

Evidence for assortative mating in sympatric populations of orange-fronted (*Cyanoramphus malherbi*) and yellow-crowned (*C. auriceps*) kākārīki

JONATHAN C. KEARVELL

Department of Conservation, Rangiora Office, 32 River Road, Rangiora 7400, New Zealand

TAMMY E. STEEVES*

School of Biological Sciences, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand

Abstract The remnant wild populations of the critically endangered orange-fronted kākārīki (*Cyanoramphus malherbi*) are restricted to 3 North Canterbury valleys where they co-occur with the yellow-crowned kākārīki (*C. auriceps*). Mixed pairs of *Cyanoramphus* kākārīki species have been documented throughout the genus, but the extent to which orange-fronted and yellow-crowned kākārīki mate assortatively, particularly when one species outnumbers the other, remains unclear. Here, we investigate the level of assortative mating between orange-fronted and yellow-crowned kākārīki. Based on 355 confirmed nests during 1999-2011, 99% ($n = 351$) were pure pairings and 1% ($n = 4$) were mixed pairings. With one exception, the ratio of orange-fronted to yellow-crowned kākārīki encountered during annual surveys ranged between zero and 0.78. These results indicate that the 2 congeners exhibit assortative mating, even when the orange-fronted kākārīki is outnumbered by yellow-crowned kākārīki. The low levels of mixed pairing we observed suggests that the reintroduction of orange-fronted kākārīki should not be precluded to sites where yellow-crowned kākārīki already occur.

Kearvell, J.C.; Steeves, T.E. 2015. Evidence for assortative mating in sympatric populations of orange-fronted (*Cyanoramphus malherbi*) and yellow-crowned (*C. auriceps*) kākārīki. *Notornis* 62 (2): 71-75.

Keywords assortative mating; *Cyanoramphus*; parakeet; conservation; translocation

INTRODUCTION

The orange-fronted kākārīki (*Cyanoramphus malherbi*) is a critically endangered New Zealand endemic parakeet (Robertson *et al.* 2013). The remnant wild population is restricted to 3 North Canterbury valleys (Poulter, Hawdon and South Branch Hurunui, herein 'Hurunui') where it occurs in sympatry with its congener, the yellow-crowned

kākārīki (*C. auriceps*) in southern beech (*Nothofagus* spp.) forests (Kearvell 2013). The orange-fronted kākārīki has also been translocated to 4 predator-free offshore islands (Kearvell 2013). The species is notoriously difficult to count, but the conservative estimate for mainland and island populations combined is 200-300 mature individuals (Kearvell 2013).

The orange-fronted kākārīki was previously the centre of a lengthy taxonomic debate, but it was recognised as a full species following genetic

Received 16 March 2015; accepted 18 May 2015

*Correspondence: tammy.steeves@canterbury.ac.nz

research based on mitochondrial sequence data (Boon *et al.* 2000 & 2001; see review in Kearvell *et al.* 2003). Additional research has highlighted that the orange-fronted kākārīki is also phenotypically and, to some extent, ecologically and behaviourally distinct from the yellow-crowned kākārīki (Elliott *et al.* 1996; Boon *et al.* 2000; Kearvell 2002; Kearvell *et al.* 2002; Kearvell & Briskie 2003; Kearvell 2013; Kearvell *et al.* 2014). Subsequent genetic research based on nuclear microsatellite genotype data further indicates that the orange-fronted and the yellow-crowned kākārīki are genetically distinct (Andrews 2013).

Several species of *Cyanoramphus* kākārīki have been observed to form mixed breeding pairs with closely related sympatric congeners in the wild (Taylor 1975; Veitch 1979; Taylor 1985), but it is unclear whether these mixed pairs are indicative of a break-down in isolating mechanisms when one species outnumbers the other. Determining this has important implications for the conservation management of threatened species that co-occur with more common congeners (Randler 2006). For example, prior to this study, there was only one record of a mixed orange-fronted x yellow-crowned kākārīki breeding pair from the Hope Valley shortly after the orange-fronted kākārīki was re-discovered there in 1980 (Taylor *et al.* 1986). The number of orange-fronted kākārīki in the valley was reported to be extremely small at that time, occurring "...in a ratio of about one orange-fronted bird to 12 yellow-crowned parakeets." (Taylor *et al.* 1986). No orange-fronted kākārīki have been reported from the valley since 1983 (Taylor *et al.* 1986; S. Elkington *pers. comm.*). Given the perceived risk of mixed pairings when orange-fronted kākārīki are outnumbered by yellow-crowned kākārīki, the Department of Conservation (DoC) orange-fronted kākārīki recovery group has avoided translocating birds to sites where yellow-crowned kākārīki are already present (Grant & Kearvell 2003).

