Assessment of non-target impact of 1080-poisoning for vertebrate pest control on weta (Orthoptera: Anostostomatidae and Rhaphidophoridae) and other invertebrates in artificial refuges

Eric B. Spurr[1] and Peter H. Berben[2]
[1]Landcare Research, P.O. Box 69, Lincoln 8152, New Zealand (E-mail: spurre@landcareresearch.co.nz)
[2]Landcare Research, Private Bag 11 052, Palmerston North 5321, New Zealand

Abstract: Artificial refuges and mark-recapture techniques were used to monitor the non-target impacts of hand-broadcast application (simulating aerial application) of Wanganui No.7 cereal-based baits containing 0.15% (1500 µg g^{-1}) 1080 on populations of weta and other invertebrates in Tararua Forest Park, North Island, New Zealand. Wellington tree weta (*Hemideina crassidens*) and a cave weta (*Isoplectron* sp.) were the only species of weta that occupied the refuges. Flatworms, slugs, spiders, harvestmen, amphipods, millipedes, centipedes, cockroaches, and beetles also occupied the refuges. Invertebrate numbers in the refuges were monitored for 12 months before and 4 months after bait application on 22 August 2000. Bait application had no significant impact on the numbers of either species of weta, or on slugs, spiders, and cockroaches, the most numerous other invertebrates occupying the refuges. Bait application also had no effect on the number of individually marked tree weta resighted in the refuges. Few weta or other invertebrates were observed on baits at night. The concentration of 1080 in a cave weta collected alive from a bait, and in a tree weta collected alive from outside an artificial refuge, was less than 10% of the average lethal dose. The results indicate that 1080-poisoning for vertebrate pest control is unlikely to have any negative impact on populations of weta or the other invertebrates monitored.

Keywords: *Hemideina crassidens*; invertebrates; *Isoplectron* sp.; New Zealand; non-target species; poisons; vertebrate pest control; weta.

Introduction

The continued use of large-scale poisoning with sodium monofluoroacetate (compound 1080) as a technique for the control of introduced vertebrate pests in New Zealand, such as the brushtail possum (*Trichosurus vulpecula*) and ship rat (*Rattus rattus*), needs to be underpinned by reliable data on safety for non-target species. In this study, we investigated the impacts of hand-broadcast application, simulating aerial application, of cereal-based baits containing 1080 on weta (Orthoptera) and other invertebrates occupying artificial refuges.

Weta are large, flightless, nocturnal, endemic New Zealand invertebrates. There are two families: true weta (Anostostomatidae) with at least 40 species, and cave weta (Rhaphidophoridae) with at least 50 species (Meads, 1990; Johns, 1997; Gibbs, 1998; Morgan-Richards and Gibbs, 2001). True weta are divided into giant weta, tusked weta, tree weta, and ground weta.

Most weta are omnivorous, and eat both live and decaying matter (Barrett, 1991; Gibbs, 1998; I. Stringer, Department of Conservation, Wellington, N.Z., *pers. comm.*). At least 12 species have been observed eating carrot and/or cereal-based baits (Table 1). Residues of 1080 were detected in Auckland tree weta (*Hemideina thoracica*) and cave weta (species not identified) collected alive after a poisoning operation using Wanganui No.7 cereal-based bait containing 0.08% (800 µg g^{-1}) 1080 in Puketi Forest Park, Northland (Eason *et al*., 1993), and in Auckland tree weta and cave weta (*Gymnoplectron tuarti*) collected alive after a poisoning operation using Wanganui No.7 cereal-based bait containing 0.15% (1500 µg g^{-1}) 1080 in Rangataua Forest, central North Island (Lloyd, 1997; Lloyd and McQueen, 1998, 2000).

The concentration of 1080 found in weta appears to depend upon (a) whether the weta were collected directly from baits or from other locations within the forest, and (b) how long after bait application they were collected. The highest concentrations in both tree weta (66 µg g^{-1}) and cave weta (130 µg g^{-1}) have been found in specimens collected alive directly from baits (Lloyd and McQueen, 2000). Lower concentrations of 1080 have been detected in weta collected alive in the forest up to 4 weeks after 1080-poisoning operations (Eason *et al*., 1993).

The LD$_{50}$ of 1080 for the Wellington tree weta (*Hemideina crassidens*) is 91 μg g^{-1} (Booth and Wickstrom, 1999). Thus, on average, a 4 g adult Wellington tree weta requires about 350 μg of 1080, or 0.24 g of bait containing 1500 μg g^{-1} 1080, to receive a lethal dose. In a laboratory study, 12 tree weta (species not specified) survived more than 24 hours after oral dosing with 15 μg g^{-1} 1080; 67% of the 1080 was eliminated from the weta in 1–4 hours, and 90% in 4–6 days (Eason *et al*., 1993).

