ORIGINAL PAPER

Are footprint tracking tunnels suitable for monitoring giant weta (Orthoptera: Anostostomatidae)? Abundance, distribution and movement in relation to tracking rates

Corinne Watts · Ian Stringer · Danny Thornburrow · Darryl MacKenzie

Abstract Appropriate monitoring tools are essential for assessing the effectiveness of management for all threatened insect taxa. In New Zealand the large-bodied flightless orthopterans in the genus *Deinacrida* have mostly been monitored by searching through habitat during the day or spotlighting at night but this is time consuming and the results depend on the skill of the searcher. Recently, footprint tracking tunnels, similar to those used for monitoring small mammals in New Zealand, were found to be effective for detecting adults of various giant weta species. In this study, we compared the abundance of Cook Strait giant weta (CSGW) in the vicinity of the tunnels, estimated by mark-recapture, with the number of tracking tunnels tracked by weta. We found strong indications that both baited and unbaited tracking tunnels can be used to estimate the number of adult weta present but that this probably depends on their responses to meteorological conditions which are not yet understood. Our results also show that footprint tracking tunnels are more effective for detecting adult CSGW than searching for these insects at night and that baiting tracking tunnels with peanut butter increases their effectiveness for detecting adult CSGW. We confirmed how far Cook Strait giant weta moved each night on Matiu-Somes Island by attaching transmitters to

them and found that day roosts of three adult males were on average 8.6 m apart each day and those of adult females were on average 21.3 m apart. Both the low recapture rates of marked adult CSGW and the nightly displacements of those with transmitters suggest that adult CSGW show no site fidelity and are clearly capable of moving large distances each night. However, an individual weta is unlikely to track more than one tunnel per night if tunnels are 30 m apart. Tracking tunnels have the potential to be used with some other insects, provided their footprints are diagnostic. An advantage of using tracking tunnels is that they are non-lethal and would therefore be particularly suitable for monitoring other large threatened insect taxa.

Keywords Conservation · Monitoring tool · Tracking tunnels · Threatened taxa

Introduction

Conservation managers frequently face the problem of how to monitor rare invertebrates without harming them. In New Zealand, weta (Orthoptera: Anostostomatidae) have been the most frequently translocated insects (Watts et al. 2008a; Sherley et al. 2010) and most monitoring has involved time-consuming searches of their habitat, which often resulted only in confirmation that the insect was still present. A method that involves systematically searching their habitat was developed to estimate populations of Mahoenui giant weta (*Deinacrida mahoenui*) using site occupancy modeling (MacKenzie 2003) and artificial wooden refuges attached to trees have also been used to monitor tree weta (*Hemideina* sp.), which roost in cavities in trees (Trewick and Morgan-Richards 2000; Green 2005; Kelly 2006). Also a variety of other methods were tried

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with varied success for monitoring Mercury Islands tusked weta (*Motuweta isolata*) which roost in underground chambers (Stringer and Chappell 2008). Recently, Watts et al. (2008b) reported that footprint tracking tunnels similar to those used for monitoring small mammals could be used effectively to detect the giant weta *Deinacrida heteracantha*. Although these insects are primarily arboreal, the tunnels detected them when placed either in trees or on the ground. Baiting the tracking tunnels with peanut butter increased chances of detection. In this paper we explore whether tracking tunnels can be used to estimate the population density of a ground-dwelling weta, the Cook Strait giant weta (CSGW), *Deinacrida rugosa*, on Matiu-Somes Island, and whether they are effective for determining this weta's distribution. A ground weta species (*Hemiandrus pallitarsis*) and Wellington tree weta (*Hemideina crassidens*) are also present on Matiu-Somes Island but CSGW grow larger than both these species so the footprints of adult CSGW should be clearly distinguishable from the other species (see Watts et al. 2008b).

We first examined the footprints of all weta species on Matiu-Somes Island to determine if those of CSGW could be clearly distinguished from the other species. We then investigated if tracking tunnels were effective for both detecting adult CSGW and estimating their abundance. The latter was done by comparing the results from tracking tunnels both with the number of adult CSGW seen in the vicinity of the tracking tunnels and with the number estimated to be present using mark-recapture. We hoped to determine whether tracking tunnels could be used to provide an index of the population similar to their use with mammals (Brown et al. 1996; Blackwell et al. 2002; Gillies and Williams 2002). However, a complicating factor is that the activity levels of invertebrates are more dependent on meteorological conditions, particularly temperature, than are the activity levels of mammals.

Matiu-Somes Island was ideal for such a study because CSGW were abundant at the northern end of the island but were rarely seen at the southern end. Estimating numbers of some weta using mark-recapture should be difficult when they are known to return to the same roost on successive nights (e.g. Wahid 1978; Ordish 1992; Trewick and Morgan-Richards 2000; Stringer and Chappell 2008) but indications were that adult *D. rugosa* are quite mobile so they might mix throughout the population. McIntyre (1992) reported that on Mana Island six adult females equipped with transmitters moved on average 7.4 ± 8.4 m per night (maximum 44 m) although 21% of her sightings were near where the weta were first found. She reported that these females generally remained within a small area (a metre radius) for a few days, then moved >20 m and repeated the pattern at a new site. We similarly investigated how far

adult CSGW moved each night on Matiu-Somes Island by attaching transmitters to three adult male and three adult female CSGW. This was carried out to determine how far apart tracking tunnels should be spaced to reduce the probability of an individual CSGW tracking multiple tunnels.

Methods

Distinguishing weta species by their footprints

Weta were captured on Matiu-Somes Island and held for 2–3 h in captivity while their footprints were recorded on tracking tunnels. Footprints were obtained from 6 female and 6 male adult CSGW (9–10th instar, Ramsay 1955), large (5–8th instar) and small juvenile CSGW (<5th instar), adult tree weta, large juvenile tree weta; and 4 female and 4 male adult ground weta. The size (mm) and arrangement of the tarsal pad prints of weta were measured after they had walked over tracking cards in controlled conditions. This was repeated twice for each weta and average tarsal print lengths were obtained from up to five prints per card. The lengths (mm) of the tarsi from each right leg of the weta were also measured, and the species, sex and age class recorded.