Previous research suggests that such a conservative approach may be unwarranted. Boon *et al.* (2000) monitored the behaviour of 58 pairs of orange-fronted and yellow-crowned kākārīki in the Hurunui (1996-1999) and concluded that the 2 species exhibited assortative pairing because no mixed pairs were observed. However, whether these "pairs" were indeed breeding pairs is unknown. Boon *et al.*'s (2000) defined a pair as 2 adult birds associated together in close proximity, uninfluenced by a third adult bird, displaying non-aggressive and collaborative behaviour towards each other (*e.g.*, courting, mating, preening, nest prospecting, sitting together on a branch). In other words, they did not monitor actual breeding pairs tied to an active nest, only birds "acting" as breeding pairs. Subsequent

data obtained from DoC's orange-fronted kākārīki field programme (2001 to present), indicates that orange-fronted and yellow-crowned kākārīki interact both aggressively and non-aggressively with one another and can regularly be found in mixed feeding flocks (Kearvell *et al.* 2003). Individuals of the 2 species are also often seen "sitting together" and both have been recorded courting members of the other species, with no subsequent confirmed breeding attempt excluding those few mixed nests reported here. It is also not uncommon to see male and female congeners feeding together, despite each being a member of a conspecific breeding pair (Kearvell 2011). Thus, it is likely that at least some of the "pairs" observed by Boon *et al.* (2000) were not breeding pairs.

The lack of mixed pairings in the Hurunui reported by Boon *et al.* (2000) occurred at a time when the population of both species was relatively high. During 2000/01, a catastrophic rat (*Rattus* spp.) plague led to a disproportionate loss of the orange-fronted kākārīki population (J. van Hal, *pers. comm.*). Whereas the number of yellow-crowned kākārīki appears to have historically exceeded that of orange-fronted kākārīki elsewhere in North Canterbury (Kearvell *et al.* 2003), the number of yellow-crowned and orange-fronted kākārīki in the Hurunui prior to the rat plague was near parity (Boon *et al.* 2000; Kearvell *et al.* 2002; also see Fig 1). Thus, whether the lack of mixed pairings by Boon *et al.* (2000) are indicative of sympatric populations where orange-fronted kākārīki are outnumbered by yellow-crowned kākārīki is unknown.

Here, we use only data from confirmed breeding pairs only to investigate the evidence for assortative mating (and the frequency of mixed pairings) among numerically skewed sympatric populations of orange-fronted and yellow-crowned kākārīki for all 3 remaining mainland valleys during 13 breeding seasons from 1999-2011. We also discuss the implications of our results for the conservation management of both mainland and island orange-fronted kākārīki populations.

METHODS

Species identification

There are 3 distinct plumage differences between these 2 essentially green species of kākārīki: whereas the orange-fronted kākārīki has a bright orange frontal band and rump patches, a lemon-yellow forecrown and a distinctly blue-green tone to its contour feathers, the yellow-crowned kākārīki has a dark crimson frontal band and rump patches, a golden yellow forecrown and a distinct yellow-green tone to its contour feathers (Kearvell 2013). However, because the colour of the forecrown and contour feathers are too similar in tone to use as

Table 1. Number of nests located in 3 North Canterbury valleys for the following pairing categories: orange-fronted kākārīki x orange-fronted kākārīki (OFK x OFK); yellow-crowned kākārīki x yellow-crowned kākārīki (YCK x YCK) and orange-fronted kākārīki x yellow-crowned kākārīki (Mixed).

Valley	OFK x OFK	YCK x YCK	Mixed
Poulter	42	28	1
Hawdon	67	58	1
Hurunui	39	117	2

diagnostic species traits (Kearvell *et al.* 2014), we followed the protocol used by the DoC orange-fronted kākārīki field team in which no kākārīki was assigned to species unless an unequivocal assessment of the colour of either the frontal band or rump patches was obtained. Females and males were distinguished using a combination of morphology, appearance and breeding behaviour including courtship, mating and nest site behaviours as per Kearvell *et al.* (2014).