The non-target impacts of 1080-poisoning for possum control on weta populations have been assessed three times previously, using either call counting or pitfall trapping. At Waipoua Forest in September 1990, more weta (presumably Auckland tree weta) were heard calling at night after aerial 1080-poisoning than before (Pierce and Montgomery, 1992). At Puketi Forest Park in March 1992 and at Titirangi Scenic Reserve in June 1992, the number of cave weta (species not identified) caught in pitfall traps before and after aerial 1080-poisoning did not differ significantly in treatment and non-treatment areas (Spurr, 1994). Different monitoring techniques have different strengths and weaknesses, so it is prudent to use a range of techniques. In this study, we used artificial refuges (after Ordish, 1992; Gibbs, 1998; Sherley, 1998; Trewick and Morgan-Richards, 2000) and mark-recapture techniques to measure the impacts of 1080-poisoning on weta populations.

Table 1. Species of weta that have been reported eating carrot and/or cereal-based baits used for vertebrate pest control in New Zealand.

Family	Species	Reference
Anostostomatidae	*Hemideina crassidens*	Spurr and Drew, 1999
	Hemideina thoracica	Sherley *et al*., 1999; Lloyd and McQueen, 2000
	Hemiandrus maculifrons (=*Zealandosandrus gracilis*)	Sherley *et al*., 1999; Spurr and Drew, 1999; Lloyd and McQueen, 2000
	Hemiandrus sp. (=*Zealandosandrus* sp.)	Sherley *et al*., 1999; Spurr and Drew, 1999
	Hemiandrus n. sp. (=*Zealandosandrus* n. sp.)	Sherley *et al*., 1999
Rhaphidophoridae	*Gymnoplectron tuarti*	Sherley *et al*., 1999; Lloyd and McQueen, 2000
	Gymnoplectron sp.	Spurr and Drew, 1999
	Isoplectron sp.	Sherley *et al*., 1999; Spurr and Drew, 1999
	Neonetus sp.	Sherley *et al*., 1999; Lloyd and McQueen, 2000
	Pleioplectron sp.	Spurr and Drew, 1999
	Talitropsis sp.	Spurr and Drew, 1999
	Weta sp.	Sherley *et al*., 1999; Spurr and Drew, 1999; Lloyd and McQueen, 2000
	Unidentified sp.	Sherley *et al*., 1999; Lloyd and McQueen, 2000

Methods

The study area was in hardwood/podocarp forest, on a north-facing ridge, 400–600 m above sea level, in a tributary of the Ngatiawa River, Tararua Forest Park, North Island, New Zealand (175°74'93"E, 40°56'30" S). The area had been logged until the early 1970s, and is now regenerating.

The experimental design was a before-and-after treatment, in treatment and non-treatment plots design, commonly called a BACI (Before-After Control-Impact) design (McDonald *et al*., 2000). There were 20 plots, half of which were allocated randomly as treatment plots and half as non-treatment plots. The plots measured 50 m × 50 m, and were spaced at least 50 m apart in an attempt to ensure that weta would not move between them. Four transect lines 10 m apart were marked out within each plot, and points were marked at 10m intervals along each line (giving 16 internal points in each plot), for use during bait application and monitoring of weta numbers.

Bait application

The baits were green-dyed, cinnamon-lured, Wanganui No.7 cereal-based baits (Animal Control Products, Wanganui), nominally containing 0.15% (1500 µg g^{-1}) 1080 (w/w). Samples of bait assayed by gas chromatography in the Landcare Research Toxicology Laboratory, Lincoln, using the method of Anon. (1989), contained 1410 ± 141 µg g^{-1} 1080 (mean ± 95% confidence interval). This is within 10% of the nominal 1080 concentration.

The baits were applied to the treatment plots on 22 August 2000, by two people walking through each plot, along the four internal transect lines, and, about every 2 m, placing baits singly on the ground (marking their location) and also throwing baits approximately 2 and 4 m to each side to cover the area between the transect lines. The rate of bait application was 5 kg ha^{-1} (equivalent to about 200 × 6-g baits per plot), giving a predicted 1080 concentration in the litter of 0.01 µg g^{-1}, to a depth of 50 mm. This rate of bait application is similar to that used in management operations for possum control. The bait remained on the ground in good condition for at least 2 weeks. The first rain (15 mm) fell 5 weeks after bait application, followed by more than 1000 mm during the next week. Baits collected 1 week after application contained 750 ± 75 µg g^{-1} 1080, 2 weeks after application contained 270 ± 27 µg g^{-1} 1080, and 5 weeks after application contained <2 µg g^{-1} 1080, the lowest detectable level (LDL). There was no visible sign of bait left 6 weeks after application.