Tracking tunnels

Six lines of tracking tunnels ('Black Trakka': Gotcha Traps, 2 Young Street, RD2, Warkworth, New Zealand) were established alongside footpaths on the island (Fig. 3). Five lines comprised 12 tunnels and one (line 5) had 11 ($n = 71$). The tunnels were spaced 30 m apart and placed up to 1 m off the footpath. The position of each tunnel was recorded with a GPS (estimated accuracy < 5 m). Pre-inked tracking cards were used (Gotcha Traps).

Five lines were set around the periphery of the island for 7 nights from 8 to 15 February 2008 (included one line with 11 tunnels) and another (line 6) was set in the vicinity of the buildings on top of the island from 9 to 15 February 2008. Each evening, tracking cards were placed in the tunnels just before dusk and removed soon after dawn to reduce the numbers of footprints from diurnally active skinks, which could obscure weta footprints.

The tunnels were not baited for the first 4 nights but were baited for each of the last 3 nights by placing ca 4 g of fresh peanut butter in the middle of the inked area. Cards within tunnels were rebaited with peanut butter each evening. Peanut butter was used because it increased the tracking rate with another giant weta species, *D. heteracantha* as mentioned above (Watts et al. 2008b).

Visual searches

Visual searches along the footpaths where tracking tunnel lines were located were carried out between 2100 and 0100 h. The surface of the footpath and the immediate vegetation on either side, both at ground level and above, was searched. The footpaths were searched twice each night using two pairs of searchers. Each pair searched all the footpaths once per night. Search bias, whereby areas where weta were found previously may be searched preferentially, was reduced by: (1) individual searchers confining their search to one side of the footpath and then, the following night, searching the side they had not searched before; (2) starting the searches at different tracking tunnel lines each night; (3) varying the direction of the searches on different nights; and (4) varying the composition of the search parties as much as possible (eight searchers were available for varying numbers of days). On each night the two search parties searched the tunnel lines in the same direction but they commenced searching on different tracking tunnel lines that were a long way apart.

Mark-recapture

Each adult CSGW found was marked with a small individually numbered paper tag (2 mm wide, 3 mm long) that had been previously soaked with Araldite (I. Jamieson, personal communication). These were attached to the pronotum using a quick setting adhesive (Selleys® 'Supa glue gel'). Most weta became immobile when illuminated so the tags could usually be attached in less than a minute without handling the insects. Each time a weta was found its position was taken with a GPS (estimated accuracy usually <5 m).

Radiotracking

A radio-transmitter (Model BD-2, Holohil Systems Ltd, Canada) was attached to each of six adult CSGW (3 females and 3 males). A small aluminum saddle was first attached to the pronotum of each weta using a thin layer of quick setting glue (Selleys® 'Supa glue gel'). After 4 h, when the glue had set, a transmitter was attached to the aluminium saddle with silicone glue (Selleys® Roof and gutter sealant) and this was allowed to set for a further 4 h. Transmitters used on females weighed 1.08 g (4.8–5.2% of body mass) and had an expected battery life of 56 days while those used on the smaller males weighed 0.87 g (8.1–8.9% of body mass) and were expected to last 42 days.

Once the transmitters were attached, the weta were released where they were originally found. This was accomplished within 12 h of capture. They were located once in their roost site each day for up to 27 days from the day after release on the 10 or 11 February 2008, using a Telonics TR-4 receiver and 3-element Yagi antenna. Weta were not touched when found but their locations were recorded with a GPS (estimated accuracy <5 m). They were visually examined only when it was possible to do this without disturbing the insect or habitat.

The duration that weta were tracked ranged from 7 to 27 days. At the end of the study, the transmitters were removed by slicing through the silicone glue and the aluminum saddles were left attached to the weta.

ESRI® ArcMap™ version 9.2 was used to calculate the mean distances traveled per night, the total path distances, and the displacement from the release point to the last known position for each weta. These distances are overall daily displacements, not the actual paths followed by the insects.

Meteorological data

Hourly measurements of temperature and relative humidity were taken using Tinytag® dataloggers (Gemini Data Loggers (UK) Ltd: −10 to +40°C, ± 0.4 C°; 0–100% RH, ± 3%). Both units were housed in a Stephen type screen (ACS-5050) hung 2 m above the ground in open forest.

Analysis

All results are given with ± 95 confidence intervals so that significant differences are apparent by inspection.

Mark-recapture data were used to estimate population sizes of adult males and females along each line using Program MARK. The results of the two nightly searches were aggregated so that a weta was either found, or not, each night. This allows standard closed population models to be used to estimate population density. In a closed population it is assumed there are no additions or deletions to the population (i.e. the weta within the vicinity of the line) during the study. Because of the low number of recaptures, models involving heterogeneity and behavioral effects (Otis et al. 1978) were not considered as there were likely insufficient data to be able to identify and account for them reliably. Low numbers of weta were found along some lines and these had very low recapture rates so we also assumed that the capture rates along all lines were approximately equal. The only factors that were considered possibly to influence capture rates were therefore the night of survey (N) and gender (G). It is biologically reasonable to assume that if there is a difference between males and females, that difference would be relatively consistent, hence an interaction between these factors (i.e. implying that the difference between males and females changes each night) was not considered. Model averaging based on the AICc model weights was used to account for model

selection uncertainty (Burnham and Anderson 2002) in our final estimates of capture rates and population size.

The relationship between the average tracking rate of tracking tunnels baited with peanut butter or unbaited and the estimated numbers of weta nearby (abundance) was obtained using a minimum adequate model using R (Version 2.9.2) after normalising both the rate and abundance by log-transformation. The best fit (using AIC) was a linear model with equal slopes for baited and unbaited tracking tunnels.

