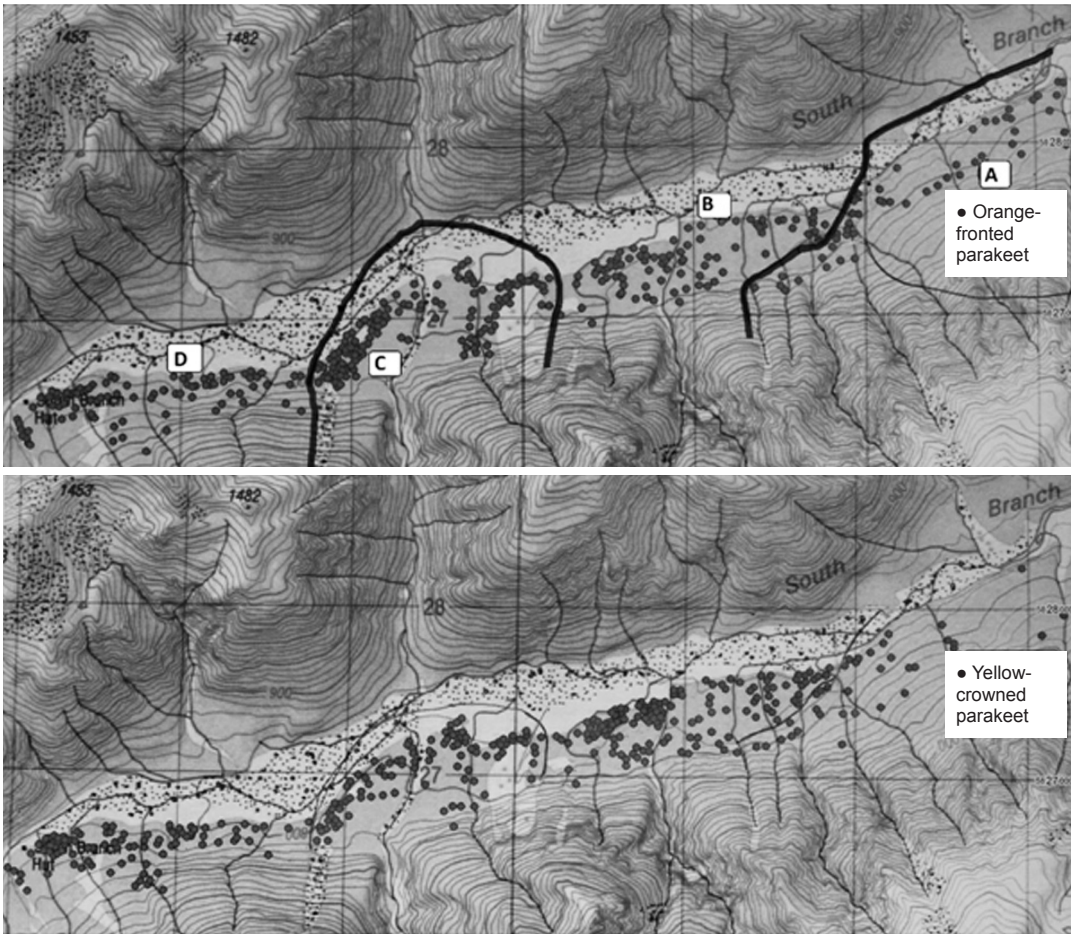

Fig. 1. (Top) Distribution of orange-fronted parakeet sightings in the South Branch Hurunui study site. Grid lines show valley distribution into 6 equal sections. 4 sections, based upon geomorphology, are shown as A, B, C & D and are delineated by lines. (Lower) Distribution of yellow-crowned parakeet sightings in the study site.

region of the South Island (Birdlife International 2014). Estimates put numbers at ~150 to 300 mature individuals. To save the orange-fronted parakeet from extinction, captive bred individuals have been released since 2005 onto 4 predator-free islands (Kearvell 2013). In contrast, the yellow-crowned parakeet is not currently threatened, although it has declined in range and abundance (Elliott 2013).

