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RESEARCH

Recovery of North Island kākā (*Nestor meridionalis septentrionalis*) within Pureora Forest Park, 2000-2020

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Abstract: To test the long-term efficacy of mammalian pest control, annual distance sampling estimates of the density of North Island kākā (*Nestor meridionalis septentrionalis*) within the southern Waipapa Ecological Area (WEA), Pureora Forest Park from 2008–2020 are compared to previously published estimates made at the same sites and time of year (October) between 2000–2007. Kākā density increased approximately four-fold from an average of c. 0.5 (95% CI 0.5–0.6) birds ha^{-1} between 2000 and 2007 to c. 2.3 (95% CI 1.9–2.8) birds ha^{-1} in 2020. The average of rate of increase between 2000 and 2018 was c. 6.9% per annum. Kākā recovery is likely to be a function of multiple mast events and long-term (> 20 years), large-scale, frequent, effective control of possums (*Trichosurus vulpecula*) and probably mustelids. It is recommended that the current pest control as well as kākā and pest monitoring continue.

Keywords: brush-tail possums, conservation, distance sampling, mustelids, pest control, Psittaciformes

Introduction

Long-term monitoring is required to assess the efficacy of conservation actions, prioritise resource allocation, and report on the status of native biodiversity as required by international agreements (Allen et al. 2003; McGlone et al. 2020). Long-term monitoring programmes are, however, scarce due to a lack of understanding of their importance, clear objectives, appropriate sampling design, standardised methods, and resourcing (Pollock et al. 2002; Lindenmayer et al. 2012; Pavlacky et al. 2017; Bellingham et al. 2020).

Kākā are a long-lived (c. 40 years), large (340–690 g) parrot, endemic to New Zealand (Powlesland et al. 2009). North Island kākā (*Nestor meridionalis septentrionalis*) have a conservation threat status of Recovering while the South Island kākā (*N. m. meridionalis*) are classified as Nationally Vulnerable (Robertson et al. 2021). Historically abundant and widespread, kākā declined dramatically because of habitat destruction and hunting, but even within remaining undisturbed forests on the mainland they are now relatively rare due to ongoing predation by introduced mammals (Greene & Fraser 1998; Wilson et al. 1998; Moorhouse et al. 2003; Powlesland et al. 2009).

Kākā density is dependent on breeding productivity and survival, which may be influenced by a range of environmental variables such as the extent, intensity and frequency of mast events (i.e. the synchronous and irregular production of large quantities of flowers, fruits and seeds), the density of introduced mammalian predators and the effectiveness of conservation actions taken to control them (Powlesland et al. 2009). Female kākā nest for extended periods of time within large tree cavities and breed episodically and synchronously with the mast events of dominant forest canopy species, particularly beech and podocarp species (e.g. beech Nothofagaceae, rimu *Dacrydium cupressinum*, mataī *Prumnopitys taxifolia*, miro *Pectinopitys ferruginea*, and kahikatea *Dacrycarpus dacrydiodes*) (Greene et al. 2004; Powlesland et al. 2009). In addition to initiating kākā breeding, large mast events usually trigger rodent (mouse *Mus musculus* and rat *Rattus* spp.) irruptions which in turn trigger large increases in mustelid abundance and survival (Blackwell et al. 2001). Cavity nesting birds, such as female kākā, their eggs and chicks, are particularly susceptible to predation by possums and stoats (Moorhouse et al. 2003; Greene et al. 2004; Powlesland et al. 2009).

From 1993 onwards, the Department of Conservation (DOC) has controlled possums (*Trichosurus vulpecula*) and ship rats (*Rattus rattus*) within the Waipapa Ecological Area (WEA) Pureora Forest Park (78 000 ha) using a range of methods at varying intervals (Moorhouse et al. 2003; DOC unpubl. data; Table 1). Mustelids (particularly stoats *Mustela erminea*) were also controlled via secondary poisoning (Murphy et al. 1998). To test the efficacy of this mammalian pest control, distance sampling was used to estimate kākā density (Buckland et al. 2001). During October 2000–2007, kākā density estimates within the southern WEA were relatively stable, averaging 0.5 birds ha^{-1} (95% CI 0.4–0.6) (Greene et al. 2010).

