10.1071/PC20094_AC

Pacific Conservation Biology

SUPPLEMENTARY MATERIAL

Managing for cultural harvest of a valued introduced species, the Pacific rat (*Rattus exulans*) in Aotearoa New Zealand

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Kiore capture indices based on trapping

We estimated relative abundance indices and tested methods of observing kiore (Pacific rats) on Mauitaha during the trapping period, although our exploratory trapping approach with a single long trap-line and two trap types means that further sampling is required to draw robust conclusions. To recap our trapping methods, we placed trap stations c. 21 m apart along a winding line (830 m) that traversed the island from east to west to achieve a representative sample of potential kiore habitats present on the island. The line began in low-elevation shrubland and forest, crossed harakeke-dominated slopes, and followed a small track through

higher-elevation forest and scrub. To augment our trap numbers, we placed two additional trap stations in forest on a short 35-m line, perpendicular to and 50 m south of the main line. We trapped kiore with Victor Professional rat snap traps ('snap traps'; Woodstream Corporation, Lancaster PA, USA) and Elliott live-capture box traps ('live traps'; Elliott Scientific Equipment, Upwey, Vic., Australia). At each trap station we set a pair of snap traps (27 pairs on the first night and 39 pairs on the second night). Paired traps were placed back-to-back inside a corrugated plastic (Corflute) tunnel (500 × 120 × 120 mm), with plastic baffles restricting entrance holes to 40 × 40 mm to reduce the risk of bycatch of non-target species, primarily birds.

In the first 2 nights, the snap traps caught one kiore and one lizard. We then replaced most pairs of snap traps with single live traps on nights 3 and 4 to increase our kiore capture rate and prevent additional lizard mortality. We placed one live trap in each of 39 tunnels and removed the plastic baffles that had restricted tunnel entrance sizes. We retained two pairs of snap traps (one pair at the site of the first night's successful snap trap capture) to maximise captures. On the final night, we added two more live traps based on the presence of kiore sign. All traps were baited with a mixture of peanut butter and rolled oats and checked each morning. Kiore captured in live traps were euthanased by cervical dislocation. With all snap traps and live traps combined, we completed 220 trap-nights (number of traps × number of nights they were set).

We estimated relative abundance of kiore using trap catch rates. Kiore capture rate was expressed as the number caught per 100 trap-nights, corrected for sprung traps including those that had caught kiore and non-target species (kiore per 100*CTN*: Nelson and Clark 1973). We estimated capture rates for each trap-type separately and for both types combined. Binomial 95%

confidence intervals (CI) for each index were estimated with the score test method (Wilson 1927) in the R package binom (Dorai-Raj 2015). We then compared the Mauitaha combined capture index against the 5th and 95th percentiles of past kiore snap-trap indices (n = 10) from other NZ islands that, like Mauitaha, are small, northerly, and lack stoats (*Mustela erminea*), feral cats (*Felis catus*), and other rat species. These included indices (n = 8) from islands 11–520 ha in area at 5.0–36.4°S compiled by Moller and Craig (1987), excluding one zero capture index from a very small island (<1 ha) in spring, when kiore numbers are generally low. They also included indices (n = 2) from Ririwhā (35.0°S, 123 ha) and Whakahau (37.1°S, 268 ha) (Stephenson and Slipper Islands, respectively; Table 1). Prior to calculating percentiles, capture indices were square-root transformed, as recommended for count-based data (Crawley 2002).

We captured 16 kiore (9 females and 7 males; Table S2) in 140 snap-trap-nights (138 *CTN*) and 80 live-trap-nights (72.5 *CTN*) in March (autumn) 2016. Of these, two kiore were caught in snap traps (1.4 kiore per 100*CTN*; trap-nights 2 and 3) and the remainder in live traps (19.3 kiore per 100CTN; trap-nights 3 and 4). The combined trap-catch index in both trap types was 7.6 (5–12 95% CI) kiore per 100*CTN*. This value is not unusually low nor high compared with information from other NZ islands; it lies within the 5th – 95th percentile range (1.8–55.3) of non-zero indices from 10 small northern islands lacking mammalian predators and other rat species (Fig. S1).