Nest location

Active nests were located from 1999 to 2011 in the Hawdon (42° 58.18' S, 171° 44.52' E) and the Hurunui (42° 45' W 172° 5' E), and from 2003 to 2011 in the Poulter (42° 54.19' S, 171° 51.97' E) during the activities of the DoC orange-fronted kākārīki field team. Active nests were also located during related research projects conducted in the Hurunui only (1997 to 2002; Kearvell 2002), and in all 3 mainland valleys (2004 to 2008; Rhodes *et al.* 2008). In all cases, active nests for both species were located by following pairs or single birds. Active nests (*i.e.*, nests with at least 1 egg or nestling present) were confirmed either by climbing or, if trees were unable to be climbed, by repeated ground observations. Repeated ground observations can provide an accurate assignment of each nest stage. For example, females exhibit distinctive and predictable behaviour during incubation and nestling stages (Kearvell 2011). All confirmed active nests were regularly monitored throughout the breeding season and were allocated to 1 of 3 categories: orange-fronted kākārīki x orange-fronted kākārīki (OFK x OFK), yellow-crowned kākārīki x yellow-crowned kākārīki (YCK x YCK) and mixed (OFK x YCK).

Annual encounter ratio

During the activities of DoC orange-fronted kākārīki field teams in the Hawdon and the Hurunui from 1999 to 2011, and in the Poulter from 2003-2011 (but see Results for exceptions), an hourly encounter rate for each species was calculated by recording all encounters of each species during nest searches between November and December. A start time was recorded at the beginning of a search and

when a kākārīki was encountered a stop time was recorded. There were no fixed lines used in these encounters, rather the sampling was opportunistic as the observer moved through the forest to locate birds of both species. When a kākārīki was identified to species, or it flew away unidentified, the search re-started as above. We used these data to calculate an annual encounter ratio for each mainland valley (*i.e.*, the ratio of the total number of orange-fronted kākārīki encountered each year to the total number of yellow-crowned kākārīki encountered each year).

Orange-fronted and yellow-crowned kākārīki exhibit ecological and behavioural differences, but there is considerable overlap. In addition to readily forming mixed feeding flocks (Kearvell *et al.* 2003), ecological similarities between these 2 species include diet and nest site selection (Kearvell *et al.* 2002). Breeding behaviour is also similar, with both species breeding over the same period, with the same incubation and nestling periods (Elliott *et al.* 1996; Kearvell 2002, 2013). Thus, we are confident that the annual encounter ratio provides an adequate measure of the relative abundance of orange-fronted and yellow-crowned kākārīki because both species are equally likely to be encountered during searches and any repeat encounters are unlikely to be biased towards one species.

RESULTS

Frequency of mixed pairings

The identity of pairs at a total of 355 nests was confirmed: 351 (99%) nests were attended by pairs of conspecifics (either OFK x OFK or YCK x YCK) and only 4 (1%) nests were attended by mixed pairs (OFK x YCK; Table 1). The observed frequencies were significantly different to those expected under the expectation of random mating ($\chi^2 = 243.32$; $p < 0.001$). Each of the 4 mixed nests consisted of a male orange-fronted kākārīki and a female yellow-crowned kākārīki.

Annual encounter ratios

With the exception of 1999 when the annual encounter ratio of orange-fronted kākārīki exceeded that of yellow-crowned kākārīki in the

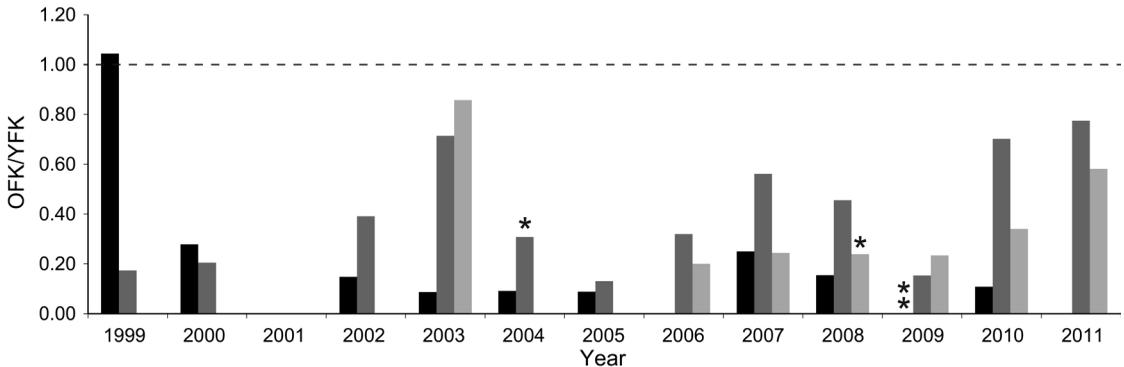


Fig. 1. Ratio of orange-fronted kākāriki (OFK) to yellow-crowned kākāriki (YCK) encountered annually during opportunistic searches in the Hurunui (black shading), Hawdon (dark grey shading) and Poulter valleys (light grey shading). See text for details regarding annual encounter ratios of zero. Dotted line indicates parity. Asterisks denote mixed pairs.