Results

### Distinguishing between footprints of CSGW and other weta species

Adult CSGW had significantly larger protarsal, mesotarsal and metatarsal pad lengths than either juvenile CSGW or the other two weta species present (Fig. 1). However, the footprints of large juvenile CSGW often overlapped with adult tree weta and the footprints of juvenile CSGW, large juvenile tree weta, and adult ground weta were of similar sizes (Fig. 1). Footprints in tracking tunnels used in the field trial were therefore recorded as either adult CSGW or as 'other weta'.

The tarsal pads were longer than the prints they left on the cards for all 68 weta examined, regardless of species, sex and age class. Only 57% (±1.5%), 63% (±2.8%), and 82% (±5.1%) of the length of the protarsal, mesotarsal and metatarsal pads were recorded on cards.

Tracking tunnels

Footprints of adult CSGW were found in 139 (28.7 ± 4.2%) out of a total of 485 tracking tunnel-nights. Footprints of smaller weta (species undetermined) were found in 141 tunnels (29.1 ± 4.2%) and 39 tunnels (8.0 ± 2.4%) had footprints of both adult CSGW and smaller weta. Fifty-one tunnels had footprints of *Mimopeus opaculus* beetles (Coleoptera: Tenebrionidae) (10.3 ± 2.8%), and the footprints of an unidentified insect were found in one tunnel. In addition, 2 tunnels had tuatara footprints, 29 tunnels had gecko footprints (6.0 ± 2.2%), and 33 tunnels had skink footprints (6.8 ± 2.2%).

Tunnels baited with peanut butter were tracked approximately twice as often by adult CSGW as tunnels without peanut butter (mean tracking rate per night over three nights: peanut butter, 5.1%; no peanut butter, 2.4%). This difference appeared to be unrelated to average temperature or relative humidity during the night (Fig. 2). Adult CSGW footprints in both baited and non-baited tunnels set over three nights indicated there were more
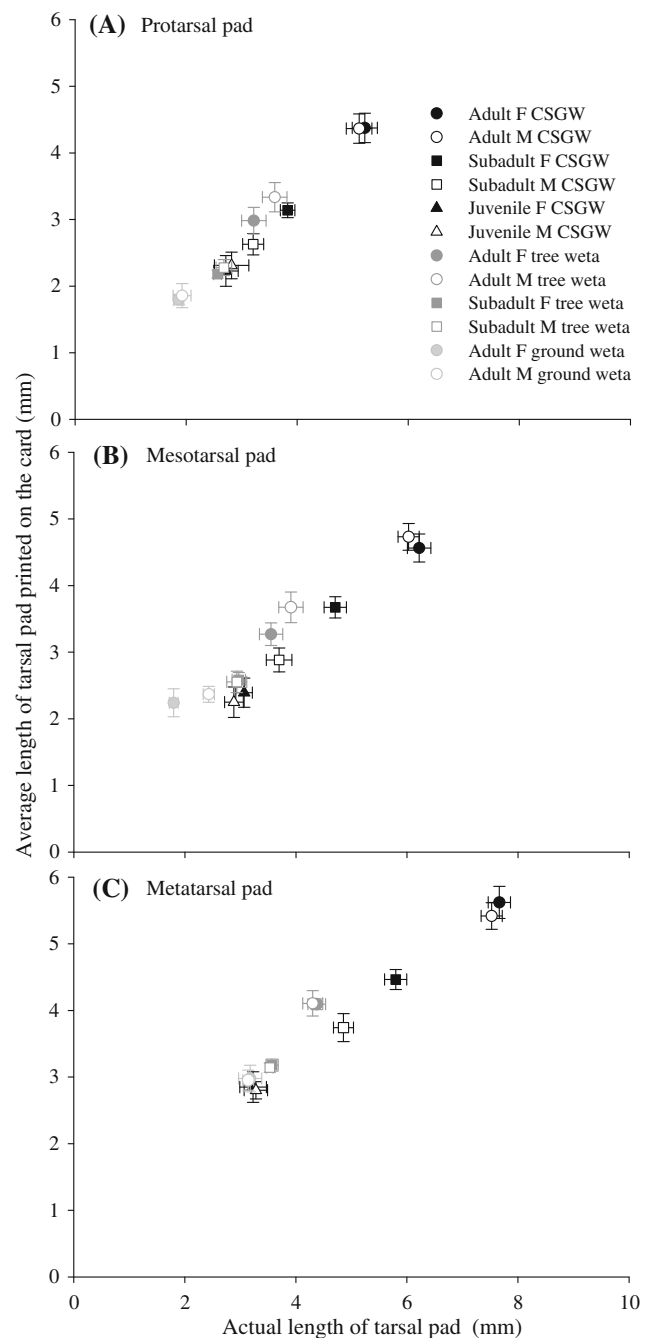
Fig. 1 Relationship between length of tarsal pads and the average lengths of their footprints on card. Adult Cook Strait giant weta footprints were significantly larger than the two other weta species present. *Bars* show 95% confidence intervals

weta towards the northern end of the island and fewer towards the southern end. The relative increase in tracking rate between baited and unbaited tunnels also tended to be larger at the north end of the island (Fig. 3).

