Manaaki Whenua
Landcare Research

Bait delivery systems for control of dama and Bennett's wallabies

Part I: Investigation of current feeder designs

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Part I: Investigation of existing feeder designs

Contract Report: LC4377

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Summary

Project and client

- Manaaki Whenua – Landcare Research (MWLR), with assistance from 'Day in the Bush' contractors, was commissioned by the Ministry for Primary Industries on behalf of the Tipu Mātoro National Wallaby Eradication Programme to assess bait feeder designs for control of invasive dama and Bennett's wallabies. This report summarises a field trial aimed at identifying key parameters to be considered when designing or modifying wallaby bait feeders.
- Data on current bait feeder designs were collected in the South Canterbury and Rotorua districts between October 2022 and January 2023.

Objectives

- Assess the efficacy of two existing pellet feeder designs (Marley® hockey-stick and modified Philproof®).
- Compare the efficacy of ground vs. raised non-toxic Ferafeed® strikers.
- Collect preliminary data on two prototype bait feeders (Rotoplas™ and Spinner).
- Investigate whether possum carcases near bait feeders deter Bennett's wallabies from using the feeders.

Methods

- Fieldwork was undertaken at Titoki Estate near Rotorua (for dama wallabies) and Blue Cliffs Station in inland South Canterbury (for Bennett's wallabies).
- Feeding behaviour of wallabies and other wildlife at the four bait feeder designs was compared to their behaviour toward ground-laid wallaby pre-feed pellets.
- Wallaby behaviour was monitored using pairs of infrared trail cameras at 30–40 baiting sites: for 10 weeks at Titoki and 8 weeks at Blue Cliffs.
- We counted wallaby visits to each station and scored whether those visits resulted in investigation and subsequent feeding at the station. At 2-week intervals, each site received a different bait feeder treatment to control for differences in wallaby activity among sites.
- At Blue Cliffs, additional trials were run to collect preliminary data on Rotaplas™ and Spinner feeders and on the effect of the presence of possum carcases on wallaby feeding behaviour.

Results

- At Titoki, we recorded an average of 12.1 dama wallaby visits and 22.1 possum visits per station per week (for a total of 2,374 wallaby visits over 10 weeks). At Blue Cliffs, we recorded 26.1 Bennett's wallaby visits and 16.7 possum visits per station per week (for a total of 3,421 wallaby visits over the first 4 weeks).
- Activity of wallabies at the bait feeders peaked at dusk and declined as possums started using the feeders.

- For both wallaby species, the number of visits per week to each of the four feeder designs did not differ statistically from visits to pre-feed pellets on the ground.
- Feeding rate at strikers (whether on the ground or raised) was similar to feeding rates for pre-feed on the ground. The time taken for wallabies to begin interacting with strikers did not differ statistically between ground and raised strikers.
- Feeding rates were significantly reduced at Marley and Philproof feeders. Wallabies were reluctant to put their heads inside these enclosed feeder designs but learned to do so over time. Some juvenile dama wallabies could not access bait in Philproof stations 300 mm above ground.
- Bennett's wallabies were unable to extract pellets from the narrow mouth of the Rotoplas™ feeders and were deterred by the feeders' swinging motion when hung from tree branches.
- Bennett's wallabies readily fed on bait dispersed onto the ground by the Spinner, including during daylight hours, but were deterred by possum activity at the Spinner.
- The presence of a fresh possum carcase at a bait feeder led to an estimated 86% reduction in Bennett's wallaby interactions with that feeder over the subsequent week. Interaction rates rebounded during the second week, as the carcase decomposed or was scavenged.

Conclusions and recommendations

- We were unable to demonstrate a significant advantage of ground-laid strikers over strikers raised 20–30 cm above the ground on narrow wooden stakes. A toxic striker trial would be unlikely to find a meaningful difference in the kill rates achieved by these two methods.
- Designs that allow the timing of bait delivery to be controlled have some potential to exploit the different 24h activity patterns of Bennett's wallabies and possums. This approach is unlikely to be effective for dama wallabies.

Recommendations

- Designs that require wallabies to put their head into the bait station reduce feeding rates, although wallabies eventually learn to use such feeders. Stations with wide openings or 'tray' designs – mounted on stakes in open areas rather than on tree trunks – are therefore recommended.
- We recommend against using designs that require wallabies to use their forepaws to extract bait or stabilise the feeder.
- We recommend measures to reduce possum activity at bait feeders to increase wallaby feeding rates. We also recommend measures to minimise possum carcases lying near bait feeders.
- Bait feeders are often emptied of non-toxic bait by possums, rats and hedgehogs before wallabies get a chance to feed at them. To address this problem, we recommend that future bait feeder comparisons should trial pulses of toxic bait to suppress interference by non-target species.

1 Introduction

Manaaki Whenua – Landcare Research (MWLR), with assistance from 'Day in the Bush' contractors, was commissioned by Ministry for Primary Industries (MPI) on behalf of the Tipu Mātoro National Wallaby Eradication Programme to assess bait feeder designs for control of invasive dama and Bennett's wallaby populations. This report summarizes a non-toxic trial of several existing feeder designs that aimed to identify key parameters to be considered when designing or modifying bait feeders to better target wallabies. Data were collected in South Canterbury and Rotorua district between October 2022 and January 2023.

2 Background

Bennett's wallabies (*Notamacropus rufogriseus*) were liberated on the east of The Hunters Hills, near Waimate, in 1874. The initial spread of Bennett's wallabies was within a 'containment area' bounded by natural geographic features (Latham et al. 2019a) but low-density populations have subsequently emerged over a much larger area of Canterbury and Otago (Latham & Latham 2022). Dama wallabies (*Notamacropus eugenii*) were liberated in Rotorua district in 1912 and again in 1940 and have since expanded in abundance and geographic range in that region (Latham et al. 2019a).

Dama and Bennett's wallabies are primarily grazers, supplementing their diet with browse when in scrub and forest habitats. Feeding activity is predominantly crepuscular and nocturnal. Both species are considered significant pests of agriculture, silviculture, and native vegetation – and so have been subject for many years to ongoing control measures, including by shooting, aerial poison baiting, and application of poison baits in bait stations.

Bait stations containing pelleted cereal baits are a well-established control method in New Zealand for invasive possums (*Trichosurus vulpecula*) and wallabies, but the approach is less effective for wallabies, in part because wallabies do not use their paws to extract pelleted bait from enclosed feeder designs (compare Figures 1a, b). Wallabies are also thought to exhibit greater vigilance and neophobia than possums, resulting in reluctance to feed from enclosed feeders that block their vision and hearing.

To investigate the impact of different station designs on wallaby behaviour, Williams (1997) undertook dama wallaby pen trials on three bait station types (Philproof®, 1 kg ACP®, and Marley® hockey-stick) and reported a preference for the hockey-stick design. Henderson et al. (2014) found that the highest bait consumption by penned dama wallabies was of bait laid on the ground, in strikers, and in hockey-stick feeders. Henderson et al. (2014) also reported that Philproof feeders modified by enlarging the entrance hole were more effective than standard Philproof feeders. However, these pen studies are not necessarily representative of how free-ranging wallabies react to bait stations. Furthermore, neither study included investigation of Bennett's wallabies, which are significantly larger than dama wallabies (mean adult female weights of the two species are 11 kg and 5 kg, respectively; Latham & Warburton 2021).

a) b)

Figure 1. Typical feeding stances at a Marley® hockey-stick feeder: a) Bennett's wallaby; b) brushtail possum. Wallabies rarely use their paws to extract pellets from this type of enclosed feeder.

A key function of traditional bait feeder designs is to provide weather protection for pelleted cereal baits, which degrade rapidly if left unprotected from rain and dew. In recent years, Ferafeed® and Feratox® 'striker' baits – have been developed as an alternative approach to improve weather resistance of possum and wallaby baits. The Ferafeed striker consists of a palatable wax coating surrounding a peanut butter paste to which toxic cyanide capsules can be added. Strikers are designed to be stapled to trees or posts, without the need for an additional protective enclosure. Agricultural Compounds and Veterinary Medicines (ACVM) regulations require that toxic strikers be installed >20 cm above ground level. Based on informal observations of strikers dropped onto the ground by possums, there has been speculation that wallabies are more willing to feed on strikers on the ground than strikers raised as currently required.

It has also been suggested (R. Harland, GWRC, pers. comm., 28 November 2022) that wallabies are deterred by possum carcases, so that they are less likely to visit a station where possums eating fast-acting Feratox died beside the station.

To address these information gaps, MPI – on behalf of the Tipu Mātoro National Wallaby Eradication Programme – commissioned MWLR to evaluate current bait station designs to identify parameters that need to be considered when designing or modifying bait stations to better target wallabies. The Ministry also requested an assessment of the relative efficacy of raised vs. ground delivery of non-toxic Ferafeed strikers for both wallaby species, as a first step towards a potential raised- vs. ground-deployed Feratox striker trial. If the Ferafeed (and later Feratox) trial results were promising, these data could support an AVCM application for a variation to allow ground deployment of Feratox strikers.