In addition to the above, 100 baits were placed singly on the ground at about 2 m intervals (and their positions marked), on each of two lines, at least 100 m away from the plots, so that weta (and other invertebrates) could be collected for species identification and analysis of 1080 residues (see below) without affecting numbers on the plots.

Weta and other invertebrates recorded on baits

The instantaneous numbers of weta and other invertebrates feeding on baits on the transect lines inside and outside the treatment plots were recorded from about 1 hour after sunset, for about 3 hours, for the first 3 nights after baits were put out. Weta and other invertebrates were collected from baits outside the plots and analysed for 1080 residues in the Landcare Research Toxicology Laboratory, using the method of Ozawa and Tsukioka (1989).

Impacts of bait on weta and other invertebrates

Artificial refuges were constructed from untreated pine (*Pinus radiata*). The design was similar to that shown by Sherley (1998), except there were three replicates of the top third of the refuge (i.e. there were six galleries in each refuge) (Fig. 1). The entrances were all 12 × 20 mm. The large galleries were 20 mm deep × 50 mm wide × 75 mm long, with a tunnel 12 × 20 × 80 mm leading from the entrance. The small galleries were 20 × 20 × 75 mm, with no tunnel.

The artificial refuges were located randomly at 10 of the 16 marked points along the internal transect lines within each treatment and non-treatment plot. The refuges were thus at least 10 m apart. Initially, half of the refuges were attached vertically to the base of the closest tree or tree fern, on the sheltered side, with the bottom touching the ground, and half were placed flat on the ground (either under the closest log, or closest patch of scrub or moss) and sheltered so rain could not enter, in the hope that ground weta as well as cave weta and tree weta would occupy them. However, after January 2000, all refuges were attached vertically to the base of trees or tree ferns, because of the low occupancy of those lying on the ground.

The artificial refuges were put out in August 1999 (12 months before bait application), and inspected for occupancy by weta and other invertebrates at monthly intervals from October 1999 to July 2000 (3 weeks before bait application), and from late August 2000 (1 week after bait application) to late December 2000 / early January 2001 (4 months after bait application).

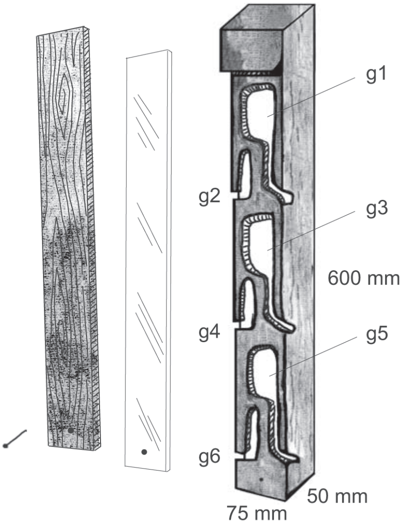

Figure 1. Structure of artificial refuges used for monitoring weta populations (g1–g6 represent individual galleries).

Tree weta occupying the refuges were individually marked with coloured, high-quality, fast-drying enamel nail polish or white spirit-based correction fluid applied to the back of the thorax, abdomen, and/or hind-legs. Cave weta could seldom be individually marked because of their small size and rapid movements. Twelve "colours" were used for marking: red, pink, sparkling red, sparkling blue, gold, silver, and rainbow (all Revlon brand), lavender, orange, green, and flesh (all Sally Hansen brand), and white (Orbit correction fluid). Red, pink, lavender, orange, green, and flesh were the easiest to detect in the dim forest light. The markings were renewed every 2–3 months on previously marked individuals still present in the refuges.

Weta were identified either to species, genus, or family, and tree weta were also identified individually from a combination of colour-markings, sex, and length at each inspection. Length was measured from the tip of the head to the rear of the abdomen (excluding the antennae, cerci, and ovipositor), using calipers whenever possible, otherwise estimated to the nearest 5 mm, without handling the weta. Length is an indicator of age: Spencer (1995) found males matured between the 8th instar (average 36.6 mm body length) and the 10th instar (average 54.5 mm), whereas females matured only in the 10th instar (average 44.9 mm body length). Other invertebrates occupying the refuges were recorded when present.