To test the efficacy of long-term (> 20 years) mammalian

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Table 1: Summary of predator control efforts and scale of mast events within the area surveyed for kākā.

Year*	**Area****	**Pest Control**	**Mast**[†]	**Dominant Species**
1993/94	Waipapa All	Bait stations (1080)	?	?
1994/95	-	-	?	?
1995/96	Waipapa South	Bait Stations (1080 + Brodifacoum)	?	?
1996/97	Waipapa All	Aerial 1080 (carrot) + Bait Stations (Brodifacoum)	Partial	?
1997/98	Waipapa All	Bait Stations (Brodifacoum)	Full	Rimu + Mataī
1998/99	Waipapa South	Bait Stations (Brodifacoum)	Full	Kahikatea + Hīnau
1999/00	Waipapa All	Bait Stations (Brodifacoum)	Poor	Mataī
2000/01	Waipapa South	Bait stations (1080)	Poor	Rimu
2001/02	Waipapa South	Aerial 1080 + rat traps	Partial	Kahikatea
2002/03	Waipapa South	Rat traps	Partial	?
2003/04	-	-	Partial	?
2004/05	Waipapa South	1080 paste	Full	?
2005/06	Waipapa South	Bait bags (Coumatetralyl)	Partial	?
2006/07	-	-	Partial	?
2007/08	-	-	Poor	-
2008/09	Waipapa South	Aerial 1080 + Bait stations (Coumatetralyl)	Full	Kahikatea +Tōtara
2009/10	Waipapa South	Bait stations (Coumatetralyl)	Partial	Kahikatea
2010/11	-	-	Partial	Rimu + Tōtara
2011/12	-	-	Full	Rimu + Kahikatea
2012/13	Waipapa South	Bait stations (Diphacinone)	Poor	-
2013/14	Waipapa South	Bait stations (Diphacinone)	Full	Rimu + Kahikatea
2014/15	Waipapa All	Aerial 1080	Full	Rimu + Kahikatea
2015/16	-	-	Partial	Kahikatea + Mataī + Tōtara
2016/17	Waipapa All	Aerial 1080	Partial	Kahikatea
2017/18	Waipapa South	Bait stations (Pindone)	Poor	Tōtara
2018/19	Waipapa All	Bait stations (Pindone)	Full	Kahikatea + Rimu
2019/20	Waipapa South	Bait stations (Pindone)	Poor	-

*Year reflects the kākā breeding season and the seasonal development and ripening of available fruits and seeds.

**Includes management interventions relevant to the kākā survey within the Waipapa treatment block. 'Waipapa South' comprises the entire area surveyed for kākā and 'Waipapa All' the wider area including North, South, East and Mires blocks.

[†] Mast follows classification mast magnitude proposed by Wardle (1984): 'Full' = 4000+ seeds m^{-2}, 'Partial' = 500–4000 seeds m^{-2}, 'Poor' = 0–500 seeds m^{-2} for five species (hīnau, kahikatea, mataī, rimu, tōtara) known to be important components of kākā diet during breeding years (TCG, unpubl. data) within the WEA. Unpublished data (TCG) and anecdotal observation used to classify mast seeding events prior to introduction of seed traps in 2008.

pest control, this paper repeats the distance sampling methods at the same location, sites, and time of year (October) within the WEA to reassess kākā density estimates and population trends over a 20 year period from 2000–2020.