Overall, when the results of both baited and unbaited tunnels were considered together they indicated that adult CSGW were present over most of the island with relatively
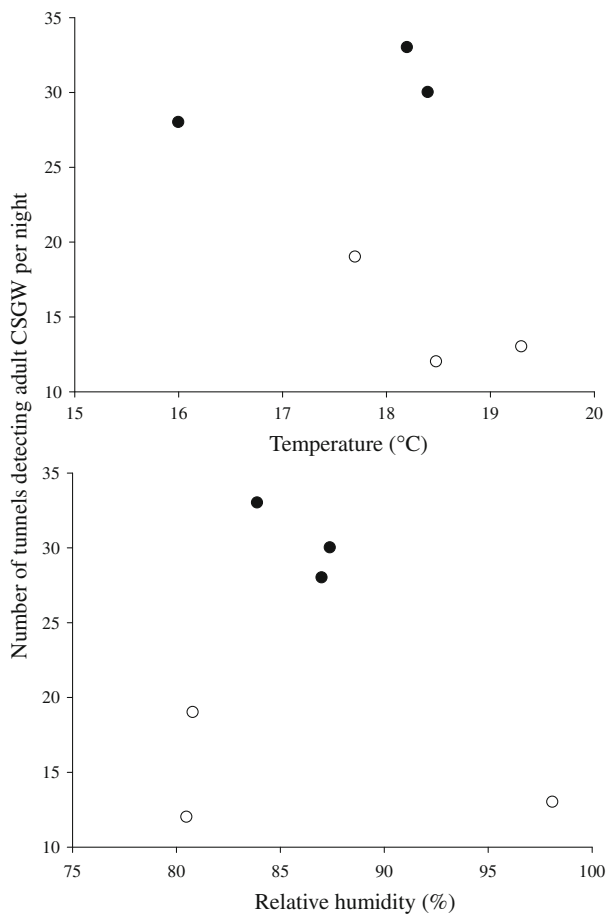
Fig. 2 Relationship between the number of Cook Strait Giant weta footprints found in tracking tunnels and the average temperature (*upper*) and relative humidity (*lower*) during the night. *Open circles*, no bait; *closed circles*, peanut butter bait. Data shown only for nights 9–14 Feb 2008

few locations (15) located in the north west, south and south west where no adult CSGW footprints were recorded (Fig. 3).

Searching for weta at night

A total of 248 adult CSGW were seen and marked during the 7 nights. They comprised 179 different females (72.2%) and 69 different males (27.8%). In addition, 32 juvenile weta were seen but were not marked (19 male, 12 female, 1 indeterminate).

Adult CSGW were observed most often towards the northern end of the island and few were seen at the southern end (Fig. 4). This distribution was similar to that shown by using tracking tunnels (Fig. 3).

No significant relationship was apparent between the number of weta seen per night and either the mean temperature during the observation period ($F_{1,4} = 0.3769$, $P = 0.57$) or the mean humidity ($F_{1,4} = 0.947$, $P = 0.39$) although observations were made on only six nights.

Mark-recapture

Of the adult weta captured during the 7 nights, 206 were only captured once, 30 captured twice, 4 captured 3 times, 4 captured 4 times, 3 captured 5 times, and one captured 6 times. Four models were fitted to the data and ranked according to AICc (Table 1). These results suggest strong evidence that capture rates varied among nights (summed model weights = 1.00), and reasonably strong evidence for the importance of gender (summed model weights = 0.69). Model averaged capture probabilities were estimated to be very low (<0.10 each night; Fig. 5). The density of male and female weta estimated at each line is given in Fig. 6; approximately a 4.3 and 2.7 fold increase (respectively) on the number of weta actually seen along each line during the 7 nights. Estimated total numbers along each line are given in Table 2.

The highest proportion of weta recaptured was of those that roosted under the Visitor Centre building. Here, 19 different adult CSGW were found and tagged and 4 of these were recaptured up to 4 times within 15 m of the building. Overall, fifteen recaptures were made there, representing 22% of the resightings. This building, together with a small garden of native shrubs, was isolated from scrub and rank grass by a surrounding lawn.

No significant difference was detected between the daily displacements (distance between consecutive observations divided by number of nights between observations) of marked adult males and female CSGW using log transformed data, although the male sample was small (Table 3). All recaptured males were found the night after they were first found, whereas females were found up to four nights later. The distances between the first and last sightings for females were as follows: 30 had moved <10 m, 9 had moved 10.0–21.5 m, and one weta each moved 53, 98, 164, and 285 m.

Relationship between numbers of weta sighted
and numbers of weta detected in tracking tunnels

Adult CSGW were detected in more locations using tracking tunnels baited with peanut butter than through either unbaited tunnels or visual searches near the tracking tunnels.

However, the effectiveness of visual searches depended on the size of the search area around the tracking tunnels (Table 4). For example, if only weta within 5 m of tunnels were included, then baited tunnels detected their presence in 52% of the sites where weta were not seen and failed to detect them in 3% of sites where they were seen. In contrast, 24% of unbaited tunnels detected weta where they were not seen within 5 m and 18% failed to detect them where they were present. Increasing the search area around