3 Objectives

- Assess the efficacy of two existing pellet feeder designs (Marley hockey-stick and modified Philproof).
- Compare the efficacy of ground vs. raised non-toxic Ferafeed strikers.
- Collect preliminary data on two prototype bait feeders (Rotoplas and Spinner).
- Investigate whether possum carcases near bait feeders deter Bennett's wallabies from using the feeders.

4 Methods

4.1 Field sites

Bait feeder observations were carried out at Titoki Estate near Rotorua (for dama wallabies) and at Blue Cliffs Station in inland South Canterbury (for Bennett's wallabies).

Titoki Estate is a privately owned farm within the dama wallaby core area, north-east of Rotorua. The site has a low-intensity livestock operation, with areas of the property retired from farming. The property includes substantial areas of native forest, pine forest, scrubland, pasture, restoration plantings and wetlands, all of which provide suitable habitat for wallabies. Aside from some limited recreational shooting, the wallaby population on the farm had been relatively undisturbed before this trial. Possums are common in the wallaby habitat and surrounding forest at Titoki so, in preparation for the trial, possum numbers around the trial sites were lowered using methods that did not affect wallaby numbers (i.e., a combination of leg-hold traps and night-shooting). Over the 3-month period prior to the trial, over 350 possums were trapped, and 186 possums were shot during several night-shoots. Possum control efficacy was not formally measured, but nightly possum encounters had been reduced by >90% by the end of the night-shooting.

Blue Cliffs Station, 30 km south-west of Timaru, is a livestock operation on hilly farmland with short and tall tussock, matagouri scrub, and remnant forest in gullies dominated by māhoe (*Melicytus lanceolatus*) and broadleaf/kapuka (*Griselinia littoralis*). The site has high numbers of Bennett's wallabies and has been used previously for a trial of wallaby surveillance methods (Latham et al. 2019b). The farm is hunted for wallabies periodically by contract shooters and occasionally by recreational hunters. Possum populations at the site had been reduced in recent years as part of OSPRI's TB control programme but were rebounding at the time of our trial. Access to Blue Cliffs was restricted during lambing so observations began there several weeks later than at Titoki. During the trial, cattle were excluded from the site, but sheep grazed near some bait feeders.

4.2 Bait station treatments

We assessed two existing pellet feeder designs (modified Philproof and Marley hockey-stick), and two Ferafeed striker presentations (raised and ground-laid). Wallaby feeding activity at each was compared to their 'baseline' feeding on pre-feed pellets on the ground (Figure 2). These five application methods are hereafter referred to as 'treatments':

Treatment A – Pellets in Marley hockey-stick feeder: this feeder was constructed from grey Marley downpipe (80 mm diameter) and fittings (https://www.marley.co.nz/products/rainwater/downpipes/rp80/; Figure 3a). The feeder, containing 1 kg of Pestoff® wallaby pre-feed pellets, was wired to a waratah or wooden stake that supported it 30 cm or 50 cm above the ground (height measurements are for dama and Bennett's wallabies, respectively).

Treatment B – Pellets in Modified Philproof feeder: this was a commercially available white plastic feeder (Possum Bait Station Large Gen II; https://www.philproof.co.nz/possum-bait-station-large-gen-ii.html) modified by enlarging the entrance (Figure 3b). The station, containing 1 kg of pre-feed pellets, was installed in the same manner as the Marley feeders.

Treatment C – Raised Ferafeed strikers: eight Ferafeed strikers (18 g; https://www.connovation.co.nz/products/ferafeed-striker-18g-213-paste-backing-card) were stapled to a wooden stake that raised the bottom of the lowest strikers 20 cm or 40 cm above ground level (Figure 3c).

Treatment D – Ground-laid Ferafeed strikers: eight Ferafeed strikers nailed to board that was then pegged to the ground (Figure 3d).

Treatment E – Ground-laid pre-feed pellets: a 1 kg pile of Pestoff® 16 mm RS5 wallaby pre-feed pellets (https://orillion.com/products/) placed on the ground beside a short stake (Figure 2).

At Blue Cliffs, we collected preliminary data on two additional prototype feeder designs:

Rotoplas™ feeder: this prototype plastic feeder (Figure 4a) was developed by Rotoplas™ Canterbury (https://rotaplas.co.nz/). Two feeders, each containing 1 kg of pre-feed pellets, were initially hung from tree branches at Blue Cliffs with their bases 50 cm above ground level. Preliminary observation indicated that wallabies could not extract pellets from freely swinging feeders, so additional observations were made on Rotoplas feeders wired firmly to waratahs at the same height.

Spinner: MWLR built this prototype feeder (Figure 4b) by modifying a Moultrie® All-In-One Programmable Feeder Kit (https://www.moultriefeeders.com) to dispense cereal pellets. This was done by attaching a 5 kg capacity bait hopper and replacing the kit motor with a 30 rpm high torque motor. The feeder, containing 1 kg of pre-feed pellets, was programmed to dispense c. 20 pellets daily at 00:00 h and again at 12:00 h. Two Spinners were initially hung from tree branches and later wired to pairs of waratahs with their base c.120 cm above ground level.

Figure 2. The ‘baseline’ treatment, consisting of 1 kg of Pestoff® 16mm RS5 wallaby pre-feed pellets on the ground and monitored by two infrared trail cameras.

Figure 3. The four designs evaluated at both sites: a) Marley® hockey-stick; b) modified Philproof® feeder; c) raised Ferafeed® strikers; d) ground-level Ferafeed® strikers.

a) b)

Figure 4. The two prototype designs evaluated at Blue Cliffs: a) Rotoplas™ feeder; b) Spinner.

4.3 Bait station layout and treatment replication

At both field locations, replicates of the five treatments were deployed at 200 m intervals along transects (Figures 5 a, b). Sites were located near wallaby runs and pads so that wallabies would pass by feeders twice on most nights, on their way to and from bedding and feeding areas. The Rotoplas feeders and Spinners were trialled separately in wallaby habitat near to the Blue Cliffs transects.

At Titoki, 6 replicates of each of the 5 treatments (i.e. n = 30) were observed for 10 weeks (i.e. 60 station-weeks of observation per treatment). At Blue Cliffs, where deployment of stations was delayed by lambing, 8 replicates of each of the 5 treatments (i.e n = 40) were observed for 8 weeks (i.e. 64 station-weeks of data per treatment). At Blue Cliffs, very high rates of wallaby visitation were recorded relative to the Titoki trial, so only the first 4 weeks of Blue Cliffs data were analysed.

At 1-week intervals, any pellets and strikers remaining at each site were weighed (to nearest 50 g), and missing bait was replaced. This meant that bait-take per site was capped at a maximum of 1 kg of pellets – or 8 strikers per week. At 2-week intervals, treatments and controls were rearranged along the transect, using a semi-randomised layout that ensured that every site received a different treatment from the preceding 2 weeks (Figure 6).

Wallaby feeding behaviour each treatment was monitored with infrared cameras, as described in Section 4.5.

a)

b)