The orange-fronted parakeet has declined markedly since the introduction of mammalian predators such as rats (*Rattus* spp.), possums (*Trichosurus vulpecula*) and stoats (*Mustela ermina*) in the 19th century (Innes *et al.* 2010; Kearvell *et al.* 2003). A decline in numbers of orange-fronted parakeets was first reported by Phillpotts (1919), even suspecting the species might be close to extinction. By the time of its verification as a distinct species, it was in a critical state (Grant & Kearvell 2003). A study on the largest remaining population in the South Branch Hurunui began in 1997, but a rat plague removed ~85% of this population in 2001 (J. van Hal, *pers. comm.*).

Mean encounter rates per hour indicate the severity of this decline. In 1999, orange-fronted parakeet were encountered at a rate of 1.44 birds/h, increasing to 2.11 birds/h in 2000, after a prolonged breeding season brought on by a large mast seeding by beech trees across the valley (Kearvell 2013). By 2000, and after 2 successive beech mast events, their numbers declined to 0.09 birds/h in 2002/03 and 0.06 birds/h in 2003/04. In contrast, yellow-crowned parakeets were encountered at rates of 1.33 birds/h in 1999, 7.58 birds/h in 2000, 0.65 birds/h in 2002/03, and 0.69 birds/h in 2003/04 (Kearvell 2001). While these figures are not statistically comparable, they illustrate the serious decline in the orange-fronted parakeet, which coincided with rat plagues noted at the time.

Table 1. Number of parakeet encounters within each section (1 - 6) and the area (ha) of sections A to D. OFP = orange-fronted parakeet; YCP = yellow-crowned parakeet. A to D area divisions based upon geomorphology; 1 to 6 are based upon equal area.

Species	Section number						Total
	1	2	3	4	5	6	
OFP	30	51	62	86	66	57	352
YCP	18	70	93	74	37	70	362

Species	Section letter			
	A	B	C	D
Area (ha)	73.9	76.7	49.5	54.8
OFP/ha	0.68	1.13	2.66	1.51
YCP/ha	0.45	1.81	1.92	1.73

Although some observations on habitat use (Kearvell *et al.* 2003) and nest site selection in orange-fronted parakeet obtained prior to the population crash was published (Kearvell 2002), little else is known about the biology of this species prior to it reaching its current critical state. A better understanding of the biology of orange-fronted parakeet is needed given the population of this speciesin the Hurunui has not recovered (M. Farley, *pers. comm*.; Kearvell 2013), even though the yellow-crowned parakeet population has shown signs of recovery. Here, I examine the distribution of orange-fronted and yellow-crowned parakeets in high alpine *Nothofagus* spp. forest just prior to the catastrophic rat plague.

METHODS

Study area

The study site was located in the upper reaches of the South Branch Hurunui (172°5′ E and 42° 45′W), a steep-sided valley with a tree-line at ~1300 m. The study site on the valley floor was located on the true right at an altitude of 750 to 900 m and was 7 km long to a maximum width of 600 m.The area of the study site covered 255.15 ha (Fig. 1).

Across the study site, the forest canopy averaged 21 m in height and is dominated by a mixture of red beech (*Nothofagus fusca*), silver beech (*N. menziessi*) and mountain beech (*N.solandri* var. *cliffortioides*). The understory is generally open and dominated by silver beech, broadleaf (*Griselinia littoralis*), mountain toatoa (*Phyllocladus alpinus*), *Pseudopanax* spp. and *Coprosma* spp. Since 1995, the valley has been part of a Department of Conservation Mainland Island restoration project with valley-wide integrated pest control (Saunders & Norton 2001).