The effect of treatment (1080-poisoning) on the populations of weta and other invertebrates occupying the artificial refuges was determined using a generalised linear model (McCullagh and Nelder, 1989) in the statistical package S-Plus 6 for Windows (Insightful Corporation, Seattle, Washington, U.S.A., 2001). The analysis compared the mean numbers of each taxon per plot in the treatment and non-treatment plots each month. A generalised linear model provides the same type of inferences as a linear model, but corrects for the variance of counts being proportional to their mean rather than constant. A log transformation was also used because equal proportional differences are generally of equivalent biological importance. The effect of treatment (1080-poisoning) on the survival of individually marked tree weta occupying the artificial refuges was determined using a log rank test (Fleming

Table 2. Weta and other invertebrates recorded on Wanganui No.7 cereal-based baits at night (1900–2200 hours), Tararua Forest Park, 22–24 August 2000. The percentage of baits with other invertebrates on them is generally less than the number of invertebrates divided by the number of baits because some baits had more than one invertebrate on them.

	Night 1	Night 2	Night 3	Total
No. of baits checked	1132	883	1071	3086
No. of weta:				
Cave weta	6	2	5	13
Ground weta	0	2	0	2
Tree weta	0	0	1	1
Total weta	6	4	6	16
No. of weta per bait	0.005	0.005	0.006	0.005
% of baits with weta	0.5	0.5	0.6	0.5
No. of other invertebrates:				
Snails (Stylommatophora)	0	1	0	1
Slugs (Stylommatophora)	1	0	0	1
Spiders (Araneae)	4	1	2	7
Mites (Acari)	3	0	0	3
Harvestmen (Opiliones)	26	10	1	37
Amphipods (Amphipoda)	15	7	13	35
Millipedes (Diplopoda)	2	1	0	3
Springtails (Collembola)	18	14	15	47
Cockroaches (Blattodea)	0	0	1	1
Beetles (Coleoptera)	2	5	5	12
Caterpillars (Lepidoptera)	0	0	2	2
Flies (Diptera)	0	0	1	1
Ants (Hymenoptera)	1	2	4	7
Unknown	1	0	0	1
Total other invertebrates	73	41	44	158
% of baits with other invertebrates	5.2	4.5	3.8	4.5

and Harrington, 1981), and assessed for significance against a Chi-square distribution, also in the statistical package S-Plus 6.

Results

Weta and other invertebrates recorded on baits

Only 5% of the 3086 baits inspected at night had weta or other invertebrates on them at any one instant (Table 2). Thirteen cave weta (12 *Isoplectron* sp. and one *Weta* sp.) were observed on baits. Two ground weta (species not identified) and one Wellington tree weta were also observed on baits. None of the weta on the baits was marked (see below). The other invertebrates recorded on baits were mainly springtails (Collembola), harvestmen (Opiliones), and amphipods (Amphipoda) (Table 2).

One cave weta (probably *Isoplectron* sp.) collected alive from a bait, 2 nights after bait application, contained 4.0 μg g^{-1} 1080 (LDL = 0.02 μg g^{-1}). One tree weta collected alive, though lethargic, on the ground outside an artificial refuge 7 days after bait application contained 8.6 μg g^{-1} 1080 (LDL = 0.02 μg g^{-1}). One weevil (species not identified) collected alive from a bait (on night 2) contained 10.0 μg g^{-1} 1080 (LDL = 2.0 μg g^{-1}). No invertebrates were found dead, but dead possums and ship rats were found on the treated plots.

Impacts of bait on weta in the artificial refuges

Only two species of weta occupied the artificial refuges: the Wellington tree weta and *Isoplectron* sp. cave weta. The number of refuges (and galleries within these refuges) occupied by the two species increased steadily over time (Fig. 2). At the end of the study, after 16 months, tree weta occupied 47% of the 100 refuges (12.3% of the 600 galleries) in the treatment plots, and 44% of the 100 refuges (11.5% of the 600 galleries) in the non-treatment plots. At the same time, cave weta occupied 25% of the refuges (5.5% of the galleries) in the treatment plots, and 36% of the refuges (9.8% of the galleries) in the non-treatment plots. There was almost always only one weta per gallery, and in only two instances did the two species share the same gallery.