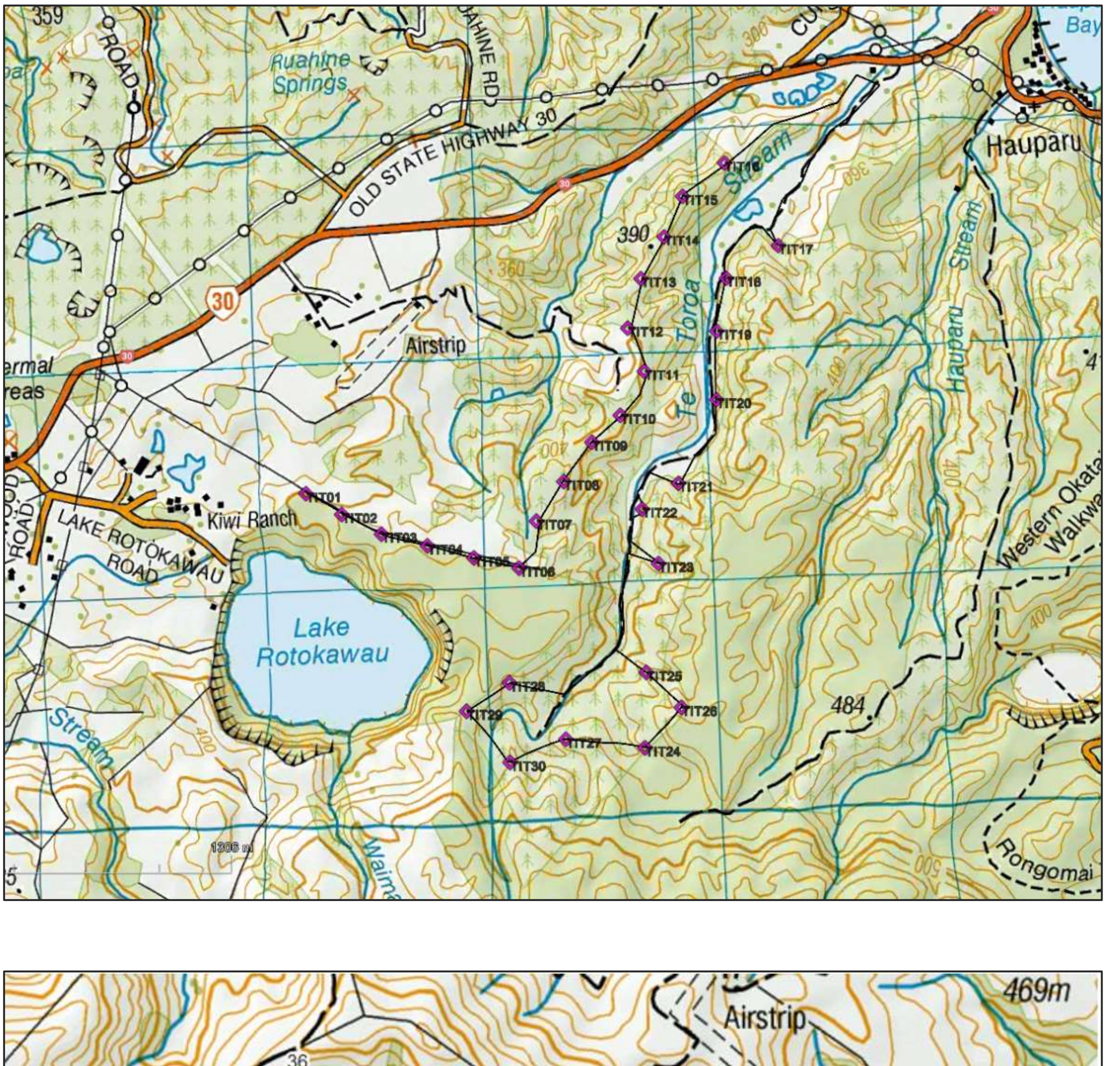

Figure 5. Treatment sites spaced at c. 200 m intervals along transects at: a) Titoki Estate (*n* =30); b) Blue Cliffs Station (*n* = 40). Base layers sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 International licence.

a) Titoki Estate

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	E	D	B	A	C	C	A	E	D	A	E	E	D	C	B	A	E	A	C	B	D	A	D	B	C	B	D	C	B	E
2	E	D	B	A	C	C	A	E	D	A	E	E	D	C	B	A	E	A	C	B	D	A	D	B	C	B	D	C	B	E
3	C	B	D	E	B	A	B	B	E	C	D	C	B	B	A	D	C	E	A	D	C	D	E	C	E	D	E	A	A	A
4	C	B	D	E	B	A	B	B	E	C	D	C	B	B	A	D	C	E	A	D	C	D	E	C	E	D	E	A	A	A
5	D	A	C	B	D	B	C	D	A	B	A	A	E	A	C	E	D	B	D	E	B	C	C	E	B	E	A	E	C	D
6	D	A	C	B	D	B	C	D	A	B	A	A	E	A	C	E	D	B	D	E	B	C	C	E	B	E	A	E	C	D
7	B	E	A	D	A	E	E	C	C	E	C	B	A	D	D	B	A	D	B	C	A	E	B	D	D	A	C	B	E	C
8	B	E	A	D	A	E	E	C	C	E	C	B	A	D	D	B	A	D	B	C	A	E	B	D	D	A	C	B	E	C
9	A	C	E	C	E	D	D	A	B	D	B	D	C	E	E	C	B	C	E	A	E	B	A	A	A	C	B	D	D	B
10	A	C	E	C	E	D	D	A	B	D	B	D	C	E	E	C	B	C	E	A	E	B	A	A	A	C	B	D	D	B

Treatment

A	Marley hockey-stick
B	Modified Philproof
C	Raised strikers
D	Ground strikers
E	Ground pellets

b) Blue Cliffs Station

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	E	D	B	A	C	E	A	E	D	A	C	E	D	C	B	A	E	A	C	E	D	A	D	B	C	B	D	C	B	C	B	E	A	D	B	A	B	D	C	E
2	E	D	B	A	C	E	A	E	D	A	C	E	D	C	B	A	E	A	C	E	D	A	D	B	C	B	D	C	B	C	B	E	A	D	B	A	B	D	C	E
3	A	B	D	E	B	A	B	D	E	C	D	C	A	B	A	D	C	E	A	D	C	D	E	C	E	D	E	B	A	B	A	C	E	B	E	D	A	C	B	D
4	A	B	D	E	B	A	B	D	E	C	D	C	A	B	A	D	C	E	A	D	C	D	E	C	E	D	E	B	A	B	A	C	E	B	E	D	A	C	B	D
5	D	A	C	B	D	B	E	D	A	B	A	D	E	A	C	E	D	B	D	C	B	E	C	A	B	E	A	E	C	D	E	D	B	A	D	A	C	B	E	C
6	D	A	C	B	D	B	E	D	A	B	A	D	E	A	C	E	D	B	D	C	B	E	C	A	B	E	A	E	C	D	E	D	B	A	D	A	C	B	E	C
7	C	E	A	D	A	C	D	B	E	C	B	A	B	D	E	C	A	C	E	B	E	C	B	D	A	C	B	D	E	A	D	B	D	C	A	E	D	E	A	B
8	C	E	A	D	A	C	D	B	E	C	B	A	B	D	E	C	A	C	E	B	E	C	B	D	A	C	B	D	E	A	D	B	D	C	A	E	D	E	A	B

Figure 6. Allocation of the five treatments (A–E) to *n* = 30 sites at Titoki and *n* = 40 sites at Blue Cliffs. The extra sites at Blue Cliffs compensated for access at that site in October 2022 being restricted by lambing.

4.4 Effect of possum carcases on wallaby behaviour

During the final 2 weeks of the Blue Cliffs trial (mid-January 2023), fresh possum carcases obtained from a local pest control contractor were placed beside a subset of the bait stations for either one week (*n* = 12) or two weeks (*n* = 8). Sites were selected semi-randomly, with carcases placed at 4 stations of each treatment type. Notes were kept on subsequent carcase decomposition. The wallabies' responses to the carcases were monitored with cameras, as described in Section 4.5.

4.5 Camera monitoring

Each feeding site was monitored with a pair of Reconyx Hyperfire 2 Covert IR trail cameras (http://reconyx.com). Cameras were placed 2.0 m and 3.5 m from each bait feeder, at 45-degree angles from the front of the station (see Figure 1). Analysis of continuous video from 60–80 cameras for 8–10 weeks would have been logistically infeasible, so cameras were set to record 5 still images per triggering event, with 'no delay' between events (The actual retriggering delay was approximately 0.4 s, providing short bursts of 'near video' imagery). PIR sensitivity was set to 'high', and the image capture schedule was set to 'day/night', which produced colour images during the day and monochrome infrared-illuminated images at night.

During each trip to refill the bait stations, the previous week's images were retrieved, and camera batteries were checked and replaced where necessary.

4.6 Image analysis and statistical analysis

We analysed 2.2 million images at Titoki and 1.8 million images at Blue Cliffs, with several measures taken to achieve a tractable workload for image analysis. SD cards were downloaded to a fast hard drive, with images from the 2.0 m cameras only used as backup (for example, if clambering possums altered a 3.5 m camera's angle of view). Thumbnails from the 3.5 m cameras were scanned to identify and delete images triggered by wind-blown vegetation or livestock. For each remaining image, the date and time were extracted from metadata into an Excel spreadsheet. An Excel macro then assigned each image to a unique 'visit' and calculated visit duration, with a 'visit' defined as a sequence of images of a single species (either one or several individuals) in which successive images were separated by intervals of no more than 5 min. Animals making repeat visits to stations were not individually identifiable, so visitation rate is an index of animal activity rather than abundance.

For each visit, a researcher manually scanned the images and recorded the number of animals seen, whether multiple species were present, and whether any interactions between species occurred. For each visit by wallabies, the researcher also recorded whether the bait station was investigated and if so whether bait was eaten. Once all bait had been removed from the site, subsequent images for that week were disregarded. We did not attempt to quantify bait take by wallabies, as bait was also being consumed by visiting possums and other non-target species, but we recorded the number of days it took for all bait to be removed from each feeder.

For each week of the study, we calculated wallaby visits per site (i.e. the total number of wallabies seen during each visit, summed for the week) and the proportions of those wallabies that investigated and fed at the station.