Data collection

Observations on both species of parakeet were collected over a period of 48 days during the austral spring of 1998 and austral summer of 1999, between 13 November and 24 February (Kearvell *et al*. 2003). The study site was divided into 2 approximately equal areas, each sampled on consecutive days. A fixed route was followed from 6 start points (3 start points in each area), with observations starting from one starting point chosen at random. The author was the only observer. All parakeets were noted within a 100 m radius from the observer while walking on the route. If a parakeet was heard or seen at a distance, the fixed route was left for a maximum distance of 100 m. Once the observation was completed the observer returned to the fixed line. Observations started 1 hour after sunrise and took ~7 hours to complete. Individual parakeets were not identified as none were banded, therefore it is possible that some birds may have been counted more than once.

For each parakeet positively identified to species a number of parameters were recorded, including a map co-ordinate accurate to ~50 m (see explanation in Kearvell *et al*. 2003). This was possible because a series of stoat traps was spaced at 100 m intervals along the bush edge, which could be used as landmarks. In 2008, each stoat trap was given a GPS (Global Positioning System) co-ordinate which allowed me to convert my location estimates onto a map.

To compare my sightings of parakeets with variation in habitat types, I undertook a study of the forest structure within the study site, using plotless sampling (Cottam & Curtis 1956). I selected 100 plots, measuring 400 trees (Table 3). These were fixed by randomly selecting a stoat trap from the 108 available along the edge of the study site. At each selected trap, a random number then dictated the perpendicular distance walked into the forest, to a maximum of 600 m. From that point a random selection of a number between 1 and 360 dictated the compass bearing to follow to the nearest tree greater than 2 m in height. This then became the centre point for sampling. The sample area was then divided into 4 quarters using a line perpendicular to the forest edge as a meridian. In each quarter the nearest tree was selected to the centre point. Each tree was identified to species, and its height (m), diameter at breast height DBH (cm), and distance from the centre point (m) was estimated. It was noted whether the tree reached into the canopy or not.

Analysis of the forest structure data followed Mitchell (2007). I calculated trunk area (m^2), basal area (m^2), canopy mean height (m), canopy trees mean DBH (cm), absolute density (trees/ha), mean distance between trees (m), overall DBH (cm), DBH

Table 2. Vegetation description of study site using 4 sections based upon geomorphology. See Fig. 1 for location of sections.

	A	B	C	D	F	*P*
Canopy mean ht (m)	21.69	20.02	20.65	20.37	1.31	0.273
Canopy trees mean DBH (cm)	42.75	44.06	49.96	46.54	0.3	0.76
Overall mean DBH (cm)	19.29	28.48	25.51	25.02	3.42	0.01
Mean distance between trees (m)	2.186	3.434	2.479	2.584	13.31	0.0001
Absolute density trees/ha	2092.6	849.9	1627.2	1497.6	-	-
Total trees in section	154810	65188	80687	82212	-	-

Table 3. Distribution of measured tree species within each section. STD = Standing dead tree.

Section	Canopy				Sub canopy			Total
	Silver beech	Red beech	Mountain beech	STD	Silver beech	Red beech	Moutain beech	
A	11	11	14	8	80	0	4	128
B	18	14	12	6	37	1	1	96
C	8	10	8	4	27	1	10	68
D	10	14	11	8	48	7	10	108

greater than 28 cm and number of trees measured in each selected section (Table 3).

To analyse the distribution of parakeets across the study area, I divided the study site in one of two ways: (i) 6 equal sections using grid lines (Fig. 1), irrespective of any variation in vegetation or geomorphology, and (ii) 4 sections based upon naturally occurring geomorphology (Fig 1). The 4 sections were: (A) river terrace 40 to 60 m above valley floor, slopping over 100 m, (B) flat river valley floor, (C) river fan between 2 active slips, and (D) narrow steep-sided valley above top active slip. The number of parakeets observed in each section were compared using Pearson's Chi-squared (χ^2) goodness-of-fit, including Yate's correction, where departure from an expected 1.0 ratio was considered. The vegetation description was investigated using ANOVA followed by post-hoc Tukey HSD test to investigate pair wise differences, but only if F was significant (Table 2).