We used both snap and live trapping of kiore to provide an estimate of relative abundance. Of the two methods, live capture aligns more closely with traditional trapping methods that allow handling and inspection of live animals (Wilson 1877; Best 1908, 2005; Beattie 1994), and assessments of condition and palatability from pelage colour and coat condition, body size and

other visual indicators (Haami 1994; H. Parata, Ngātiwai elder, unpublished data 2011 and pers. comm. 2017), and results in the best long-term sustainable harvesting models (A. Monks, C. Stone and P. Wehi unpubl. data). A live-trap-catch index (the number of unique individuals captured) is generally related to population size (Slade and Blair 2000; McKelvey and Pearson 2001). Other benefits are that live-trapping allows release of unwanted captures, including underweight or juvenile individuals, and non-target species (e.g. lizards), as are also achieved in traditional live-trapping. Periodic monitoring to assess population trends and health, and thus modify long-term management as required, would help secure the future of Mauitaha's kiore population.

Relative abundance based on inked footprint tracking tunnels

Twelve inked footprint-tracking tunnels (Black Trakka; 100 x 100 x 500 mm; Gotcha Traps, Warkworth, NZ) were placed 50 m apart on the main trapline by Department of Conservation (DOC) staff 3 months prior to our visit, to allow kiore to become habituated to them. We increased the number of tunnels to 21 on the first night they were activated (the second night of trapping, above), and to 37–39 on nights 2–3 (22 m apart on average, alternating with trap stations), to further increase the chance of detecting kiore. Tunnels were baited with peanut butter and rolled oats placed on a leaf in the centre of each. Each morning they were checked for kiore tracks and rebaited if necessary. Tracks of lizards and invertebrates were recorded on the final day, representing the entire period. We calculated a one-night kiore tracking tunnel index on the basis of 16 tunnels (including the 12 tunnels in place since 3 months prior to our fieldwork) spaced 50 m apart (standard spacing in the rodent tracking protocol of Gillies and

Williams 2013), by omitting data from intervening tunnels. A binomial 95% CI for the index was estimated as described above.

Camera trapping: kiore behaviour at trap-tunnels

To test for the possibility that kiore were present but not entering traps, we mounted camera traps (Bushnell Trophy Cam™ Model 119576C; Bushnell Outdoor Products 2012) vertically (i.e. facing down), 1.7 m above tunnels containing traps (Nathan 2016). On the second trap-night, cameras were placed above each of two tunnels containing snap traps. On the third and fourth trap-nights, cameras were placed above each of nine tunnels containing live traps, including the two tunnels that had held snap traps. A camera was triggered when its passive infra-red motion sensor detected animal movement, in daylight or darkness. Once activated, cameras recorded video for 60 s and then paused for 5 s before they could respond to a new trigger (Nathan 2016).

We plotted histograms of elapsed time between consecutive camera triggers because a distinct peak of elapsed times shorter than a given duration could indicate repeat 'captures' of an individual on the same camera (Brook et al. 2012). However, our results did not demonstrate such a peak (Results), possibly because our camera settings ensured a minimum elapsed time of 65 s between consecutive triggers. Therefore, we made no assumptions about repeat captures, and analysed each video segment as an independent 'encounter' (nomenclature as in Nathan 2016). For each encounter, we identified four kiore behaviours in relation to the tunnel, based on Nathan (2016):

Approach	A directed movement towards the tunnel

Investigation	Interest indicated by closely sniffing or touching the tunnel
Interaction	A capture, i.e. entering the tunnel and the trap it contains
No approach	None of the above behaviours.

Our definition of interaction differed slightly from that of Nathan (2016), which required that a rat enter a tunnel containing an inactivated snap trap, in a manner that would result in a capture if the trap had been set. We also calculated a one-night camera-capture index for comparison to the capture and tracking indices. A binomial 95% CI for this index was estimated as described above.

Kiore activity based on footprint tracking indices and camera trapping

The standardised one-day kiore tracking index (n = 16 tunnels, 50 m apart) was 25% (95% CI 11–49%). This 25% rate was not affected by including tunnels placed during our fieldwork (n = 4) with those set out 3 months earlier (n = 12).