We used linear mixed-effects models (*lmer* function in R; R Core Team 2023) to control for differences in location (SITE as a random effect) and trends over time (WEEK) while testing for an effect of TREATMENT on: i) the weekly number of wallaby visits; ii) the proportion of wallaby visits resulting in bait consumption. If the treatment effect was significant, we proceeded to a post hoc comparison of each treatment mean against the baseline treatment (E). Data were log-transformed for analysis and back-transformed for visualisation.

To further investigate whether wallabies responded differently to strikers on the ground vs. those on raised on stakes, we calculated the number of hours elapsing between striker deployment and the first wallaby interaction (we termed this *latency*). If all strikers had been removed by other species before the first wallaby visit, the site was excluded from analysis. We again used *lmer* to test for significant differences in latency between wallaby species, over successive weeks, and between raised and ground deployment of strikers. We graphed marginal means (obtained using proc *emmeans*) to visualize the effect of the three factors on latency.

5 Results

For the 10-week Titoki study, we analysed all wallaby visits and the majority of visits by other species. The resulting data set comprised 10,605 wild mammal visits to the 30 bait feeders, of which 22% were dama wallabies (*n* = 2374), 63% were possums, 8% were hedgehogs and 7% were rats. This represented an average visitation rate of 12.1 wallabies and 22.1 possums per station per week. Other wildlife seen occasionally at the stations included feral cats, rabbits, hares, deer, pigs, goats, and several bird species.

The 40 feeders at Blue Cliffs were monitored for 8 weeks but here we report results for the first 4 weeks only. We recorded 6,548 wild animal visits to feeders, of which 52% were Bennett's wallabies (*n* = 3,421), 41% were possums and 5% were hedgehogs. This represented an average visitation rate of 26.1 wallabies and 16.7 possums per station per week. Other non-target wildlife seen at stations included red deer, feral pigs, rabbits, hares, rodents, feral cats, ferrets, stoats, and several bird species.

At both study areas, wallabies visited feeders at all hours of day, but with pronounced early evening and near-dawn activity peaks (Figure 7).

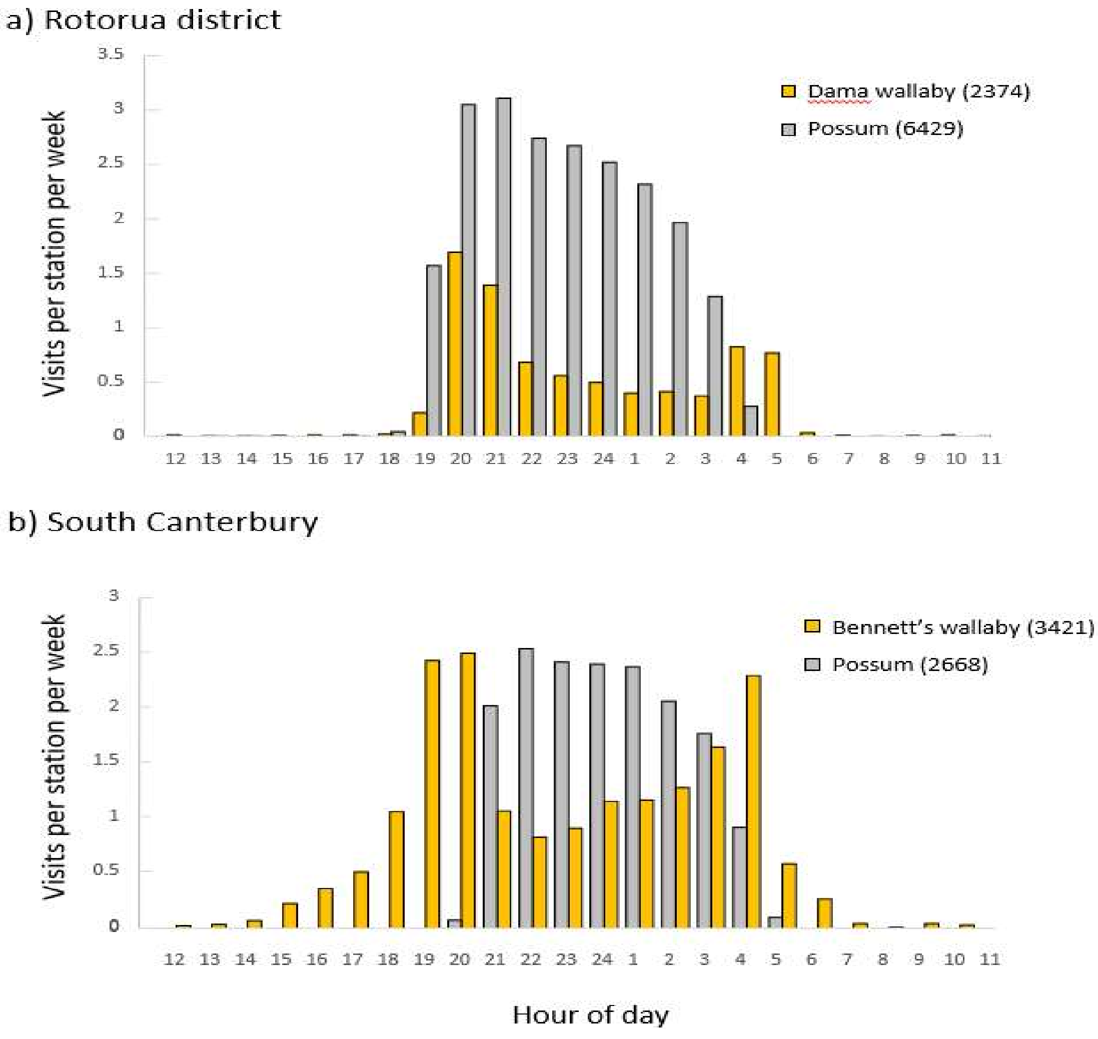

Figure 7. Wallaby and possum hourly activity at bait feeders: a) at 30 stations monitored for 10 weeks at Titoki (Rotorua district); b) at 40 stations monitored for 4 weeks at Blue Cliffs (South Canterbury). Total number of visits shown in parentheses.

Dama wallaby activity began to increase at 17:00 h and peaked at 20:00 h; Bennett's wallaby activity increased earlier, from 15:00 h onwards, and peaked at 20:00 h. For the next several hours, possums dominated the stations at both study areas and wallaby activity declined. From around 03:00 h, as possums left the feeders, there was a resurgence in wallaby activity that lasted until dawn.

5.1 Wallaby behaviour at the four feeder treatments

There was no measurable difference in the number of *visits* made by either wallaby species to the four feeder treatments versus RS5 pellets on the ground (Tables 1, 2). There were also no statistically significant differences in *feeding rates* at ground strikers and raised strikers versus RS5 pellets on the ground.

Dama wallabies were, however, significantly less likely to investigate and feed at Marley and Philproof feeders versus RS5 pellets on the ground (Table 1). We estimate that feeding rate (i.e., the product of number of visits and proportion feeding) was reduced by 59% at Marley feeders and by 63% at Philproof feeders (these reductions were marginally non-significant statistically). We noticed that some juvenile dama wallabies were unable to feed from Philproof feeders set 300mm above ground level (Figure 8).

Table 1. Total number of dama wallabies visiting each feeder type at Titoki October–December 2022, with the proportions that investigated and fed at the feeders and the mean feeding rate per station per week (n = 10 weeks). Asterisks indicate post hoc statistical comparisons with RS5 pellets on ground: * $P < 0.05$, ** $P < 0.01$.

Feeder type	Wallaby visits	Proportion investigating	Proportion feeding	Feeding events per week (± SEM)
All feeders	**2,374**	**43.3%**	**23.6%**	**2.0 ± 0.4**
Pellets on ground	482	51.7%	36.8%	3.2 ± 0.9
Strikers on ground	392	59.7%	33.8%	2.3 ± 1.1
Raised strikers	341	46.9%	30.7%	1.9 ± 0.5
Marley feeder	398	39.8% *	18.4% **	1.3 ± 0.7
Philproof feeder	761	28.5% *	8.2% **	1.2 ± 0.7
Overall statistical difference among treatments	$F_{4,44} = 1.42$ $P = 0.24$	$F_{4,44} = 3.23$ $P = 0.021$	$F_{4,44} = 5.74$ $P < 0.001$	$F_{4,44} = 2.10$ $P = 0.09$

Figure 8. A juvenile dama wallaby attempting unsuccessfully to feed at a Philproof® feeder mounted 300 cm above ground level.

Similarly, Bennett's wallabies were less likely to feed at Marley and Philproof feeders than on RS5 pellets on the ground (Table 2). We estimate that there was a statistically significant 72% reduction in feeding rate at Marley feeders ($P < 0.05$) and a highly significant 88% reduction in feeding rate ($P < 0.01$) at Philproof feeders (Table 2).