Fig. 3 Positions of tracking tunnels on Matiu-Somes Island showing where adult Cook Strait giant weta were detected in relation to no bait (*left*) or baiting with peanut butter (*right*). Tunnels were run on three successive days. *Numbered* tracking tunnel lines are shown
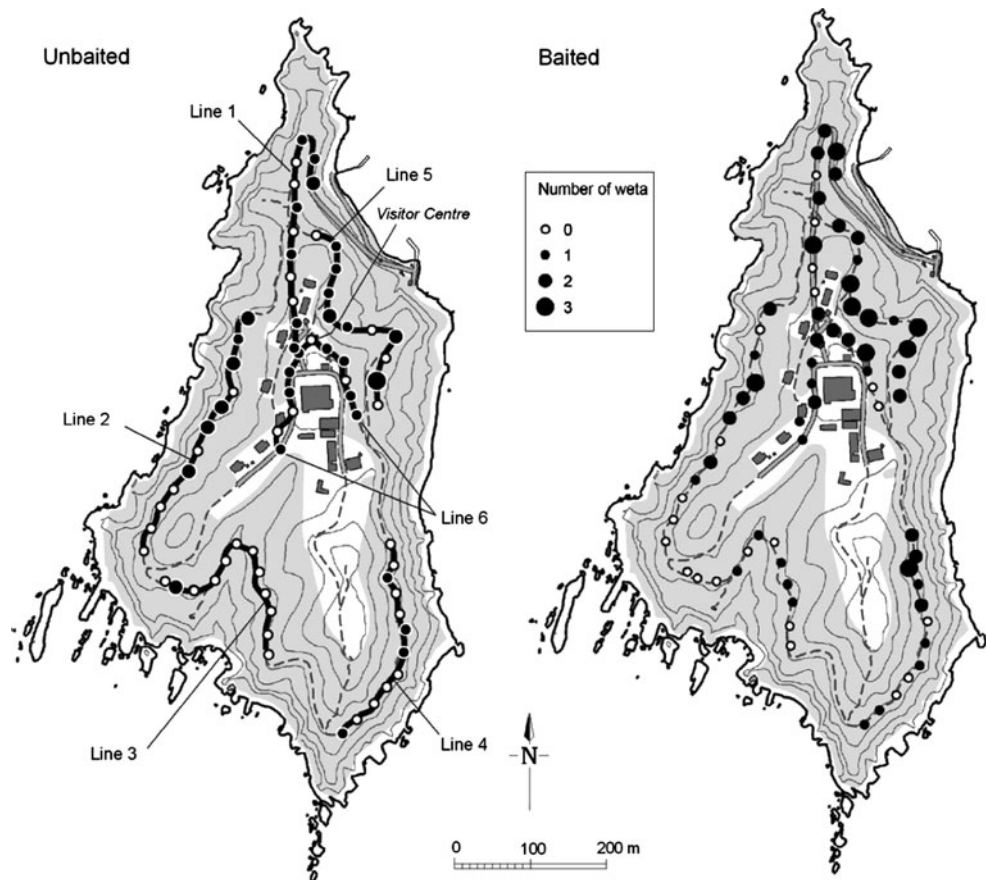
the tunnels resulted in fewer tunnels detecting weta where no weta were seen, but conversely, more tunnels gave false negatives (did not detect weta where they were present). This occurred using both baited and unbaited tunnels, although, overall, baited tunnels were always more effective for detecting weta (Table 4).

Relationship between the number of tunnels with weta footprints and the estimated numbers of weta present

The average number of tracking tunnels tracked by giant weta showed a significant positive relationship with the estimated numbers of these weta present near the tunnels (after log transformation of both variables) when either baited with peanut butter or not baited. Tunnels baited with peanut butter did, however, track significantly more often (2.6 times) than unbaited tunnels (Table 5).

Movements of radiotracked weta

The time followed; total distance travelled; minimum, maximum and average distance travelled per night; and distance from release site at end of study for each adult CSGW are given in Table 6. There was no relationship

between average distance traveled per night and the proportion of transmitter weight to weta body weight ($r = -0.342$, $n = 6$, $P > 0.05$).

Most adult CSGW remained in the northeastern part of the island except for female #55, which travelled towards the southeastern end (Figs. 7, 8). On average, female weta travelled a total displacement distance of 302.3 m (21.3 m per night) compared with 188.1 m (8.6 m per night) for males. Female #55 moved the furthest overall, whereas the highest average displacement per night and maximum displacement per night was recorded by female #60, which was only tracked for 7 days (Fig. 8; Table 6). The greatest daily displacement path followed by a male (weta #47) was 288.8 m during the study (26 days). Its last position was 112.6 m from its release point (Fig. 8; Table 6).

When radiotagged weta were located during the day, they were sighted on 51% of occasions, and of these 37% were in rank grass, 17.4% were under leaf litter in forest, 16.3% were amongst low vegetation, 14.1% were under fallen wood, 12.0% were amongst the base of flax, and 3.3% were under a building. Two radiotagged males were found copulating with unmarked females and one of these was seen mating with different females on three consecutive days. Overall, 77% of daytime refugia were within 10 m of a track or mown grass.
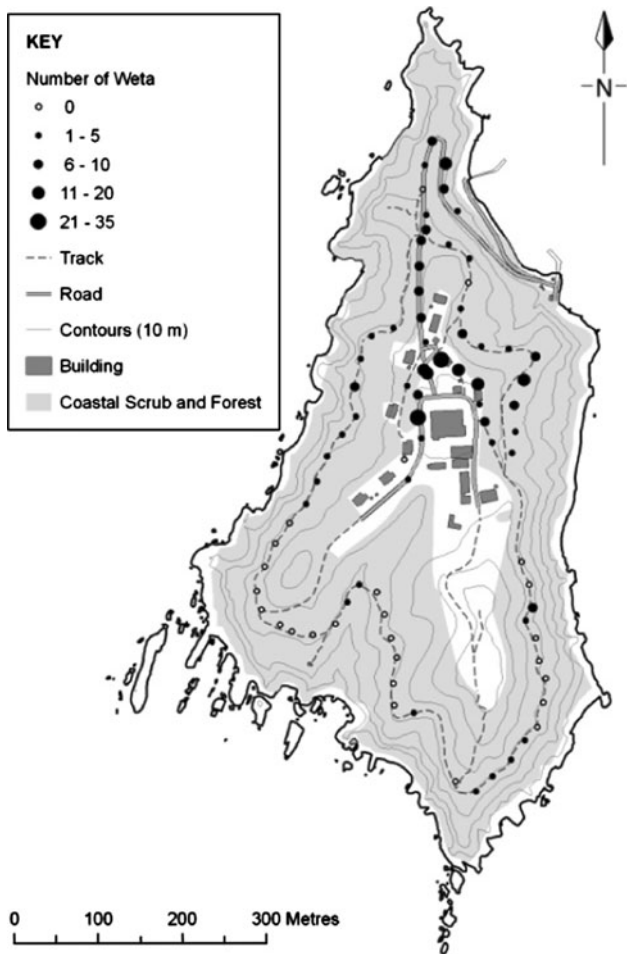
**Fig. 4** Number of Cook Strait giant weta seen within 15 m of each tracking tunnel on Matiu-Somes Island