Hurunui, the annual encounter ratio of orange-fronted kākāriki to yellow-crowned kākāriki encountered was below parity (range = 0 - 0.78; Fig. 1). The annual encounter ratio was zero in the Hurunui during 2001, 2009 and 2011, and in the Poulter during 2005 (*i.e.*, yellow-crowned kākāriki, but no orange-fronted kākāriki, were recorded). Annual encounter ratios were not calculated in the Hawdon during 2001, in the Poulter during 1999-2002 and 2004, and in the Hurunui during 2006 because encounters were not conducted in these valleys during these years. Orange-fronted kākāriki were outnumbered at least 3:1 by yellow-crowned kākāriki in each of the 3 valleys during most years in which ratios were calculated, including the 3 years that the 4 mixed nests were recorded in 1 of the 3 valleys (Fig. 1).

DISCUSSION

Our results provide compelling evidence for assortative mating in sympatric populations of orange-fronted and yellow-crowned kākāriki. Taylor *et al.* (1986) did find one mixed nest in the Hope Valley, when the orange-fronted kākāriki population was reported as extremely small and the yellow-crowned kākāriki population was presumably relatively large. However, the small number of mixed nests found in this study (1%), despite orange-fronted kākāriki being largely outnumbered by yellow-crowned kākāriki, suggests that rarity alone does not invariably lead to mixed mating between these 2 congeners. Indeed, there is historical evidence that orange-fronted kākāriki may naturally be the least common of the 3 sympatrically occurring mainland species: referring to the red-crowned (*C. novaezelandiae*), yellow-crowned and orange-fronted kākāriki, Phillipotts (1919) states "*Cyanoramphus malherbi* Sounacé,

which was never so abundant as the other two...". This may in part explain why, in contrast to other *Cyanoramphus* congeneric pairs where one species is out-numbered by the other following anthropogenic disturbance (*e.g.*, Forbes kākāriki [*C. forbesi*] and the Chatham red-crowned kākāriki [*C. novaezelandiae chathamensis*] on Mangere Island; Chan *et al.* 2006), assortative mating persists in orange-fronted and yellow-crowned kākāriki, even as the relative number of orange-fronted kākāriki continues to decline (Robertson *et al.* 2013; Birdlife International 2013).

It is interesting to note, though bearing in mind the small sample size, that all 4 mixed pairs found in this study consisted of a male orange-fronted kākāriki and a female yellow-crowned kākāriki. Whether this is due to male preference or an excess of orange-fronted kākāriki males is unknown, but it raises the possibility that mixed species mating may be more likely if there is a highly skewed sex ratio in one, or both, species (Steeves *et al.* 2010). Thus, although orange-fronted kākāriki may have been generally less common than yellow-crowned kākāriki prior to anthropogenic disturbance, even the gradual decline of a critically endangered species like the orange-fronted kākāriki could inadvertently lead to a highly skewed sex ratio due to the stochastic effects of small sample size (*e.g.*, the chance survival of more male than female offspring).

Our results indicate that the complete absence of yellow-crowned kākāriki may not be required to prevent mixed pairing prior to the reintroduction of orange-fronted kākāriki to mainland sites where they have been recently extirpated or severely reduced (*e.g.*, Hurunui) or prior to the translocation of orange-fronted kākāriki to predator-free offshore islands. However, further research is warranted prior to the commencement of such conservation

management action (e.g., an investigation of the appropriate number of founder individuals necessary to avoid a highly skewed sex ratio due to the stochastic effects of small sample size).

ACKNOWLEDGEMENTS

We are grateful to the Department of Conservation's orange-fronted kākārīki field teams for their efforts in locating nests and the yellow-crowned kākārīki field teams for allowing us to use some of their unpublished data. We also thank Matt Walters for graphics support and an anonymous referee for providing helpful suggestions that improved this manuscript.