Table 2. Total number of Bennett's wallabies visiting each feeder type at Blue Cliffs November–December 2022, showing the proportions that investigated and fed at the feeders and the mean feeding rate per station per week (*n* = 4 weeks). Asterisks indicate post hoc statistical comparisons with RS5 pellets on ground: * *P* < 0.05, ** *P* < 0.01.

Feeder type	Wallaby visits	Proportion investigating	Proportion feeding	Feeding events per week (± SEM)
All feeders	**3,421**	**63.4%**	**20.5%**	**4.7 ± 0.8**
Pellets on ground	789	63.6%	33.7%	8.3 ± 1.9
Strikers on ground	570	71.2%	34.6%	6.3 ± 1.2
Raised strikers	760	59.3%	22.0%	5.5 ± 1.9
Marley feeder	760	60.5%	9.3% **	2.3 ± 0.9 *
Philproof feeder	542	65.5%	5.8% **	1.0 ± 0.4 **
Overall statistical difference among treatments	$F_{7,12}$ = 1.01 P = 0.44	$F_{7,12}$ = 1.76 P = 0.19	$F_{7,12}$ = 8.43 P < 0.001	$F_{7,12}$ = 8.09 P = 0.0013

At Titoki, where many more possums than wallabies were visiting the feeders, 100% of bait was removed from every feeder every week. At Blue Cliffs, there were highly statistically significant differences (P < 0.001) in the amount of bait taken from the different feeder treatments, with a strong curvilinear relationship between the average percentage of bait removed each week and the average time it took feeders to be emptied of bait (Figure 9). For example, not much bait was removed from Philproof feeders and they were rarely emptied, whereas some strikers on the ground were entirely consumed within 2 or 3 days. Once feeders had been emptied (usually by possums) later-arriving wallabies had no access to bait.

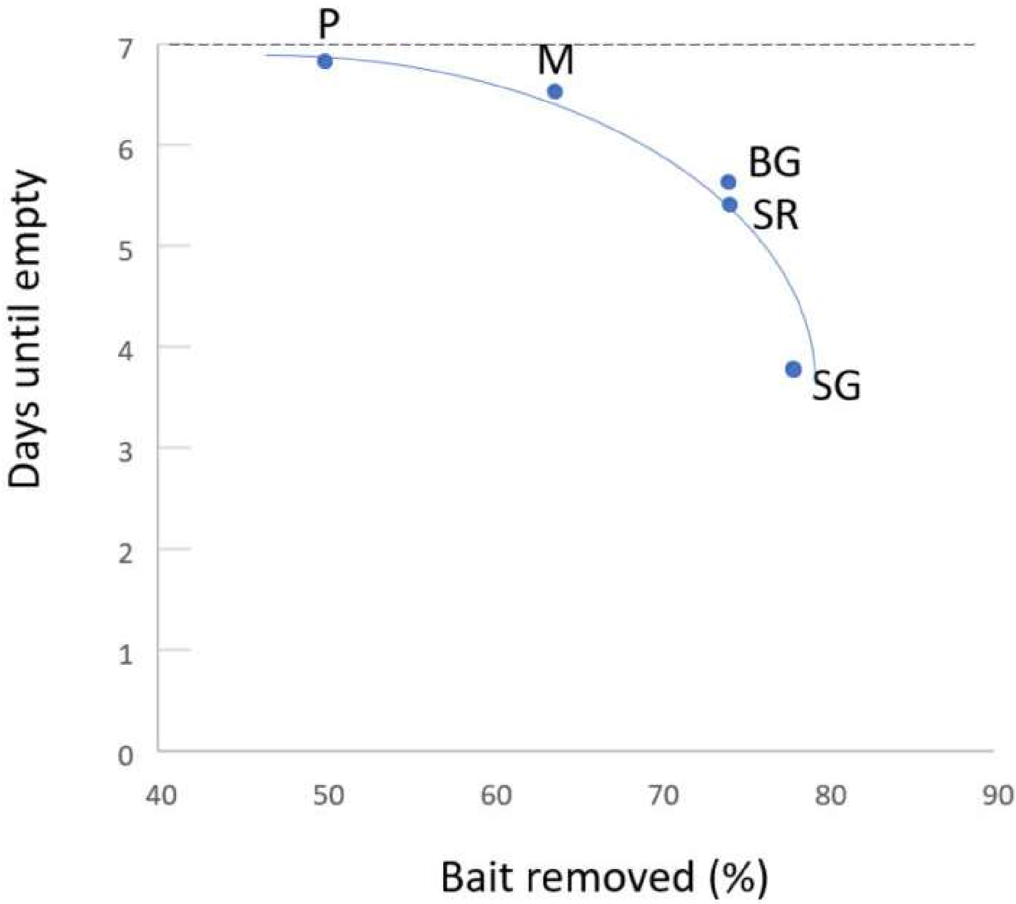

Figure 9. The relationship at Blue Cliffs between average weekly bait take (limited to a maximum of 1 kg of pellets or 8 strikers) and the average time for feeders to be emptied of bait (maximum of 7 days, as feeders were refreshed at weekly intervals). Codes: BG – RS5® bait on the ground; SG – strikers on the ground; SR – strikers raised on stakes; M – Marley® feeders; P – Philproof® feeders (P).

5.2 Wallaby interactions with raised versus ground-laid strikers

As noted in Section 5.1, we found no statistically significant difference in the rate at which wallabies fed on raised vs. ground-deployed strikers. We also investigated how long it took for wallabies to arrive and begin interacting with the two striker treatments, following each weekly refresh. This latency period was, on average, longer for Bennett's wallabies than for dama wallabies, and longer during the first week of the study than in later weeks. However, we did not detect a statistically significant difference in wallabies' latency to interact with ground-deployed vs. raised strikers (Figure 10).

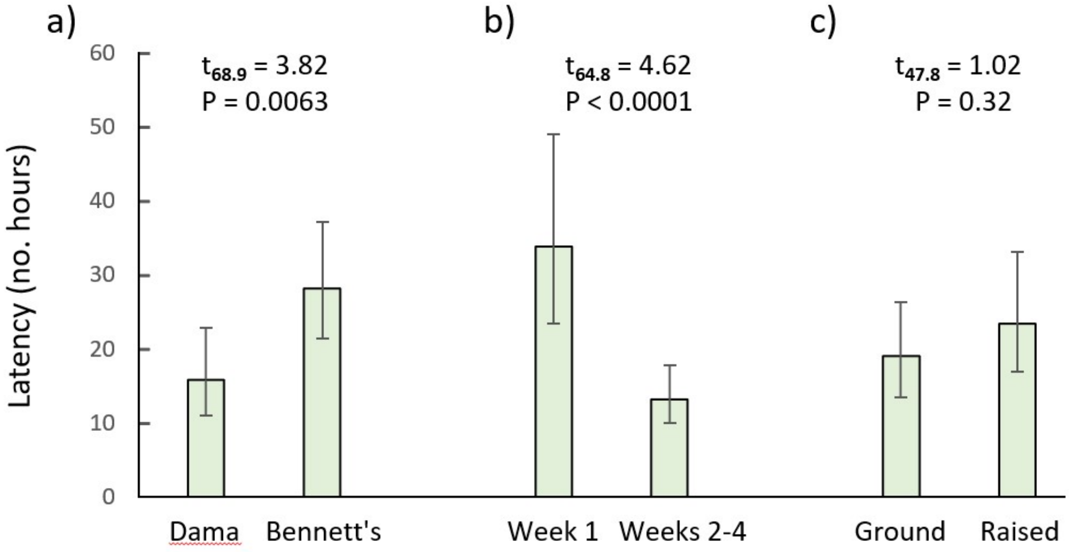

Figure 10. Latency to feed on strikers for: a) dama vs Bennett's wallabies; b) first week vs later weeks; c) ground-laid vs raised strikers. Latency was measured from noon on the day strikers were deployed, so latencies of 6–18 hours correspond to interactions during the first night fresh strikers were available. Data presented are marginal means ±95% confidence intervals.

When Rotoplas feeders were hung from tree branches at Blue Cliffs, they were largely avoided by Bennett's wallabies, with only 23 visits recorded. Of these, only 3 led to investigation the feeder (e.g. Figure 11a) and no wallaby successfully fed. We suggest three reasons for this lack of interest: i) there was high possum activity at the feeders that deterred wallabies; ii) wallabies were deterred by the motion of the feeder as it swung on the tree branch; iii) there was no feasible way for the wallabies to extract baits from the narrow feeder opening, as they did not use their paws to steady the feeder (Figure 11b).

In contrast, possums used their paws to try to extract bait from the Rotoplas (Figure 12a) and frequently hung from the tree branch to try to gain access to pellets (Figure 12b). Possums nevertheless had great difficulty in removing wallaby-sized baits from the Rotoplas, as its opening was designed for smaller possum pellets. Possums consequently spent large amounts of time fussing around the still-full Rotoplas and this activity appears to have kept wallabies away from the feeders.