Table 1 Summary of models fitted to mark-recapture data giving the Akaike Information Criterion corrected for small samples (AICc), the AICc model weight (*W*), number of parameters in the model (*K*; including 12 parameters for estimated population sizes) and model deviance

| Model	AICc	ΔAICc	*W*	*K*	Deviance
$p(N + G)$	103.11	0.00	0.53	20	325.37
$p(N)$	103.36	0.25	0.47	19	327.66
$p(G)$	116.83	13.72	0.00	14	351.33
$p(.)$	117.09	13.99	0.00	13	353.63

Model names indicate which factors are influencing capture probability in that model (N = night and G = gender)

Discussion

Our results show that footprint tracking tunnels detect adult CSGW at more sites where they are present than searching for these insects at night, that baiting tracking tunnels with peanut butter increases their effectiveness for detecting
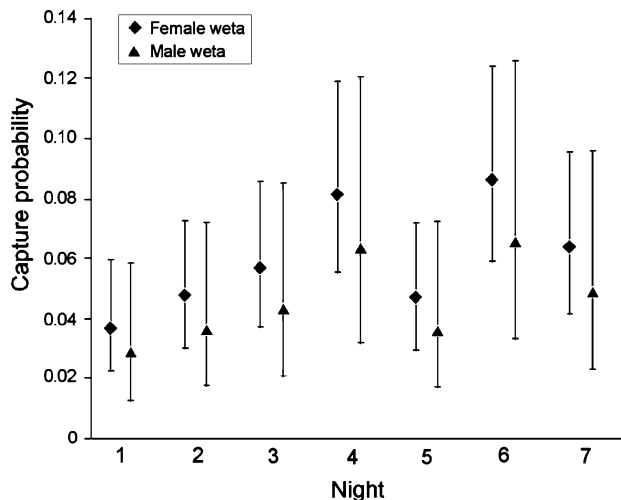
Fig. 5 Model-averaged capture probabilities estimated for Cook Strait giant weta. *Circles* denote females and triangles males. The upper and lower limits of 95% confidence intervals are indicated
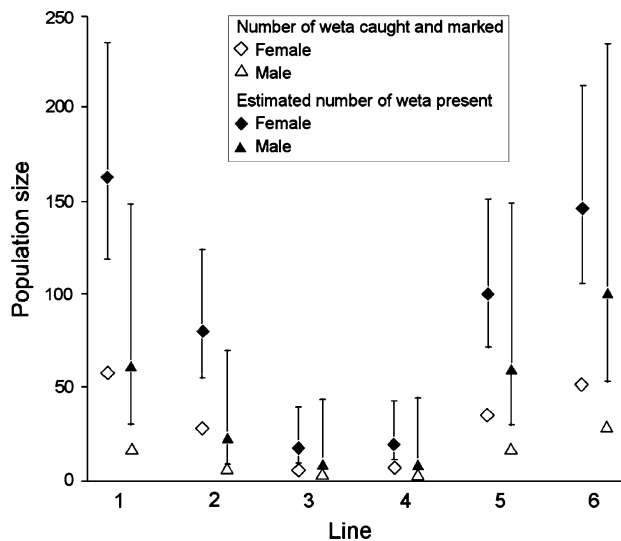
Fig. 6 Model-averaged population sizes estimated for female (*circle*) and male (*triangle*) Cook Strait weta around each line. The upper and lower limits of 95% confidence intervals are indicated. *Open symbols* indicate the mean number of weta seen along each line over the 7 nights. Refer to Fig. 3 for line numbering

Table 2 Estimated total number of weta along each line

Line	Obs	*N*	SE	Lower	Upper
1	8	24.4	8.9	12.8	63.4
2	50	161.6	35.7	82.0	439.1
3	32	98.9	21.7	51.6	260.3
4	76	251.3	55.6	125.8	693.5
5	73	228.5	43.3	118.3	607.1
6	9	27.1	9.2	14.4	70.1

Table 3 Distances (m per night) observed between recaptures of marked adult Cook Strait giant weta found on different nights

	Male	Female
Mean (SE limits)	6.1 (4.5, 8.2)	4.8 (3.8, 6.1)
Median	7.1	3.6
25% quantile	3.4	2.1
75% quantile	9.3	8.8
Range	2.2–18.8	0.5–164
No. recaptures	7	35

Mean values were used where weta were recaptured more than once. All means were obtained after log transformation

Table 4 A comparison between the percentage of tracking tunnels that detected Cook Strait giant weta when the tunnels were baited with peanut butter or unbaited and the percentage of areas within 5, 10 and 15 m of these tunnels where these weta were found by searching along the footpath on the same nights

Search distance from tunnels (m)		Difference in relation to visual searching (%)		
		5	10	15
Unbaited	Detection	23.9	18.3	12.7
	Non-detection	18.3	23.9	26.8
Baited	Detection	52.1	36.2	22.5
	Non-detection	2.8	7.0	9.9

Unbaited tunnels were set for 272 tunnel-nights; baited tunnels for 213 tunnel-nights

Table 5 Relationship between the average number of tracking tunnels tracked by Cook Strait giant weta and the estimated numbers of these weta nearby

|	Estimate	Standard error	t-value	P value
Intercept	−0.622	0.658	−0.946	0.369
Log (estimated abundance)	0.474	0.140	3.395	0.008
Unbaited	−0.967	0.265	−3.647	0.005