LITERATURE CITED

- Andrews, B.J. 2013. Conservation genetics of the orange-fronted kākārīki (*Cyanoramphus malherbi*). Unpubl. M.Sc. thesis, University of Canterbury, Christchurch, New Zealand.
- Birdlife International. 2013. *Cyanoramphus malherbi*. The IUCN Red List of Threatened Species. Version 2014.3. <www.iucnredlist.org>
- Boon, W.M.; Kearvell, J.C.; Daugherty, C.H.; Chambers, G.K. 2000. Molecular systematics of New Zealand *Cyanoramphus* parakeets: conservation of orange-fronted and Forbes' Parakeets. *Bird Conservation International* 10: 211-239.
- Boon, W.M.; Kearvell, J.C.; Daugherty, C.H., Chambers, G.K. 2001. Molecular systematics and conservation of orange-fronted parakeet (*Cyanoramphus* spp). *Science for Conservation* 176: 1-46.
- Chan, C.H.; Ballantyne, K.N.; Aikman, H.; Fastier, D.; Daugherty, C.H.; Chambers, G.K. 2006. Genetic analysis of interspecific hybridisation in the world's only Forbes' parakeet (*Cyanoramphus forbesi*) natural population. *Conservation Genetics* 7: 493-506.
- Elliott, G.P., Dilks, P.J.; O'Donnell, C.F.J. 1996. The ecology of yellow-crowned parakeets (*Cyanoramphus auriceps*) in *Nothofagus* forest in Fiordland, New Zealand. *New Zealand Journal of Zoology* 23: 249-266.
- Grant, A.D.; Kearvell, J.C. 2003. *Orange-fronted parakeet (Cyanoramphus malherbi) Recovery Plan, 1999-2005*. Wellington: New Zealand Department of Conservation.
- Kearvell, J.C. 2002. Nest sites of sympatric orange-fronted (*Cyanoramphus malherbi*) and yellow-crowned parakeets (*C. auriceps*). *Notornis* 49: 261-263.
- Kearvell, J.C. 2011. Unpublished Department of Conservation internal document DME-1039105: Nest stages from ground observations.
- Kearvell, J.C. 2013. Orange-fronted parakeet. In Miskelly, C.M. (ed.) *New Zealand Birds Online*. <http://nzbirdsonline.org.nz/species/orange-fronted-parakeet>.
- Kearvell, J.C.; Briskie, J.V. 2003. Similarity of chatter calls between orange-fronted parakeet *Cyanoramphus malherbi* and yellow-crowned parakeet *C. auriceps*. *Ibis* 145: 333-336.
- Kearvell, J.C.; Connor, C.; Farley, M. 2014. Field identification of the orange-fronted parakeet (*Cyanoramphus malherbi*): pitfalls for the unwary. *Notornis* 61: 200-204.
- Kearvell, J.C.; Grant, A.D.; Boon, W.M. 2003. The orange-fronted parakeet (*Cyanoramphus malherbi*) is a distinct species: a review of recent research into its taxonomy and systematic relationship within the genus *Cyanoramphus*. *Notornis* 50: 27-35.
- Kearvell, J.C.; Young, J.R.; Grant, A.D. 2002. Comparative ecology of sympatric orange-fronted parakeets (*Cyanoramphus malherbi*) and yellow-crowned parakeets (*C. auriceps*), South Island, New Zealand. *New Zealand Journal of Ecology* 26: 139-148.
- Phillipotts, A. 1919. Notes on birds of Southwest Otago. *Transactions and Proceedings of the New Zealand Institute* 51: 222.
- Rhandler, C. 2006. Behavioural and ecological correlates of natural hybridization in birds. *Ibis* 148: 459-467.
- Rhodes, M.; Elliott, G.; Kemp, J. 2008. Unpublished Department of Conservation internal document DME-384475: Parakeet nesting success with and without predator control in the Hurunui Valley, North Canterbury.
- Robertson, H.A.; Dowding, J.E.; Elliott, G.P.; Hitchmough, R.A.; Miskelly, C.M.; O'Donnell, C.F.J.; Powlesland, R.G.; Sagar, P.M.; Scofield, R.P.; Taylor, G.A. 2013. *Conservation status of New Zealand birds, 2012*. New Zealand Threat Classification Series 4. Wellington: Department of Conservation.
- Steeves, T.E.; Maloney, R.F.; Hale, M.L.; Tylianakis, J.M.; Gemmill, N.J. 2010. Genetic analyses reveal hybridization but no hybrid swarm in one of the world's rarest birds. *Molecular Ecology* 19: 5090-5100.
- Taylor, R.H. 1975. Some ideas on speciation in New Zealand parakeets. *Notornis* 22: 110-121.
- Taylor, R.H. 1985. *Status, habits and conservation of Cyanoramphus parakeet in the New Zealand region*. ICBP technical publication no. 3: 195-211.
- Taylor, R.H.; Heatherbell, E.G.; Heatherbell, E.M. 1986. The orange-fronted parakeet (*Cyanoramphus malherbi*) is a colour morph of the yellow-crowned parakeet (*C. auriceps*). *Notornis* 33: 17-22.
- Veitch, C.R. 1979. Parakeet hybridisation. *Notornis* 26: 395.