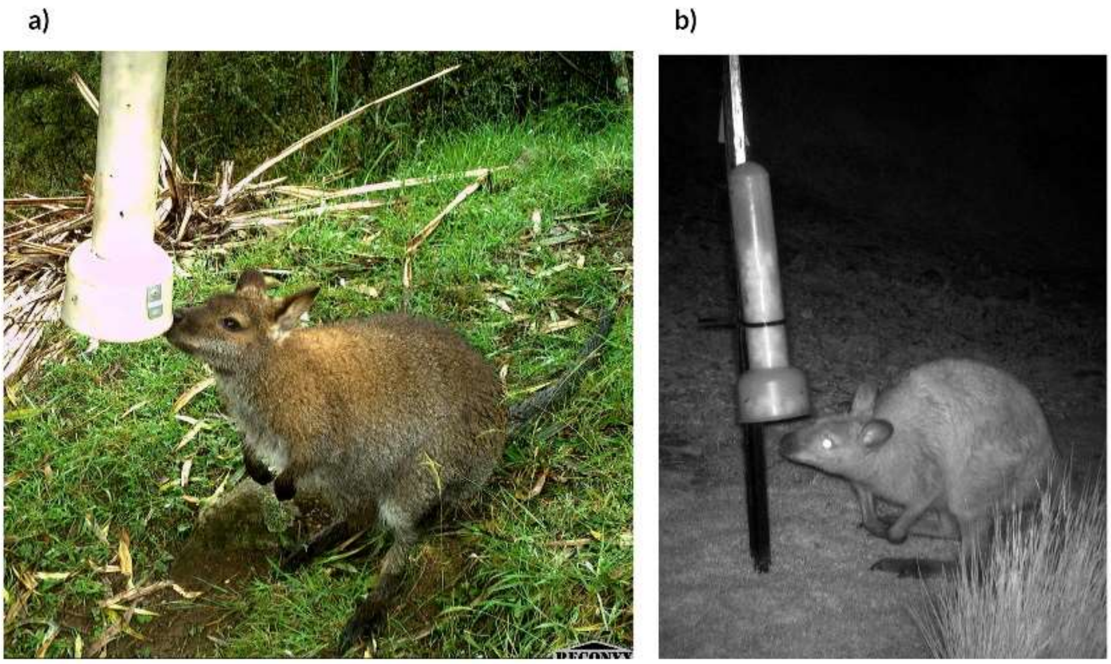

Figure 11. Bennett's wallabies interacting with Rotoplas™ feeders: a) feeder hanging from a branch; b) feeder wired to a waratah.

Given these unpromising initial results, the Rotoplas feeders were later wired firmly to waratahs and relocated to higher elevation sites where possums were less abundant. In this new setting, we recorded much higher numbers of wallaby visits to the feeders but nevertheless saw no successful feeding. Unlike possums, the wallabies did not use their forepaws to try to extract pellets (compare Figures 11b and 12c).

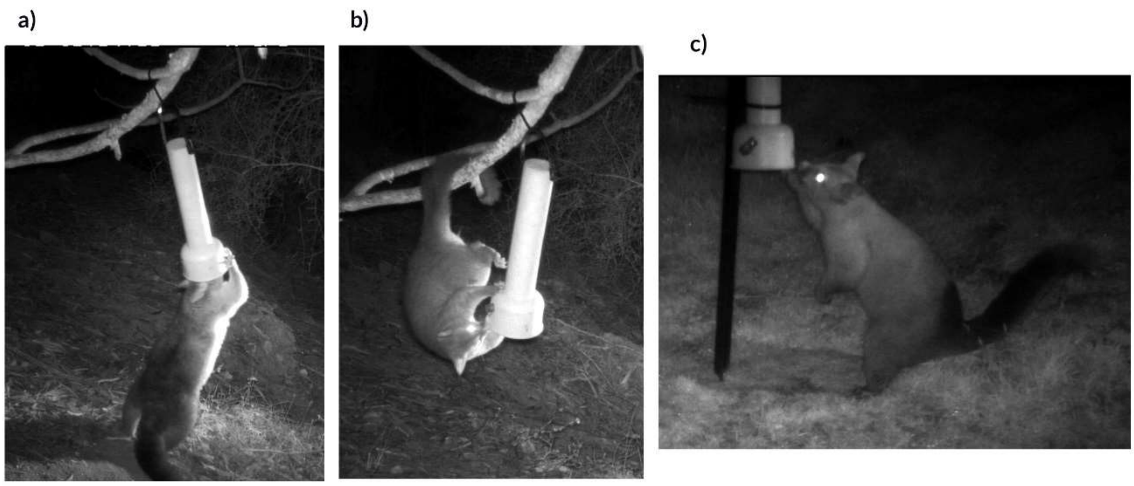

Figure 12. Possums interacting with Rotoplas™ feeders: (a, b) a hanging Rotoplas™ feeder; (c) a rigid Rotoplas™ feeder wired to a waratah.

5.3 Preliminary observations on Spinner feeders

Spinners were initially hung from tree branches at sites with abundant possums. As was the case with the nearby Rotoplas feeders, few wallabies were seen at these Spinners, which were quickly emptied of pellets by possums. On two occasions, possums were recorded climbing onto a Spinner (Figure 13a), causing additional pellets to spill – and in one case prying off the spinner's lid. Both Spinners were emptied within 2 nights.

On Week 5, the Spinners were moved to higher elevation sites with less possum activity, and instead of being hung from trees were wired firmly between a pair of waratahs (Figure 4b). Following this change we saw extensive feeding by wallabies (both night and day) on the pellets dispersed by the spinner. It was common for two or three wallabies to feed side-by-side on the Spinner baits (Figures 13 b,c).

Possums also fed at the Spinners, but wallabies exhibited a much wider range of feeding times at the Spinners, including some daytime feeding (Figure 14). Since the Spinner dispensed feed at midday as well as midnight, this meant that wallabies had several hours of undisturbed access to pellets before possums became active in the evening.

Following heavy rain at Blue Cliffs in December 2022 and January 2023, water seeped into the electronics of both Spinners and they eventually stopped operating.

a) b) c)

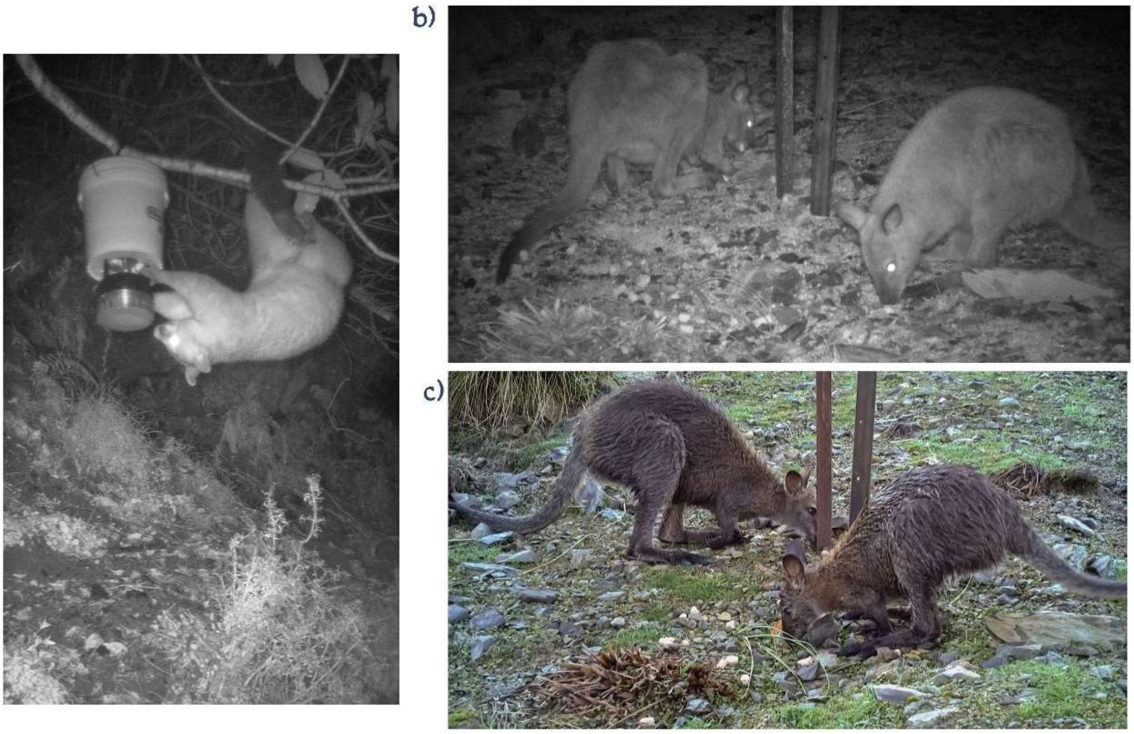

Figure 13. Possums and wallabies interacting with Spinners: (a) a possum extracting pellets from a hanging Spinner; (b) Bennett's wallabies feeding on pellets dispensed onto the ground by a Spinner; (c) Bennett's wallabies feeding on pellets dispensed by a Spinner wired to a pair of waratahs.