adult CSGW and that using either baited or non-baited tracking tunnels can be used to indicate the number of weta present near tunnels. We did not test whether the ink affected those CSGW that moved through the tracking tunnels but none of the six individuals of a closely related species, *D. heteracantha*, died or showed reduced daily displacements over 7 days after going through tracking tunnels (Watts, unpublished data). The overall distribution of adult CSGW on Matiu-Somes Island shown by using tracking tunnels in this study gave similar results to a previous study where visual searching alone was used (Watts et al. 2009). Our subjective assessment is that the use of tracking tunnels is more efficient (more data were obtained per unit effort) than using visual searching because the tracking tunnels can be left over several nights whereas searches have to be repeated if few weta are active. However, in the present study we rebaited the tracking tunnels each day and we have not examined the effectiveness tracking tunnels without freshly rebaited peanut butter. A major advantage of using tracking tunnels is that the tracking rate provides an index of the number of adult weta present nearby. This implies that tracking tunnels could be used for estimating the numbers of weta in a similar way as is used for estimating the numbers of small mammals (Brown et al. 1996; Blackwell et al. 2002; Gillies and Williams 2002). As such they seem ideal for monitoring adult CSGW. However, the activity levels of weta are probably more dependent on temperature and other meteorological conditions than are those of mammals and further research is required to determine what these conditions are and to confirm the relationship between tracks and actual numbers. Our results indicate that the response of CSGW to tracking tunnels may not be related to temperature or humidity alone, although we acknowledge that our study occurred over a relatively small temperature range and involved few data points. We gained the subjective impression that fewer weta were seen on cloudy nights when more light was reflected from Wellington city (7.5 km away), and that fewer weta were seen in locations illuminated directly by this light, but we did not measure

Table 6 Distances (m per day) between day roosts of Cook Strait giant weta on Matiu-Somes Island

Weta Sex	#55 F	#58 F	#60 F	#45 M	#47 M	#49 M
Total number of nights observed	27	27	7	27	26	9
Total displacement (m)	382.8	236.8	287.2	215.7	288.8	59.9
Mean displacement per night (m)	14.2	8.8	41.0	8.0	11.1	6.7
Maximum displacement per night (m)	50.0	30.6	69.6	24.2	41.9	12.1
Minimum displacement per night (m)	0.0	0.7	12.6	1.1	1.2	1
Distance from release site at end of study (m)	291.2	112.3	44.2	126.9	112.6	8.6

Weta were repeatedly located after attaching micro-radio transmitters to them. Means were obtained after log transformation of the data
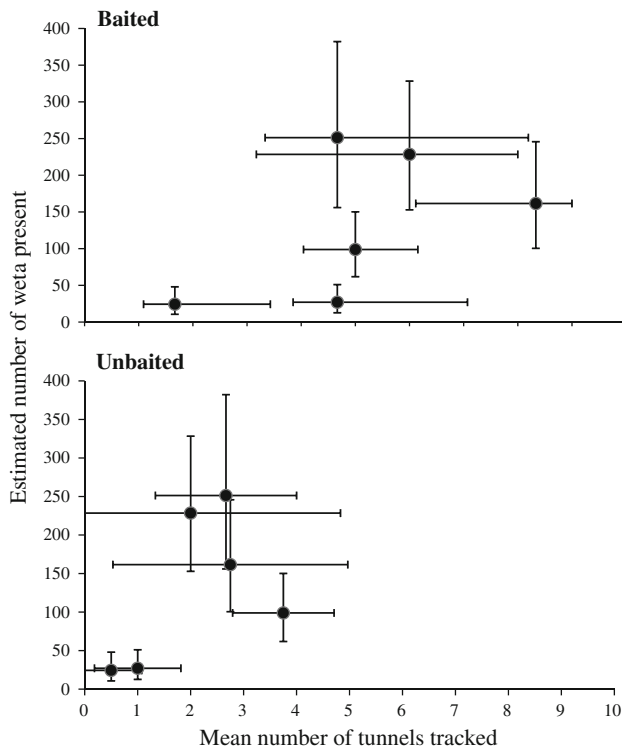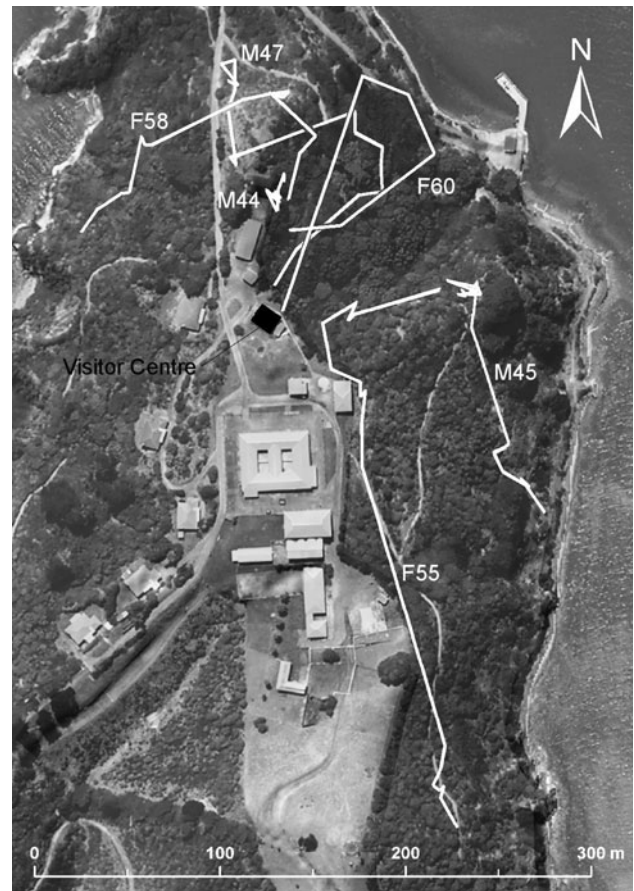
Fig. 7 Relationships between the estimated number of weta present and the mean numbers of tracking tunnels with weta footprints at baited (top) and unbaited tracking tunnels. Bars are 95% confidence intervals

Fig. 8 Dispersal movement of Cook Strait giant weta on Matiu-Somes Island

light intensity. In contrast, however, McIntyre (2001) reported that CSGW were not apparently affected by moonlight on Mana Island.