Methods

The Waipapa Ecological Area (38° 25 S, 175° 35 E) covers an area of 5112 ha and is approximately 45 km north-west of Taupō and 7 km north of Pureora village (see Greene et al. 2010). The southern WEA (1150 ha) is relatively flat (540–580 m a.s.l.) unlogged podocarp forest, the topography and vegetation of which was described by Greene et al. (2010). Except for 2019, when no counts were undertaken, annual distance sampling of kākā within the southern WEA were undertaken each October from 2000–2020. Sampling design, time of year, location, sample sites ($n = 131$), distance sampling methods, effort and analytical procedures (using DISTANCE 7.0 software, Thomas et al. 2010) to estimate annual kākā density (birds ha^{-1}) followed Greene et al. (2010). A low kākā density was estimated in 2002 due to a small sample size. This was excluded from the initial analysis by Greene et al. (2010) but subsequently reanalysed and included in the analysis presented here.

Detection functions were computed independently for each survey period as most years had sufficient detections for robust modelling (Table 2; Greene et al. 2010). Good model fit was usually obtained using half-normal or uniform models with varying numbers of adjustment terms and assessed using comparison of Akaike's Information Criterion (AIC), goodness of fit statistics (GoF) and Q-Q plots (Buckland et al. 2001, 2004; Burnham & Anderson 2002). Model averaging was not required for this analysis as there were either few competing models ($\Delta\text{AIC} < 3$; Burnham & Anderson 2002) or averaging produced little appreciable change in computed estimates. Models with the lowest ΔAIC values were used exclusively to derive density estimates in this analysis.

Possum, rat and stoat control was undertaken by DOC either within the southern, eastern and northern blocks of the WEA, or over the entire area in 19 years out of the 26 year period between 1993/1994–2019/2020. Rat traps and a variety of toxins (i.e. 1080, brodifacoum, coumatetralyl, diphacinone, and pindone) were delivered in bait stations or bait bags on the ground and aerial 1080 was applied every 2–7 years

Table 2: Kākā density and abundance estimates derived from annual distance sampling estimates for each survey year from 2000–2020. Obs = number of observations, GOF = goodness of fit, %CV = % Coefficient of Variation, $\hat{D}$ = estimated density (95% CI), $\hat{N}$ = estimated abundance (95% CI). Model refers to the key function + series expansion used.

Year	Obs	Model	GOF	%CV	$\hat{D}$	$\hat{N}$
2000	89	Hnorm+herm	0.9	18.7	0.56 (0.39–0.81)	646 (448–931)
2001	127	Unif.+poly	0.98	12.1	0.57 (0.45–0.72)	652 (515–826)
2002	52	Hnorm+herm	0.8	27.2	0.24 (0.14–0.41)	275 (162–467
2003	100	Unif.+cos	0.74	17.4	0.6 (0.42–0.84)	687 (489–966)
2004	95	Unif.+cos	0.87	18.0	0.5 (0.35–0.71)	577 (406–820)
2005	141	Unif.+cos	0.5	25.6	0.72 (0.50–0.94)	843 (591–1095)
2006	75	Unif.+cos	0.77	20.4	0.55 (0.37–0.82)	631 (424–939)
2007	114	Hnorm+cos	0.91	16.8	0.57 (0.41–0.80)	659 (474–916)
2008	141	Hnorm+cos	0.93	14.7	0.81 (0.61–1.08)	932 (698–1243)
2009	102	Hnorm+cos	0.6	16.8	0.68 (0.49–0.94)	778 (561–1081)
2010	76	Unif.+cos	0.49	18.8	0.57 (0.39–0.82)	651 (450–940)
2011	245	Unif+poly	0.47	12.7	0.56 (0.44–0.72)	643 (501–824)
2012	173	Unif+poly	0.89	14.3	0.89 (0.67–1.18)	1023 (772–1354)
2013	111	Unif+poly	0.41	18.3	1.06 (0.74–1.51)	1217 (852–1739)
2014	150	Unif+cos	0.69	12.5	1.49 (1.17–1.91)	1714 (1341–2191)
2015	162	Haz+poly	0.2	14.2	1.05 (0.80–1.39)	1211 (916–1599)
2016	177	Unif+cos	0.9	11.5	1.51 (1.21–1.90)	1740 (1390–2179)
2017	109	Hnorm+cos	0.99	16.2	1.0 (0.73–1.38)	1153 (839–1585)
2018	203	Haz+cos	0.544	11.6	1.25 (1.0–1.57)	1441 (1148–1808)
2020	217	Unif+cos	0.8	9.21	2.32 (1.93–2.78)	2666 (2224–3195)