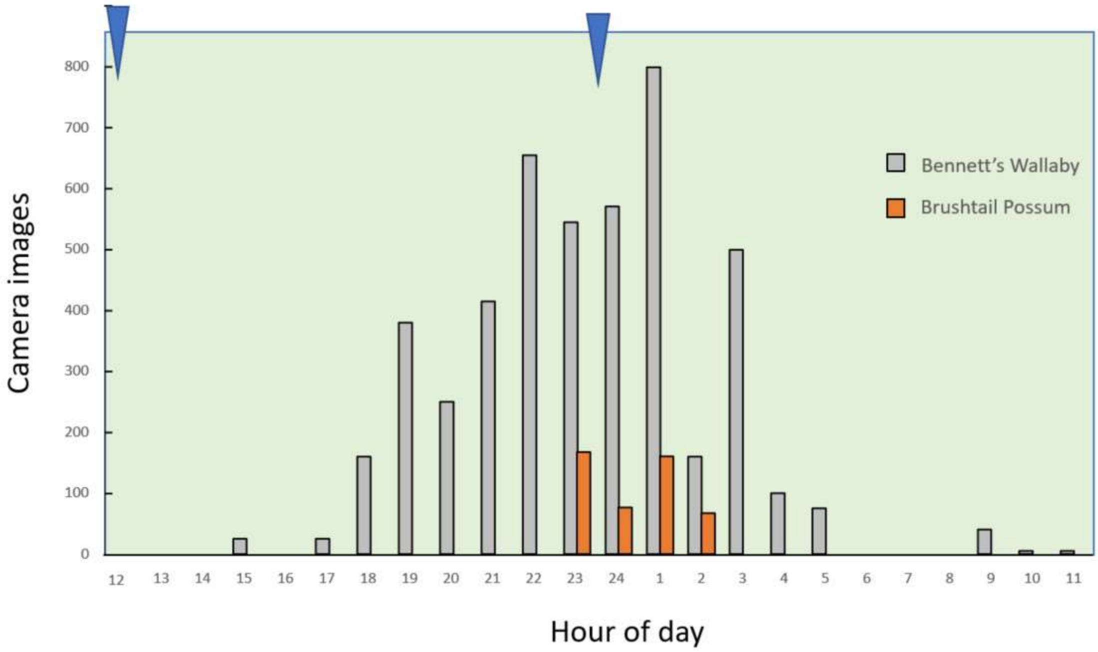

Figure 14. Hourly activity of Bennett's wallabies and possums at a Spinner installed at a site with low possum activity. The Spinner was set to dispense c. 20 pre-feed pellets daily, at midday (12 h) and again at midnight (24 h) (blue triangles).

5.4 Possum carcases as a potential deterrent

Possum carcases placed close to bait feeders deterred wallabies from interacting with the feeders (Figure 15), but the effect was relatively short-lived. Interactions with stations fell by 86% during the first week carcases were in place ($P < 0.01$) but recovered during the second week (to 38% below pre-carcase rates, which was not a statistically significant reduction). The trial was undertaken during warm summer weather; by the second week of placement all carcases were either in an advanced state of decomposition (Figure 16) or had been dragged away by pigs or cats.

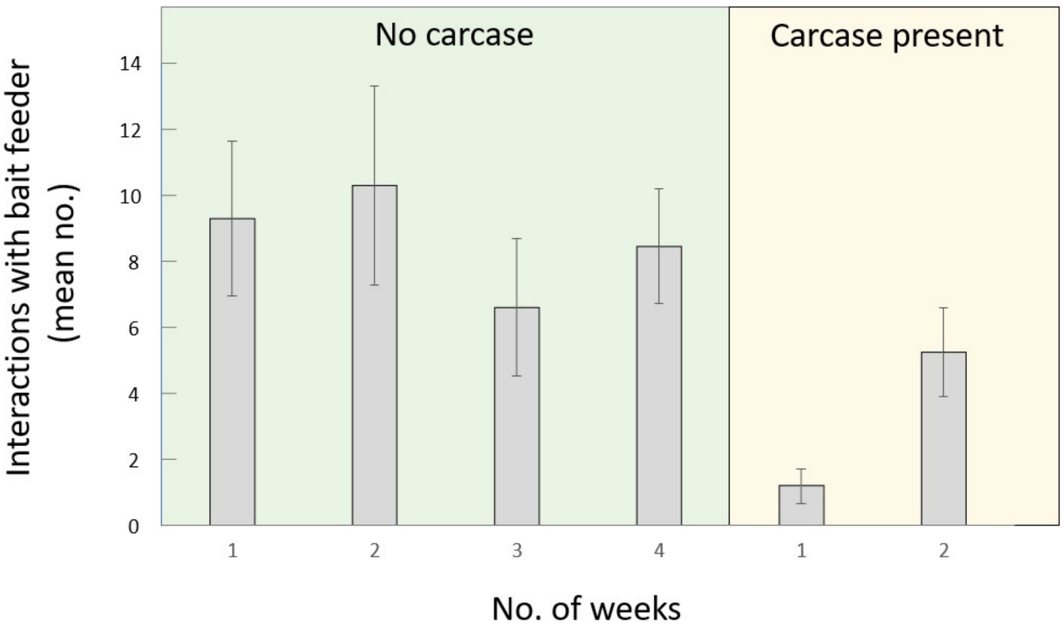

Figure 15. Effect of possum carcase placement on the average number of weekly interactions of wallabies with bait stations (Means ± SEM; *n* = 20 sites before placement and for Week 1 of placement; *n* = 8 for Week 2 of placement).

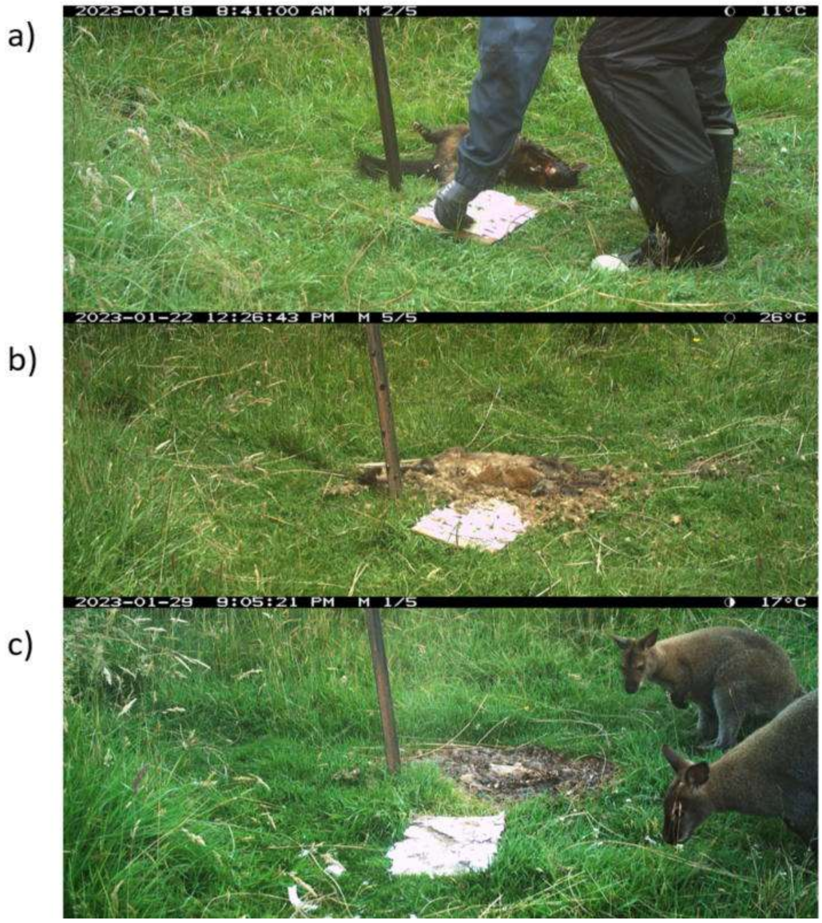

Figure 16. Progressive decay of a possum carcase at a ground striker site: a) placement day, b) after 1 week; c) after 2 weeks. In both weeks the strikers were removed by possums, which were not deterred by the carcase. Wallabies did not interact with the feeder until the second week.