The numbers of both tree weta and cave weta per plot increased steadily over the 16 months of the study, and were generally similar in the treatment and non-treatment plots (Fig. 3, Table 3). However, there were nearly twice as many tree weta in the treatment plots as in the non-treatment plots in May 2000 ($F_{1,18} = 5.059$, $P = 0.037$), and fewer than half as many cave weta in the treatment plots as in the non-treatment plots in May ($F_{1,18} = 4.785$, $P = 0.042$) and June 2000 ($F_{1,18} = 6.098$, $P = 0.024$), 2–3 months before bait application. In July 2000, 3 weeks before bait application, there were 56 tree weta (46 males, 10 females) and 38 cave weta (sex mostly unknown) in the 600 galleries in the 10 treatment plots, and 46 tree weta (43 males, 3 females) and 43 cave weta (sex mostly unknown) in the 600 galleries in the 10 non-treatment plots. The mean numbers of individuals per plot did not differ significantly between the treatment and non-treatment plots for either tree weta ($F_{1,18} = 0.368$, $P = 0.551$) or cave weta ($F_{1,18} = 0.097$, $P = 0.759$).

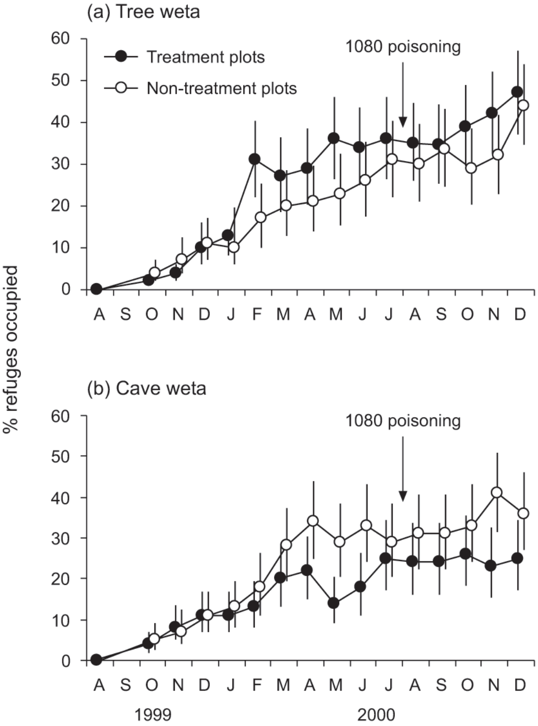

Figure 2. Percentage of artificial refuges (± 95% binomial confidence intervals) occupied by weta, Tararua Forest Park, August 1999 to December 2000.

The hand-broadcast application (simulating aerial application) of 1080 baits in the treatment plots on 22 August 2000 had no significant impact on the numbers of either tree weta or cave weta occupying the artificial refuges 1 week to 4 months afterwards (Fig. 3, Table 3). The number of cave weta in the treatment plots in November and December 2000 appeared to be lower than in the non-treatment plots, but unlike May and June 2000 the difference was not statistically significant.

By December 2000, 604 individual tree weta (423 males, 135 females, and 46 of unknown sex) had

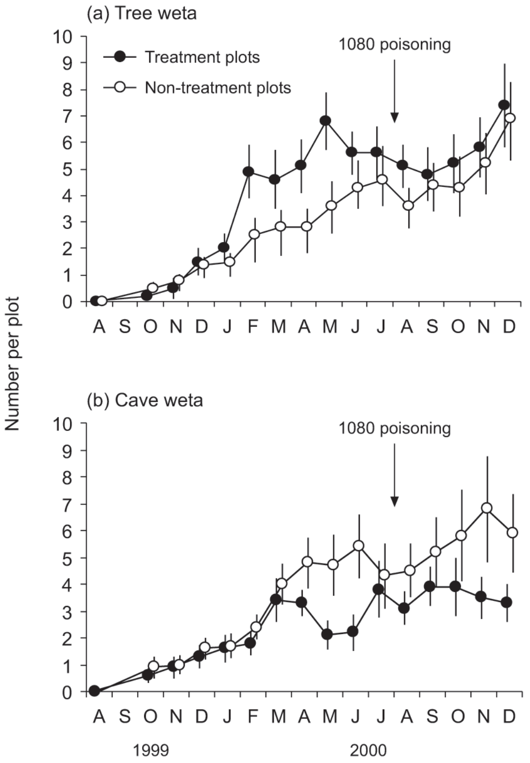

Figure 3. Mean number of weta per plot (± standard error) occupying artificial refuges, Tararua Forest Park, August 1999 to December 2000.

occupied the artificial refuges during the course of the study. Most female tree weta (63%) were 45 mm or more in length (mean 48.9 mm, range 15–80 mm). However, most males (71%) were less than 45 mm in length, and 30% were only 30 mm in length (mean 38.3 mm, range 20–70 mm). Most of those of unknown sex were 20 mm or less in length. The body lengths of cave weta recorded during the study ranged from 5 mm to 30 mm. In December 2000, at the end of the study, about 50% of the females were 20 mm in length, and 50% of the males were 10 mm in length.