Sector counts

After orange-fronted parakeets were designated as a distinct species, investigations were started to find an appropriate method for estimating changes in their population. An initial trial method was "sector counts," which were trialled for 2 years and undertaken during the austral spring. They entailed 2 observers walking a 300 m wide transect for 1 hour, recording all observations of both species of parakeet. Transects were separated by a gap of 300 m and each observer walked 9 transects over 2 days, for a total of 18 transects. The procedure was repeated over the next 2 days with the observers switching to the other observer's transects from the first 2 days. Thus, a total of 36 one hour transects were counted. This produced a relative abundance index only, and was trialled because of the difficulty in obtaining robust absolute estimates. The sector counts were later discontinued, but the data remains useful as a pre-plague index of the distribution and abundance of orange-fronted parakeets and are reported here.

RESULTS

A comparison of the distribution of 2 parakeet species across the 6 equal area sections of the study site (Table 1) indicated there was a significant departure from uniformity (χ^2 = 20.37, df = 5, P = 0.0011). If the distribution of parakeets is compared across the 4 sections based upon geomorphology, there was again a significant departure from equality (χ^2 = 20.84, df = 3, $P < 0.001$). Both patterns indicate that although both species occurred across the entire study site, their areas of greatest and lowest abundance did not coincide (Table 1). The highest numbers of orange-fronted parakeets were recorded in the forest on the river fan (section C), while the highest numbers of yellow-crowned parakeets occurred more evenly across 3 sections (C, B and D). In section C, orange-fronted parakeets were encountered at 2.66 observations/ha; this was 1.76 times higher than the next most abundant section. Yellow-crowned parakeets were also most abundant in section C (1.91 observations/ha), but

only 1.05 times more than the next most abundant section, and only 1.1 times higher than the third most abundant section. Both species of parakeets were least abundant in Section A (Table 1).

There were no significant differences between the 4 sections in the height of the canopy, nor the DBH of canopy trees (Table 2). There was a significant difference between the sections when the DBH of all trees was considered (Table 2), although the Tukey test suggested the significant difference was only between sections A and B ($P < 0.05$). The DBH of trees in section A appear to be significantly smaller than those in section B, but not compared with the other 2 sections. Section A had the lowest numbers of both species of parakeets. If we consider the mean distance between trees, then the difference between the sections was significant (Table 2). The Tukey test indicates that the difference lies between section B and the other 3 sections only ($P < 0.05$). The distance between trees in section B was significantly greater than in all other sections (Table 2). Absolute density/ha also follows this pattern, with section B having a lower density of trees (849.9 trees/ha) when compared to the other sections (Table 2).

DISCUSSION

I found the distribution of the 2 parakeet species was not uniform across the study site and varied depending upon both the section and the species (Table 1). Orange-fronted parakeets were most abundant in section C, where canopy trees had the largest mean DBH and had the second highest density of trees/ha (Table 2). This section also had the fewest silver beech and a high number of sub-canopy mountain beech (Table 3). These latter species appear to comprise substantial areas of regenerating forest, characterised by thick and nearly monoculture stands of young saplings (*pers. obs*.).

At first glance, the study area appears as a beech monoculture. However, my vegetation survey indicated this is not the case, with the 4 geomorphological areas in my study site having significantly different vegetation structures. Even at this basic level, the distribution of both species of parakeet appeared to mirror these variations in the structure, as I recorded significantly different levels of encounters throughout the study area. However, whether the present vegetation structure is a relict that survived the introduction of mammalian herbivores (Innes *et al.* 2010) is unknown, as there is no pristine beech forest anywhere in New Zealand for comparison.

Since the 2001 rat plague, the population of orange-fronted parakeet throughout the 3 valleys (Kearvell & Steeves 2015) has shown few signs of recovery; indeed there are indications of an overall slow decline (Kearvell *et al*. 2014). Presently, no orange-fronted parakeets occur within the study area (*pers. comm*., M. Farley).