The following alternative methods for monitoring CSGW were considered but not investigated:

1. Systematically searching quadrats of known area during the daytime would potentially provide estimates of absolute abundance but this was not attempted because of the severe destruction of habitat that would result, particularly the dense vegetation and piles of fallen branches and logs where CSGW often roost. This method was successfully used to detect tusked weta (Motuweta isolata) and was considered more efficient than searching for them at night even though, in that case, it involved scraping off the topmost layer of soil. This was relatively easy because the sites were in forest where there was sparse ground cover (Stringer and Chappell 2008).

2. Searching quadrats for their large distinctive faecal pellets (Beauchamp 1992) but we did not attempt to do this on Matiu-Somes Island. We believe faecal pellet counts would work under open forest or even on mown grass but it would involve similar habitat destruction to searching quadrats if done in rank grass or dense

undergrowth. Using faecal pellet counts would also require estimating their rates of decay under different environmental conditions. We suggest this method may be more suited to monitoring arboreal weta such as Deinacrida fallai, D. heteracantha, D. mahoenui and tree weta in the genus Hemideina if the faeces could be intercepted on collecting sheets.

3. Artificial refuges comprising wooden shelters containing internal baffles are being tested on Matiu-Somes Island and at Karori Sanctuary at present (J. Greenman, personal communication; R. Empson personal communication). These are placed on the ground where CSGW certainly do use them, but whether they can be used to estimate relative population levels remains to be examined. Previously, placing wooden artificial refuges on the ground has been used successfully for collecting another ground dwelling giant weta species, Deinacrida herekopare, for translocation (Huggins et al. 2009). Wooden artificial refuges have also been widely used with tree weta (Hemideina species), which normally roost in cavities in tree trunks but there are opposing opinions about

whether they can be used to estimate a relative population index (Trewick and Morgan-Richards 2000; Bleakley et al. 2006; Bowie et al. 2006).

Both the low recapture rates of marked adult CSGW and the large movements of those with transmitters demonstrate that these weta show no site fidelity. This is in agreement with McIntyre (2001) who reported that adult female CSGW on Mana Island "stay within a small area (perhaps a metre radius) over several days… and then migrate (maximum recorded 56 m) overnight to a new site and repeat the pattern." She associated this behaviour with mating followed by oviposition. The daily displacements recorded by us on Matiu-Somes Island (mean displacement: male 8 m, female 21 m) differ from those reported by Kelly et al. (2008) on Maud Island (mean displacement: male 19 m, female 7 m) and Watts (unpublished data) at Karori Sanctuary (male 18 m, female 8 m). Adult males may move shorter distances on Matiu-Somes Island because they find females quickly due to the high population density. We can only suggest that on Matiu-Somes Island, females may have to move further than on Maud Island or at Karori Sanctuary to find suitable oviposition sites.

Adult Cook Strait giant weta are clearly capable of moving large distances each night, so the question arises how far apart should tracking tunnels be placed so it is unlikely an individual weta will track more than one tunnel. Our results only give displacements between observations but the weta obviously do not move in straight lines and so must travel much further than this during a night. However, when displacement only is considered then our results suggest that fewer than 10% of marked weta (4/35 females; 0/7 males) were capable of tracking two tunnels that are 30 m apart in one night. Our radiotracking data suggest the 6 weta followed could track two or more such tunnels on only 7.3% of occasions. Both such tracking estimates are overestimates because they apply only if every weta moved from one tracking tunnel to the next whereas most weta seemed to move in random directions. Our radiotracking data did show that one female CSGW (#55) followed paths much of the time she was observed and one male CSGW out of 36 individuals similarly frequently followed pathways after being translocated to Karori Sanctuary (Watts et al. unpublished data). Thus, with the exception of the occasional weta that follows pathways, most weta move in random directions so that those few that moved far enough would be very unlikely to come into contact with more than one tracking tunnel. However, we suggest the same procedure as used for monitoring small mammals (Blackwell et al. 2002; Gillies and Williams 2002) is followed when monitoring CSGW. This allows the tracking tunnels to be used for the dual purpose of monitoring both rodents and weta. The procedure involves placing tunnels 50 m apart which reduces the likelihood of sequential tracking by weta even more. The only modifications that we recommend are setting the tracking tunnels between November and May when most adults are present (Ramsay 1955; Stringer and Cary 2001; Watts et al. 2009), around the time of the new moon, and that the tracking cards are collected after at least 1 week in order to increase the chances of including nights when meteorological conditions are suitable for weta activity. In the present study, we rebaited the tunnels each day but we suspect that this may not be necessary because tusked weta (*M. isolata*) continued to move through tracking tunnels over many days when the tracking tunnels were left out and not rebaited each day for about 1 month (unpublished data).

Recommendations and conclusions

Tracking tunnels are excellent for detecting the presence of adult CSGW, and baiting them with peanut butter increases their sensitivity. As such they are ideal for mapping the distribution of these weta. Watts et al. (2008b) previously showed that tracking tunnels are also similarly useful for detecting the presence of the largest of New Zealand weta—*D. heteracantha*. In both cases, the footprints of juveniles could not be distinguished from those of other smaller weta but we suggest that tracking tunnels could potentially be used to detect the presence of adults of any large weta species, provided they are the largest weta present at the location. Tracking tunnels also show a clear indication of being suitable for use as a monitoring method because they could be used for estimating the numbers of CSGW present provided further research is undertaken to determine how the tracking rate varies with meteorological factors. We believe tracking tunnels are also likely to be suitable for monitoring other species of giant weta or the largest species of weta present.

Finally, tracking tunnels are extensively used for monitoring small mammals in New Zealand, and we recommend that in those locations where there is a conservation management requirement to also monitor a large weta, the tracking tunnels are set up and operated as for mammal monitoring and the cards are then either replaced or left for a longer period to be examined for footprints of adult weta. We believe tracking tunnels have the potential for use with some insects other than weta, because our tracking cards showed the clearly distinguishable footprints of at least two other species. An advantage of using tracking tunnels is that they are non-lethal and would therefore be particularly suitable for other large threatened insect taxa.

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