6 Discussion

6.1 Comparison between field sites

This study was successful in generating a large number of images of dama wallabies, Bennett's wallabies, and other wildlife interacting with four bait feeder designs. An obvious difference in the data from our two field sites is that Bennett's wallabies visited Blue Cliffs feeders at more than twice the rate that dama wallabies visited them at Titoki (26.1 vs 12.1 visits per station per week). While this may indicate a higher population density of Bennett's wallabies at Blue Cliffs, visitation rates were reduced by the higher level of possum interference at Titoki (despite our efforts to reduce possum numbers in the vicinity of the Titoki feeders in preparation for the feeder trial). The ratio of possum to wallaby visits at Titoki was 3.1:1, compared to 0.8:1 at Blue Cliffs, which implies a fourfold difference in the level of possum interference between the two study areas.

Despite their larger body masses, both wallaby species were clearly behaviourally subordinate to possums. Wallabies would not begin feeding at a bait station that was being used by a possum, and wallabies feeding at stations were displaced by possums arriving to feed. This influenced the daily activity patterns for the two species – wallaby activity at the stations peaked at dusk and declined thereafter as possums displaced them.

From an operational perspective, much of the dama wallaby population lives in areas with limited recent possum control, so mitigation of possum interference needs to be included when designing ground-based dama wallaby control operations. Possums were less disruptive at Blue Cliffs, but this was an area that had recently had possum control to reduce TB risk. The potential for possum interference with bait feeders is clearly an important consideration when planning Bennett's wallaby control.

6.2 Comparison between bait feeder treatments

For both wallaby species, there was no statistically significant difference in the number of visits made to the four feeder treatments relative to RS5 baits on the ground. As 'visits' measured whether wallabies appeared within the field of view of our cameras, this result simply indicates that none of the feeder designs deterred wallabies at a distance. For Bennett's wallabies, most approaches (64%) led to the wallaby interacting with the feeder, with no difference in this behaviour evident among feeder designs. In contrast, fewer dama interacted with the feeders (43%), with interaction rates being significantly lower for the Marley and Philproof designs (Table 1).

One interpretation of this result is that dama may be more wary than Bennett's of large upright feeders. Alternatively, or additionally, these two designs emptied slowly (see Figure 9) so there may have been greater opportunity for possum interference at these designs. If so, this effect would be more pronounced at Titoki, because possum activity was much higher there.

Both wallaby species fed readily on ground-laid and raised strikers, with no statistically detectable difference between the two treatments. This result is counter to previous anecdotal reports that wallabies may be more willing to feed on strikers on the ground. In our study, we raised the strikers by stapling them to narrow wooden stakes (Figure 3c) placed in relatively open habitat. Wallabies exhibit high levels of vigilance and prefer clear visibility of their surroundings while feeding. We speculate that narrow stakes help maintain close to 360° visibility for the wallabies, whereas past deployments of raised strikers may have involved attaching them to tree trunks or posts on bush margins, which would have reduced the wallabies' field of view.

Bennett's wallabies were slower to approach strikers (whether raised or on the ground) than dama wallabies. While this might indicate greater caution by the Bennett's wallabies, an alternative explanation is that the feeders at Titoki may have been closer to forest that wallabies were using for refuge.

Relative to RS5 pellets on the ground, both wallaby species exhibited reduced feeding rates at the enclosed Marley and Philproof feeder designs. Neither species used their forepaws to extract bait and both species were clearly averse to putting their head inside the feeder. This aversion appears to have been more pronounced for Bennett's wallabies (72% and 88% reductions in feeding rate, respectively) than for dama wallabies (59% and 63% reductions), perhaps because the feeder openings were a tighter fit for the larger heads of the Bennett's wallabies. Based on these findings, we suggest that feeders with larger openings, or tray-style feeding platforms, will encourage higher wallaby feeding rates. The obvious challenge with such designs is that they will be less weather-resistant and more susceptible to bait spillage and non-target interference.

6.3 Additional commentary on the individual bait feeder treatments

- Pelleted RS5 wallaby pre-feed placed on the ground was, as expected, the most readily accepted presentation to wallabies, provided the pellets remained dry. Bait piles were usually fully consumed, although piles exposed to rain turned to mush and then hardened into an unpalatable mass that wallabies and possums avoided. Pellets deployed on the ground are fully available to any livestock and other non-target species in the area.
- At sites where possums were common, strikers (both raised and on the ground) were often fully consumed before later-arriving wallabies had any opportunity to feed on them. At both sites, raising the strikers protected them from hedgehogs, which frequently consumed ground-laid strikers. At Titoki, raising the strikers also put them out of reach of the smallest juvenile dama wallabies.
- Marley feeders made bait available for an extended period but tended to clog when pellets in the mouth of the feeder became wet.
- Philproof feeders also made bait available for an extended period. However, wallabies struggled to access bait that accumulated towards the back of the feeder. Furthermore, some juvenile dama wallabies could not get bait from Philproof stations set at 300 mm above ground. Lowering the stations to 200 mm would assist juveniles but might be restrictive for larger individuals.
- In this study, Marley feeders and Philproof feeders were placed on narrow stakes in open areas, which ensured a wide field of view for wallabies as they fed. If these feeder treatments are mounted on large trees (which is common field practice in possum control operations) we speculate that the wallabies would have been even less willing to feed at them.

- The current design of the Rotoplas feeder, which has a small opening designed for possum baits, is not suitable for dispensing larger wallaby pellets. Wallabies being deterred by high possum activity was particularly noticeable with the Rotoplas design (because the feeders remained full of bait, which frustrated and incentivised the possums). Future Rotoplas-style feeders designed for wallabies should be mounted firmly rather than being allowed to swing.
- At sites with low possum numbers, pellets spread on the ground by Spinners attached to rigid waratahs were readily accepted by wallabies, with multiple individuals feeding together on pellets spread over several square metres. The small numbers of pellets being dispensed each day were quickly eaten before clumping from rain or dew.
- Diurnal (daily) activity patterns of Bennett's wallabies and possums at the Spinners differed, raising the possibility that the timing of pellet release could be set to give wallabies preferential access to the bait. However, it is possible that possums would simply learn when bait is dispensed and adjust their feeding schedules accordingly. Dama wallabies' diurnal activity patterns were too similar to those of possums for this approach to be effective.
- Our prototype Spinner design was not robust enough for field use. Pellets were easily dislodged by clambering possums, leading to the feeder being quickly emptied. Raising the Spinner feeders did not deter possums, as they readily climbed and hung from the design while feeding. Additionally, the electronics compartment was not sufficiently waterproof to withstand extended periods of heavy rain.

The pros and cons of the feeder designs we tested are summarised in Table 3.

Table 3. Characteristics of the feeder designs evaluated in the trial. BG – bait on ground; SG – strikers on ground; SR – raised strikers; M –Marley®; P – modified Philproof®; Ro – Rotoplas™; Sp – Spinner; n/a – not applicable.

Design factor	BG	SG	SR	M	P	Ro	Sp
Wallabies' willingness to feed	High	High	Medium-high	Lower	Lower	Nil	High
Wallaby learning required	Low	Low	Low	High	High	n/a	Medium[a]
Refill interval	Shortb	Short	Short	Long	Long	n/a	Long[b]
Weatherproof	None	Good	Good	Medium[c]	Good	Good	Prototype was poor
Livestock protection	Nil	Poor	Poor	Good	Good	Good	Poor
Hedgehog-proof	No	No	Mostly[d]	Yes	Yes	Yes	No
Portability	High	High	Medium	Lower	Lower	Medium	Lower[e]
Robust/low maintenance	Good	Good	Good	Good	Good	Good	Prototype was poor
Cost per station	Low	Medium[b]	Medium[b]	Medium	Medium	Medium	High

[a] Wallabies need to learn the time of day the Spinner is set to dispense pellets.
[b] Depends on the volume of bait applied.
[c] Wind plus rain can lead to wet, clogged pellets in the mouth of Marley feeders.
[d] Raised strikers were sometimes dropped by possums and wallabies.
[e] Our prototype required two waratahs.

7 Conclusions and recommendations

- We were unable to demonstrate a significant advantage of ground-laid strikers over strikers raised 20-30 cm above the ground on narrow wooden stakes. A toxic striker trial would be unlikely to find a meaningful difference in the kill rates achieved by these two methods.
- Designs that allow the timing of bait delivery to be controlled have some potential to exploit the different 24h activity patterns of Bennett's wallabies and possums. This approach is unlikely to be effective for dama wallabies.

7.1 Recommendations

- Designs that require wallabies to put their heads into the bait station reduce feeding rates, although wallabies eventually learn to use such feeders. Stations with wide openings or 'tray' designs – mounted on stakes in open areas rather than on tree trunks – are therefore recommended.
- We recommend against using designs that require wallabies to use their forepaws to extract bait or stabilise the feeder.
- We recommend measures to reduce possum activity at bait feeders to increase wallaby feeding rates. We also recommend measures to minimise possum carcases lying near bait feeders.
- Bait feeders are often emptied of non-toxic bait by possums, rats and hedgehogs before wallabies get a chance to feed at them. To address this problem, future bait feeder comparisons should trial pulses of toxic bait to suppress interference by non-target species.

8 Acknowledgements

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