Unfortunately, there is no information available on the number of either parakeet species prior to the discovery of the orange-fronted parakeet population in 1996. As damage to the habitat and mammalian introductions have been underway since at least 1850 (Inness *et al*. 2010), it seems likely that both parakeet populations have been under considerable pressure since then. The orange-fronted parakeet was considered in decline as long ago as the early 1900's (Phillpotts 1919), and thus the abundance of this species prior to human influence is unknown but it was almost certainly more abundant and widespread than at present.

The study reported here was conducted at the same time as studies on nest site selection (Kearvell 2002) and comparative ecology (Kearvell *et al*. 2002). However, neither of these studies examined the distribution of the 2 sympatric parakeet species within the study site. A time budget of the behaviours indicated many similarities: orange-fronted parakeets were observed feeding 60% of the time, breeding 12%, comfort behaviours 14% (preening, bathing, *etc*.) and calling 12% of the time; for yellow-crowned parakeet, the equivalent figures were 58%, 10%, 10% and 21%, respectively (Kearvell *et al*. 2002). These authors also found no significant differences between the species in their use of forest stratum, use of beech trees species or in use of tree sizes. However, orange-fronted parakeets were found to forage lower in the canopy more often, and appeared to consume invertebrates more than yellow-crowned parakeets (Kearvell *et al.* 2002).

Understanding the reasons for the distribution of species over a particular habitat requires careful testing, and recent examinations suggest many published examples may have limitations (Vaughan & Ormerod 2005). Although I found that both species of parakeets appear to exhibit a similar clumped distribution, the reasons for this are not clear. Kearvell *et al*. (2002) noted that most of their observations of parakeets were of birds 'feeding'. Thus, it might be reasonable to conclude that the differences in the distribution of the 2 parakeets could depend upon the distribution of their food sources. The 2 species are known to readily feed and associate in mixed species parakeet flocks (Kearvell *et al*. 2014), yet there appeared to be significant differences within the distribution of the 2 species across the valley. However, it is also possible that the clumped distribution I observed may be the result of the small population size and so each species is only found in a restricted area.

There are no indications that these 2 species of parakeet breed colonially (Kearvell *et al*. 2014) although they exhibit some significant differences in their selection of nest site (Kearvell 2002). The data

presented here also indicates significant differences between the 2 species in their distribution within the valley. As we do not know the distribution of these 2 parakeet species prior to the long-term habitat decline, the current distribution may, to some degree, reflect the distribution of an anthropogenically modified 'relict' population, rather than their original distribution.

For reasons that are not understood, the orange-fronted parakeet population in the South Branch of the Hurunui remained higher than the other 2 mainland valleys in which the species survived until recently. The difference in survival may be due to the fact that the valley has exhibited, since measurements were started in 1996, consistently lower levels of introduced mammalian predators than the other 2 valleys (A. Grant, *pers. comm*.). One reason for this may be that the valley is around 200 m higher in altitude, but at this stage I cannot rule out other habitat differences.

Despite the recent crash in the parakeet populations, the South Branch of the Hurunui retains the most intact beech forest left in the area. As it once held the largest orange-fronted parakeet population recorded (Kearvell 2001), there seems to be no reason why this cannot be the site for an equally large population again, subject to 2 caveats. First, there needs to be an effective pest control programme operating continuously, and secondly, it may be necessary to implement release programme given the low numbers of parakeets at present in the area. An orange-fronted parakeet release programme has commenced in 2015, with some initial limited success (M. Farley, *pers. comm*.). Assuming the population of orange-fronted parakeets in the valley recover then commitment in needed for regular preventative, as well as reactive, predator control. With the yellow-crowned parakeet population level seemingly showing signs of recovery in the valley then there is no reason to believe that orange-fronted parakeet cannot also regain their former numbers.

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