(Table 1). To determine the effectiveness of control, relative pest abundance was monitored using tracking tunnels and wax tags for rats and possums respectively (Gillies & Williams 2013; National Pest Control Agencies 2015). Possums and rats were effectively controlled (maintained at low relative abundance i.e. at < 5% for both indices) in 11 of the 19 years pest control was applied (DOC unpubl. data). Population monitoring of stoats was minimal throughout much of this study period (especially in earlier years) and similar levels of suppression could only be assumed (E.C. Murphy, DOC Christchurch, pers. comm.).

Temporal trends for kākā density were modelled using a generalised additive model (GAM) (Wood 2017; R Core Team 2020) with and without the effects of mast and/or management (pest-control). GAMs have substantially more flexibility than linear models because the relationship between the independent and dependent variable is not assumed to be linear and therefore is well suited to modelling trend of extensive temporal data (Buckland et al. 2004). All models were compared using AIC. Mast years were coded as 'on' if there was a "full" mast (as Wardle 1984; Table 1) and 'off' otherwise. Management years were coded as 'on' if some form of pest control took place (Table 1) and 'off' otherwise. The average annual increase in kākā density over the 20 year survey period was estimated using both distance sampling estimates of annual kākā density and the best fitting GAM model.

Results

Between 2000 and 2020 there was an increasing trend in kākā density (Fig. 1; Table 2). During 2000–2007 density estimates were relatively stable ranging from a minimum of 0.24 (95% CI 0.14–0.41) birds ha^{-1} in 2002 to a maximum of 0.7 (95% CI 0.5–0.9) birds ha^{-1} in 2005. The average density during this time was 0.5 (95% CI 0.5–0.6) birds ha^{-1}. By 2020 the density estimate had increased to 2.3 (95% CI 1.9–2.8) birds ha^{-1}.

Kākā density remained relatively stable during 2000–2011, with slight inter-annual increases following hīnau (*Elaeocarpus dentatus*), rimu and other podocarp mast events. Following a 2011/12 mast event, kākā density almost doubled during 2012–2016 to c. 1.5 kākā ha^{-1} (95% CI 1.2–1.9 birds ha^{-1}) in 2016. Density increased markedly again following 2017/18 and 2018/19 mast events to c. 2.3 kākā ha^{-1} (95% CI 1.9–2.8 birds ha^{-1}).

The best fitting GAM model (i.e. smallest AIC value) predicted an average annual increase of 6.9% between 2000 and 2018 and did not include either mast or management (smoothing terms $p < 0.001$).

Discussion

The status and trends of populations may be influenced by multiple ecological processes (e.g. population structure, seasonal weather events) that can take many years for monitoring to resolve. In addition, significant ecological change (e.g. mast events) can mask the impact of conservation actions. Long-term monitoring over many decades is required to detect the trajectory and explain the drivers and patterns of population change, and to provide a context for planning conservation actions.