Cameras recorded 108 encounters with kiore at trap-tunnels containing live traps (Table S1). Kiore approached tunnels in approximately two-thirds of these encounters and investigated tunnels in the other one third (Table 4). We observed no interactions in which kiore were captured in the traps within tunnels. The one-night camera-capture index was 44% (95% CI 19–73%), i.e. 44% of our nine cameras captured a kiore encounter on the first night they were activated. Kiore were detected between 20:43 and 06:56 hours, i.e. after sunset (c. 19:35 hours) and before sunrise (07:25), but most video segments (92%) were triggered after midnight. Elapsed times (n = 94) between the beginning of consecutive video segments varied from 79 s to

6 h. The frequency of elapsed times was evenly distributed across the three categories 1–10 min, 10–20 min and >20 min, with about one-third of elapsed times in each category.

Cameras could be a useful tool to assess relative abundance, much as direct observations (or 'eyeballing') inform harvesting activities in many Indigenous cultures (e.g. Moller et al. 2004). Whether our one-night camera-capture index is a useful indicator of kiore abundance is not known and requires further study, and comparative indices from other islands are lacking for both camera traps and tracking tunnels. However, cameras or tracking tunnels may indicate kiore presence if none are captured in live traps, and annual or seasonal indices based on these methods could supplement live-capture indices to assess changes in relative abundance of kiore.

Because kiore are predominantly nocturnal and may also be active in the evening (Wilmshurst and Ruscoe 2021; Bramley 2014; H. Ricardo pers. obs.), we expected most to be active by the time darkness fell at c. 21:00 hours. Therefore, the triggering of most video segments after midnight suggests that we may have missed evening encounters during high ambient temperatures, when the cameras' passive infrared sensors were less able to detect animals (Bushnell Outdoor Products 2012). Increasing camera sensitivity to infrared (heat) and motion via sensor settings would minimise this issue. In addition to high evening temperatures, the 5-second delay that followed each 60-second recording may also explain why cameras did not record any kiore captures in traps.

Kiore disease status

Histopathological analysis confirmed inflammation of the liver or the liver and bile ducts in three of the 16 captured kiore, with nematodes or eggs presumed to be *Calodium hepaticum* (Table

S2). Inflammation of the bile ducts was identified in three additional kiore. Faecal samples contained only low numbers of parasites, which were unlikely to be significant pathogenically: of 14 samples, one contained a nematode (possibly *Heterakis spumosa*), two contained pinworms and one contained a cestode ovum (Table S2).

Calodium prevalence in kiore on Mauitaha (in summary, six of 16 kiore with inflamed livers and/or bile ducts, three of which had nematodes or eggs) was similar to forest on Tiritiri Mātangi, where it was found in 35–50% of immature kiore (highest in summer, December–March) and 50–60% of mature kiore (Roberts et al. 1992). On Mauitaha diseased kiore (especially females) had lower subcutaneous fat scores compared with non-diseased individuals, but we did not detect any effect of these inflammations on the relationship between body mass and HBL. The *Calodium hepaticum* (syn. *Capillaria hepatica*) nematodes found in Mauitaha kiore livers are widespread in rats (Hsu 1979; Roberts et al. 2013; Fuehrer 2014). In humans, *Calodium* can cause a liver disorder known as hepatic capillariasis. People harvesting wildlife that may harbour this parasite can avoid ingesting nematode eggs by maintaining hygienic conditions and access to clean drinking water, cooking food, and not consuming viscera (Camargo et al. 2010).

Table S1. Summary of numbers of camera traps, and encounters and behaviour of kiore recorded by camera traps at trap-tunnels on Mauitaha Island in March 2016. Percentages of camera encounters that showed key behaviours (see Methods) are also given. All encounters were recorded on trap-nights 3 and 4, in tunnels containing Elliott live traps. Two cameras set at tunnels containing snap traps on trap-night 2 did not record any encounters.