Impacts of bait on marked weta

Of the 56 and 46 individually marked tree weta in the treatment and non-treatment plots in July 2000, 3 weeks before bait application, 80% and 72%, respectively, were resighted alive 1 week after bait application (Fig. 4). There was no significant difference in the proportion of individually marked tree weta resighted alive in the treatment and non-treatment plots up to 4 months after bait application ($\chi^2 = 0.5$, d.f. = 1, $P = 0.479$).

Some marked tree weta may have lost their markings between resightings, but we were not able to measure the extent of this. However, at least 76% of the 102 marked tree weta present in July 2000 were still identifiable after 1 month, and 59% after 2 months, without the markings being renewed. Of 198 marked tree weta that were resighted during the course of the study, 13 were resighted after an absence of 2–4 months, and two after 6–7 months. The nail polish on these weta lasted at least 5 months on the thorax and abdomen, and at least 8 months on the hind-legs.

Some marked tree weta may have moved out of

Table 3. Probability values derived from a generalised linear model comparison of the numbers of invertebrates occupying artificial refuges in the treatment and non-treatment plots, before (October 1999 to July 2000) and after (August 2000 to December 2000) experimental 1080-poisoning, Tararua Forest Park, 22 August 2000. Dash indicates numbers too low to test. $P < 0.05$ indicates a significant difference between treatment and non-treatment plots (highlighted in bold below).

Date	Tree weta	Cave weta	Cockroaches	Spiders	Slugs
Oct-99	0.251	0.535	0.204	**0.043**	–
Nov-99	0.562	0.852	0.820	0.374	–
Dec-99	0.865	0.615	0.339	0.086	–
Jan-00	0.443	0.886	0.680	0.695	–
Feb-00	0.054	0.359	0.944	0.670	0.391
Mar-00	0.160	0.593	0.962	0.240	1.000
Apr-00	0.067	0.157	0.543	0.295	0.201
May-00	**0.037**	**0.042**	0.355	0.777	0.121
Jun-00	0.351	**0.024**	0.534	0.746	0.174
Jul-00	0.551	0.759	0.853	0.913	0.936
Aug-00	0.177	0.243	0.712	0.086	0.825
Sep-00	0.758	0.384	0.633	0.115	0.883
Oct-00	0.584	0.350	0.381	0.465	0.664
Nov-00	0.718	0.108	0.553	0.207	0.250
Dec-00	0.813	0.103	0.141	0.761	0.746

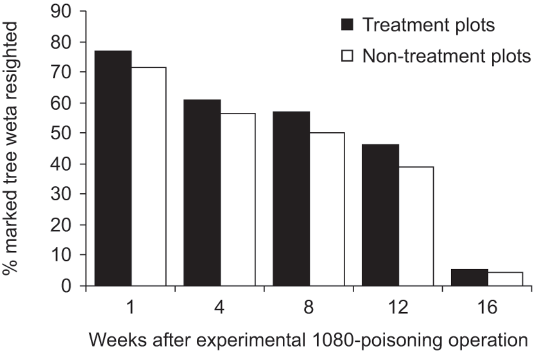

Figure 4. Percentage of individually marked tree weta resighted after the experimental 1080-poisoning operation in August 2000, Tararua Forest Park.

the refuges into natural cavities, but we had no way of measuring this. Of the 198 marked tree weta that were resighted during the course of the study, most (94%) were resighted in the same refuges (and often the same gallery) in which they were originally marked. Of the 11 tree weta (6%) that moved between refuges, seven moved 10 m to a directly adjacent refuge (in 1 month), one moved 14 m to a diagonally adjacent refuge (in 1 month), one moved 23 m (in 1 month), and two moved 30 and 32 m (in 6–7 months). No marked tree weta moved between plots (which would have involved a movement of at least 70 m).

Only nine cave weta were individually marked (in November and December 1999). No marked cave weta were present in the refuges at the time of the 1080-poisoning in August 2000.

Impacts of bait on other invertebrates

Invertebrates other than weta that occupied the artificial refuges were flatworms (Turbellaria), snails (Stylommatophora), slugs (Stylommatophora), spiders (Araneae), harvestmen (Opiliones), amphipods (Amphipoda), millipedes (Diplopoda), centipedes (Chilopoda), cockroaches (Blattodea) and beetles (Coleoptera). Cockroaches, slugs and spiders were the most common. There were no significant differences in the numbers of these invertebrates occupying the artificial refuges in the treatment and non-treatment plots before or after 1080-poisoning (Fig. 5, Table 3).