Annual counts using distance sampling within the southern WEA, Pureora Forest Park, showed that estimated kākā density increased approximately four-fold from a relatively stable population during 2000–2007 to 2020 – most of the increase having occurred from 2012–2014 onward and especially in the last few years. Modelling indicated an increasing trend from

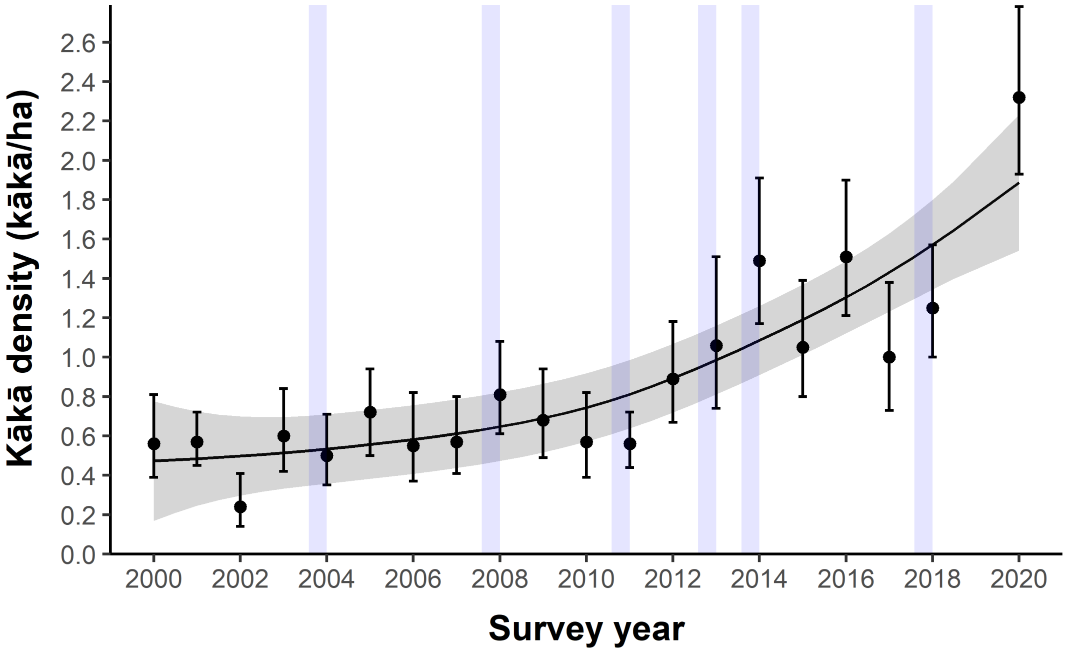

Figure 1: Density (± 95% CI) of kākā in the southern WEA between 2000 and 2020. Solid line shows predicted GAM (smoothed) estimates (and the shaded ribbon the ± 95% CI of these estimates). Vertical bars show timing of full mast seeding events (see Table 1).

2000–2018 of approximately 6.9% per annum on average. As the time of year, location, sites ($n > 130$), design, sampling protocols and effort remained similar from year to year, we are confident that the trend is real, even if the density estimates are potentially biased (Greene et al. 2010). Other modelling approaches may be preferrable for quantifying the complex effects of mast and management on population densities over time. For example, matrix modelling can include population demographic parameters (for example fecundity, recruitment and mortality) and show how the population responds to changes in these parameters as a result of mast and/or management (e.g. Leech et al. 2008) and we would encourage further investigation of such approaches.

The long-life expectancy and low reproductive rate of large, long-lived K-selected native birds such as kākā means that populations decline and increase slowly (O'Donnell & Hoare 2012). The slow increase in kākā density over many years followed by the rapid increase seen more recently is, therefore, not surprising given the relatively small initial population (apparently persisting well below carrying capacity) and the likely male biased population sex ratio (Greene & Fraser 1998). This study suggests that effective possum and stoat control once every 2–3 years and carried out at a scale of 1000–5000+ ha for 20 years will lead to increases in North Island kākā populations. A similar frequency of possum and rat control for a period of 30 years over 600–1000 ha was sufficient to change the conservation status of kōkako (*Callaeas wilsonii*) from Endangered to At Risk – Recovering (Robertson et al. 2015).