Type of summary	Component summarised	Count	%
Cameras	Cameras set	9	
	Cameras detecting kiore	7	
	Cameras not detecting kiore	2	
Encounters of kiore with trap-tunnels	Video segments with kiore	108	100
	One kiore in video segment	94	
	Two kiore in same segment	11	
	Three kiore in same segment	1	
Kiore behaviour at trap-tunnels	Approach	77	71
	Investigation	38	35
	Interaction (i.e. captured in trap)	0	0
	No approach	31	29

Table S2. Body measurements, reproductive details, liver histopathology and faecal parasites of kiore captured on Mauitaha in March 2016. 'Sample' identifies each animal for cross-reference with Table 2. Head and body length (HBL) was measured according to three different methods, (1) nose to pelvic girdle; known as the new British Museum method, Jewell & Fullager 1966), (2) nose to anus, (3) nose to end of furred part of upper tail (used for Aotea samples; JC Russell, personal communication). Females and males are listed separately, with reproductive details (for females, whether the vaginal opening was perforate or imperforate; for males, testes lengths). 'Pale regions on liver' indicates the possibility of disease. 'Liver histopathology' is the laboratory result from microscopic examination of liver tissue; where cholangitis indicates inflamed bile ducts, hepatitis indicates inflamed liver, and cholangiohepatitis indicates both. 'Faecal parasites' lists parasites identified in faecal droppings collected from the trap in which the individual was captured; dash means no sample.

					Head and body length (HBL) measurements						
Females	Sample	Sex	Weight (g)	Total length including tail	Nose to pelvic girdle	Nose to anus	Nose to end of fur on tail	Vaginal opening	Pale regions on liver	Liver histopathology	Faecal parasites

1	F	74	293	140	148	153	Perforate	Present	Cholangiohepatitis with intralesional presumptive *Calodium hepaticum* eggs, severe, chronic-active	—
3	F	99	284	133	138	142	Perforate	Present	Cholangiohepatitis with intralesional presumptive *Calodium hepaticum* eggs, severe, chronic-active	—
4	F	30	206	86	89	99	Imperforate	Absent	No significant findings	—

6	F	39	217	103	104	119	Imperforate	Absent	No significant findings	—
7	F	76	259	109	122	128	Imperforate	Absent	No significant findings	No parasites
8	F	47	228	102	106	110	Imperforate	Absent	No significant findings	1 nematode, possibly *Heterakis spumosa*
9	F	51	247	107	112	122	Imperforate	Absent	Cholangitis, mild, chronic-active	—
13	F	97	289	137	141	151	Perforate	Present	Hepatitis with intralesional sections of nematodes presumptive *Calodium hepaticum*,	—

										regionally extensive	
	16	F	78	275	122	131	137	Perforate	Present	No significant findings	—
Males	Sample	Sex	Weight (g)	Total length including tail	Nose to pelvic girdle	Nose to anus	Nose to end of fur on tail	Testes lengths (mm)	Pale regions on liver	Liver histopathology	Faecal parasites
	2	M	49	242	108	115	122	4.5, 4.5	Absent	No significant findings	No parasites
	5	M	29	210	93	98	105	5, 4.5	Absent	Cholangitis, mild, chronic-active	—
	10	M	24	192	88	95	99	5, 6	Absent	No significant findings	1 pinworm

11	M	66	258	117	128	134	7, 6	Absent	Cholangitis, mild, chronic-active	No parasites
12	M	60	243	107	117	122	6, 6	Absent	No significant findings	2 pinworms
14	M	62	252	117	123	128	5, 4	Absent	No significant findings	No parasites
15	M	18	173	80	84	90	5.5, 5	Absent	No significant findings	No parasites

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Figure S1. Kiore trap-catch indices on New Zealand offshore islands, as a function of island area, based on Appendix 2 in Moller and Craig (1987), and results from Mauitaha (our results), Ririwhā (P. O'B Lyver and C. Jones, unpublished data) and Whakahau (Ricardo *et al*. 2020). From data in Appendix 2 in Moller and Craig (1987) we calculated mean trap success weighted by effective trap nights, using midpoints where these were given as ranges. Circles show islands where no other rodents are present; squares show islands with kiore and other rodents; solid symbols show islands with no cats nor mustelids; open symbols show islands with cats or mustelids present. The solid circles and coloured symbols with 95% CIs (see legend) in the upper left region of the plot represent islands from latitudes 35.0–37.5° S.