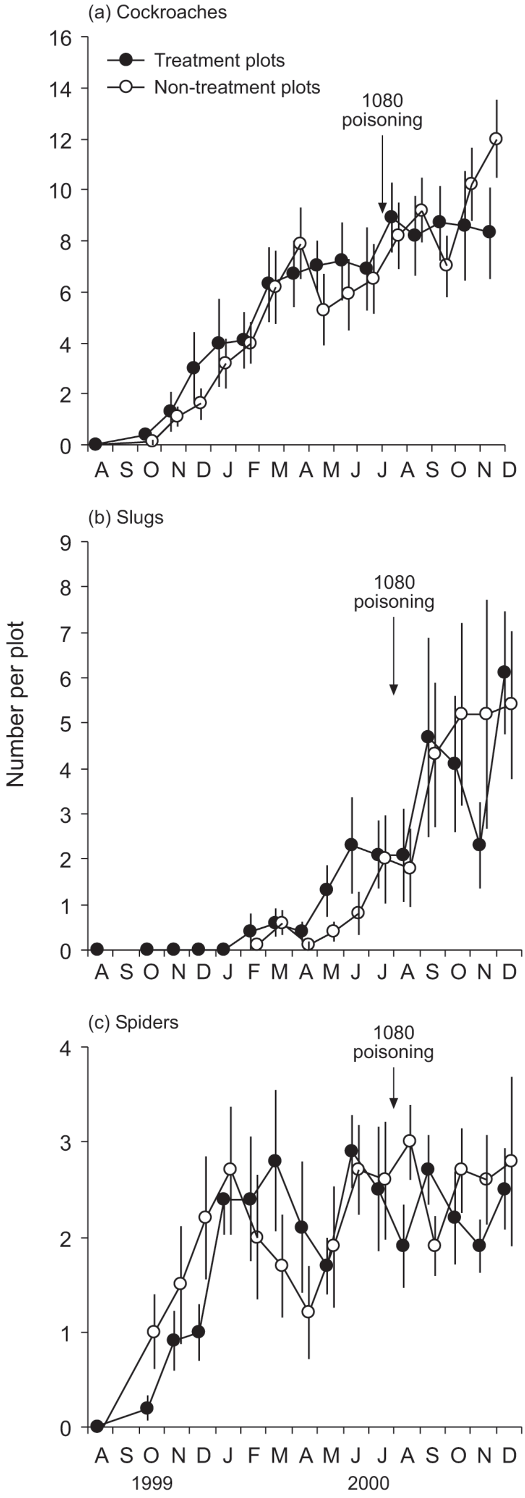

Figure 5. (at right) Mean number of cockroaches, spiders and slugs per plot (± standard error) occupying artificial refuges, Tararua Forest Park, August 1999 to December 2000.

Discussion

Impacts of 1080-poisoning

We found few weta or other invertebrates feeding on baits, 1080 concentrations in weta less than 10% of the LD_{50}, no impact on the numbers of weta or other invertebrates occupying the artificial refuges, and no impact on the numbers of marked tree weta that were resighted after bait application. This indicates that 1080-poisoning for vertebrate pest control is likely to have had no impact on the populations of weta or other invertebrates we monitored. Our results are similar to those of previous studies on other species of weta in other parts of New Zealand, using different monitoring techniques (Pierce and Montgomery, 1992; Spurr, 1994; Sherley *et al*., 1999).

Our finding that few tree weta or cave weta fed on baits is consistent with observations that mature tree weta, at least, spend little time on the ground (Moller, 1985). The 0.5% of baits that had weta on them at any one instant at night is less than the 5% we observed in rata/kamahi forest on the West Coast at a similar time of year, although at a lower altitude and probably higher temperature (Spurr and Drew, 1999). Based on an LD_{50} of 91 µg g^{-1} for tree weta (Booth and Wickstrom, 1999), the concentration of 1080 detected in the two weta (one tree weta and one cave weta) collected alive (8.6 and 4.0 µg g^{-1} in the whole specimens) is less than 10% of the average lethal dose. Of course, they may have ingested more 1080 if they had been allowed to feed on baits for longer before being collected. Cave weta (*Gymnoplectron tuarti*) have been collected alive containing up to 130 µg g^{-1} 1080 (Lloyd and McQueen, 2000). Thus, mortality of individual weta from 1080-poisoning is possible. However, given the low number of weta feeding on baits and the high LD_{50} value, it is not surprising that we found no evidence for any impact of 1080-poisoning on weta populations occupying the artificial refuges.