Frequent, large scale, effective pest control also benefits other bird species (Fea et al. 2020). North Island robins/toutouwai (*Petroica longipes*), whiteheads/pōpokatea (*Mohoua albicilla*), and yellow-crowned parakeets/kākāriki (*Cyanoramphus auriceps*) appear to be more abundant than they were c. 20 years ago (TG, TT, pers. obs.). Kōkako (*Callaeas wilsoni*) have also increased dramatically, from 8 pairs and 28 singles during 1995 to c. 200 pairs in 2019, within the WEA (DOC unpubl. data).

Although long-term monitoring of kākā density has not occurred elsewhere in New Zealand, it is likely that other mainland kākā populations have increased following mast events in areas which have had frequent, large scale, and effective pest control. There is strong evidence for improved nesting success, sex ratios (e.g. in the Eglinton Valley and Waitutu; TG, unpubl. data), and rapid increases in productivity, survival and recruitment following large mast events as long as there is effective pest control (Greene & Fraser 1998; Moorhouse et al. 2003; Powlesland et al. 2009; Taylor et al. 2009).

Although some uncertainty must remain about the underlying mechanism(s) driving the apparent increase in kākā density (i.e. observations restricted to one treated site), five-minute bird counts undertaken in Pureora Forest Park during 1978–81 then repeated during 1997/98, have also shown that the relative abundance of kākā increased in areas with pest control compared to areas without pest control (Smith & Westbrooke 2004). Similarly, simulated kākā population growth rates of birds at Lake Paringa (2009–2015) were substantially higher with effective pest control than for populations without pest control, particularly when the pest control effect lasted more than two years, when mast events occurred once every two years, and when nesting mortality was low (G. Elliott, DOC Nelson, pers. comm.).

The recovery of kākā within the southern WEA, Pureora Forest Park is likely to be a result of long-term (> 20 years), large scale, frequent and effective pest control (irrespective of the method(s) used to deliver it leading to improved reproductive success and survival (Moorhouse et al. 2003, Powlesland et al. 2009). But, even with effective pest control, kākā populations (in the WEA and elsewhere) only increase episodically when important forest trees mast (Powlesland et al. 2009). The efficacy of conservation actions can, therefore, be strongly influenced by both the frequency and intensity of mast events as well as the population dynamics of predator guilds all of which in turn may be disrupted by global warming (Bogdziewicz et al. 2021). In New Zealand, mast events show considerable synchrony within and across genera throughout their range (Webb 2018). Until the 1990s beech masting events generally occurred once every 5 years (King 1983; Elliott 1996) but by the 2000s had increased in frequency to twice very five years (Richardson et al. 2005). Despite rimu being one of the few masting species that does not follow these general patterns (Schauber et al. 2002), rimu mast events still seem to be driven by similar environmental cues (but in different directions and with different lag times) so it seems reasonable that the frequency of mast events for this species could also be changing and deserves to be examined in greater detail. The indirect impacts of shifting mast frequencies, the lack of synchrony between highly variable broadleaf species, and the consequent impacts on the size of resource pulses available in any given year (Webb 2018) on predator guilds, kākā productivity and survival, as well as the more direct energetic impacts on tree survival itself, may well have severe repercussions (Schauber et al. 2002).

The pest control being undertaken in the WEA has contributed to increased kākā density, however the impacts of climate change on kākā breeding frequency are largely unknown. It is therefore essential that not only adequate pest control continues but that kākā monitoring programmes and key drivers of successful breeding activity (e.g. the phenology of mast events) also continue and where possible, be expanded to include other remaining mainland kākā strongholds.

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Data and code availability

There is no publicly available data or code associated with this article.

Author contributions

TCG conceived the monitoring design and methodology, conducted the data analaysis, and wrote and reviewed the manuscript. TT supervised data collection, secured ongoing funding and contributed to the editing of the manuscript. BB contributed to the analysis as well as writing and editing the manuscript.

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