The other invertebrates recorded in the artificial refuges were similar to those reported by other observers from both artificial and natural galleries (Ordish, 1992; Trewick and Morgan-Richards, 2000; Field and Sandlant, 2001). Some of these invertebrate groups (e.g. cockroaches, slugs, and spiders), although not necessarily the same species, have been observed on baits. However, only 4.5% of the baits we inspected had other invertebrates on them at any one instant at night. We found no evidence for any impact of 1080-poisoning on the numbers of these invertebrates occupying the artificial refuges.

The scale of our study was too small, and the duration probably too short, to determine whether there were any benefits to weta or other invertebrates from the poisoning of possums and rats. Reinvasion of possums and rats into the small (0.25 ha) plots would have been rapid, so any relief from predation would have been short. McIntyre (2001) found a marked increase in abundance of the Cook Strait giant weta (*Deinacrida rugosa*) after the eradication of house mice (*Mus musculus*) from Mana Island. However, Rufaut and Gibbs (2003) did not detect any increase in Wellington tree weta abundance over a 4-year period after eradication of kiore (*R. exulans*) from Nukuwaiata (Inner Chetwode) Island.

Use of artificial refuges as a monitoring tool

The artificial refuges proved useful for monitoring the impacts of 1080-poisoning on some species of invertebrates. They were readily occupied by Wellington tree weta and one species of cave weta (*Isoplectron* sp.), as well as by other invertebrates such as cockroaches, slugs and spiders. Other species of weta did not occupy the refuges, although at least one species of ground weta (*Hemiandrus maculifrons* = *Zealandosandrus gracilis*) and several other species of cave weta (e.g. *Macropathus* sp., *Neonetus* sp., *Pleioplectron* sp., *Turbottoplectron* sp., and *Weta* sp.) have been caught in pitfall traps in the same general area in Tararua Forest Park (authors' unpublished data).

Ideally, weta that occupy galleries in artificial refuges should be representative of the weta population in the surrounding area in terms of sex ratio and age class. The sex ratio in *Hemideina crassidens* populations is normally 1:1 (Stringer, 2001). However, we found more males than females of both *H. crassidens* and *Isoplectron* sp. in the refuges. This is consistent with the observation that males are normally the first to occupy new galleries (Ordish, 1992).

We found a range of size classes of Wellington tree weta in the refuges, including mature adults, but none less than 15 mm in body length. This is consistent with the observation that tree weta apparently begin to occupy galleries only when about half grown (Gibbs, 1998). Most of the females in our refuges were probably adults, but most of the males were probably sub-adults, based on the age-class measurements of Spencer (1995). We were not able to monitor for long enough after bait application to determine whether a size-class gap occurred in weta occupying the refuges, which might have happened if the small size classes (or young age classes) were more susceptible to 1080-poisoning than larger, older age classes.

Use of mark-recapture as a monitoring tool

Mark-recapture (or resighting) also proved useful for monitoring the impacts of 1080-poisoning on tree weta. It enabled us to determine the fate of individual weta as well as the population response. The disappearance of marked tree weta from the artificial refuges was not necessarily the result of mortality (from natural causes, predation or 1080-poisoning). Some weta could have lost their markings between surveys or moved to natural galleries. Moller (1985) found that 58% of Wellington tree weta marked with nail polish (brand not specified) lost their markings after 1 night, and 61% after 7 nights. Ordish (1992) found that Wellington tree weta marked with quick-drying paint (brand also not specified) abandoned the gallery overnight, and suggested that this was in response to the solvent. The nail polish we used (Revlon and Sally Hansen brands) lasted longer than that used by Moller (1985), and we did not observe the mass abandonment of galleries reported by Ordish (1992). We could still identify 76% of our marked weta after 1 month, and 59% after 2 months. The nail polish on one weta lasted at least 8 months. However, we renewed the markings on most weta every 2–3 months to avoid the possibility of losing individual identity. Christensen (2003) also found that paint marks on weta lasted up to 8 months. A more permanent method of marking, such as numbered paper tags glued onto the pronotum (Jamieson *et al.*, 2000), or the use of miniature radio transmitters (McIntyre, 2001), would be an advantage for longer-term studies of adult weta.

Marking also enabled us to determine weta movements. Most marked tree weta resighted at monthly intervals were in the same refuge, and often the same gallery, in which they were marked. The longest distance moved that we detected was 32 m (in 6 months). Other observers have also noted that weta generally move only short distances (Cary, 1981; Moller, 1985; Ordish, 1992; Jamieson *et al.*, 2000; McIntyre, 2001). Thus, it is likely that the weta in our study will have remained within the study plots during the 6 weeks that baits were present on the forest floor.

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