

Distinguishing Mercury Islands tusked weta,  
*Motuweta isolata*, from a ground weta,  
*Hemiandrus pallitarsis* (Orthoptera:  
Anostostomatidae) in the field, with  
observations of their activity

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# Distinguishing Mercury Islands tusked weta, *Motuweta isolata*, from a ground weta, *Hemiandrus pallitarsis* (Orthoptera: Anostostomatidae) in the field, with observations of their activity

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## ABSTRACT

Mercury Islands tusked weta, *Motuweta isolata*, is a rare insect found naturally only on 13-ha Middle Island (official name now Atiu or Middle Island) in the Mercury Islands, northern New Zealand. The New Zealand Department of Conservation is attempting to establish additional populations of this weta on two other mammal-free islands in the Mercury Islands to enhance its long-term survival prospects. Morphological characters were needed to distinguish between juveniles of *M. isolata* and a ground weta, *Hemiandrus pallitarsis*, which is common on Middle Island and which closely resembles *M. isolata*. The best character was the number of postero-dorsal spines on the mesotibia: *M. isolata* has two and *H. pallitarsis* has three. Protibial tympanal organs are present only in 2nd instar and older *M. isolata* but were hard to distinguish (using a hand lens) from subgenual organs in small *H. pallitarsis*. Adult female *H. pallitarsis* also possess a unique elongated bilobed process between the 6th and 7th abdominal sternae. If accurate field measurements of the pronotum, protibia, and metafemur are made, many weta can be identified later using quadratic discriminant analysis. Four Mercury Islands tusked weta were found during 65 nights of searching on Middle Island between October 1998 and April 2003. These individuals were active on nights with little or no wind, little or no moonlight, temperatures 15.9–19.2°C, and relative humidity > 87.4%. Mercury Islands tusked weta translocated from captivity to Double Island (Moturehu) and Red Mercury Island (Whakau), were active on nights with similar conditions—temperatures 11.5–20.5°C, and relative humidity > 79%. The use of baited traps, oviposition trays or artificial cover objects on Middle Island did not improve detection of tusked weta. A total of 717 ground weta were found. They were active at temperatures > 9°C and relative humidity > 60%. The number of weta observed on any particular night had a significant non-linear relationship with soil temperature, soil moisture content and air temperature, but was independent of rainfall, saturation vapour deficit or relative humidity.

Keywords: New Zealand, Mercury Islands, Mercury Islands tusked weta, *Motuweta isolata*, ground weta, *Hemiandrus pallitarsis*, identification features, activity, meteorological relationship

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# 1. Introduction

This research was initiated in 1998 after the Mercury Islands tusked weta, *Motuweta isolata* Johns (Orthoptera: Anostostomatidae), was identified as a top priority for conservation research (Sherley 1998). At that time, the species was ranked as highly endangered (Molloy et al. 1994) and research was urgently required to identify its habitat requirements and to develop methods for translocating the species onto other mammal-free islands in the Mercury Islands, off the northeast coast of New Zealand's North Island (Sherley 1998) (Fig. 1). The intention of such translocations was to increase the number of populations and thereby reduce the chance that the species could become extinct by accident. This could happen if, for example, there was a fire on Middle Island (official name now Atiu or Middle Island) or rodents reached it. *Motuweta isolata* is now classified as Nationally Critical (Hitchmough 2002), and some information on its habitat and lifecycle (both in the laboratory and the field), behaviour and behavioural ecology has been reported (McIntyre 1990, 1991, 1994, 2001; Winks & Ramsay 1998; Field & Deans 2001; Field & Jarmin 2001; Gibbs 2001; Winks et al. 2002; Guignon 2005; Stringer et al. 2006). This includes information on the relationship between *M. isolata* activity and moonlight and some other meteorological conditions (McIntyre 2001). Such information is particularly relevant to survey work.

This research comprised one of three concurrent investigations related to translocating *M. isolata*. The present study was primarily directed towards increasing our knowledge of where and when they are found on Middle Island. It included, as a first step, investigating how to reliably distinguish *M. isolata* from a ground weta, *Hemiandrus pallitarsis* (Walker) (Orthoptera: Anostostomatidae), that is common on Middle Island but looks very similar to juvenile *M. isolata* of the same size (body length c. < 2.5 cm). These are the only two anostostomatid species on Middle Island. The investigation involved examining all known preserved specimens of *M. isolata* and *H. pallitarsis* from Middle Island together with preserved specimens of *H. pallitarsis* collected from elsewhere on the North Island of New Zealand. Measurements were also analysed from live specimens of *H. pallitarsis* found on the island and similar-sized juveniles of *M. isolata* that were captive-reared. The latter data for *M. isolata* came from the second of the three studies: a laboratory investigation of growth and development of Mercury Islands tusked weta. This was undertaken so that the growth stages (instars) of *M. isolata* found in the field could be recognised (Stringer et al. 2006). The third investigation was an experimental translocation of *M. isolata* onto two other islands in the Mercury Islands. The results of this study have not yet been published.

I used the opportunity of visiting Middle Island to explore some alternative methods for monitoring or detecting the presence of *M. isolata*. This involved testing three potential oviposition substrates to see if eggs of *M. isolata* could be detected, placing a variety of artificial cover objects on the ground in the hope that *M. isolata* weta might form burrows under them, and testing the attractiveness of a variety of foods for use as possible attractants. Artificial cover objects were used because M. McIntyre (pers. comm.) found that *M. isolata* weta often dug burrows under or alongside rocks. The numbers of food items tested on any one

night, and the methods used for testing attraction were severely constrained because of the risk of increasing predation on *M. isolata* and other rare animals that are present on Middle Island (Gibbs 1989; Towns et al. 1990). This study was also used to record observations on the ground weta *H. pallitarsis* because they are commonly found wherever *M. isolata* weta occur and whenever they are active.

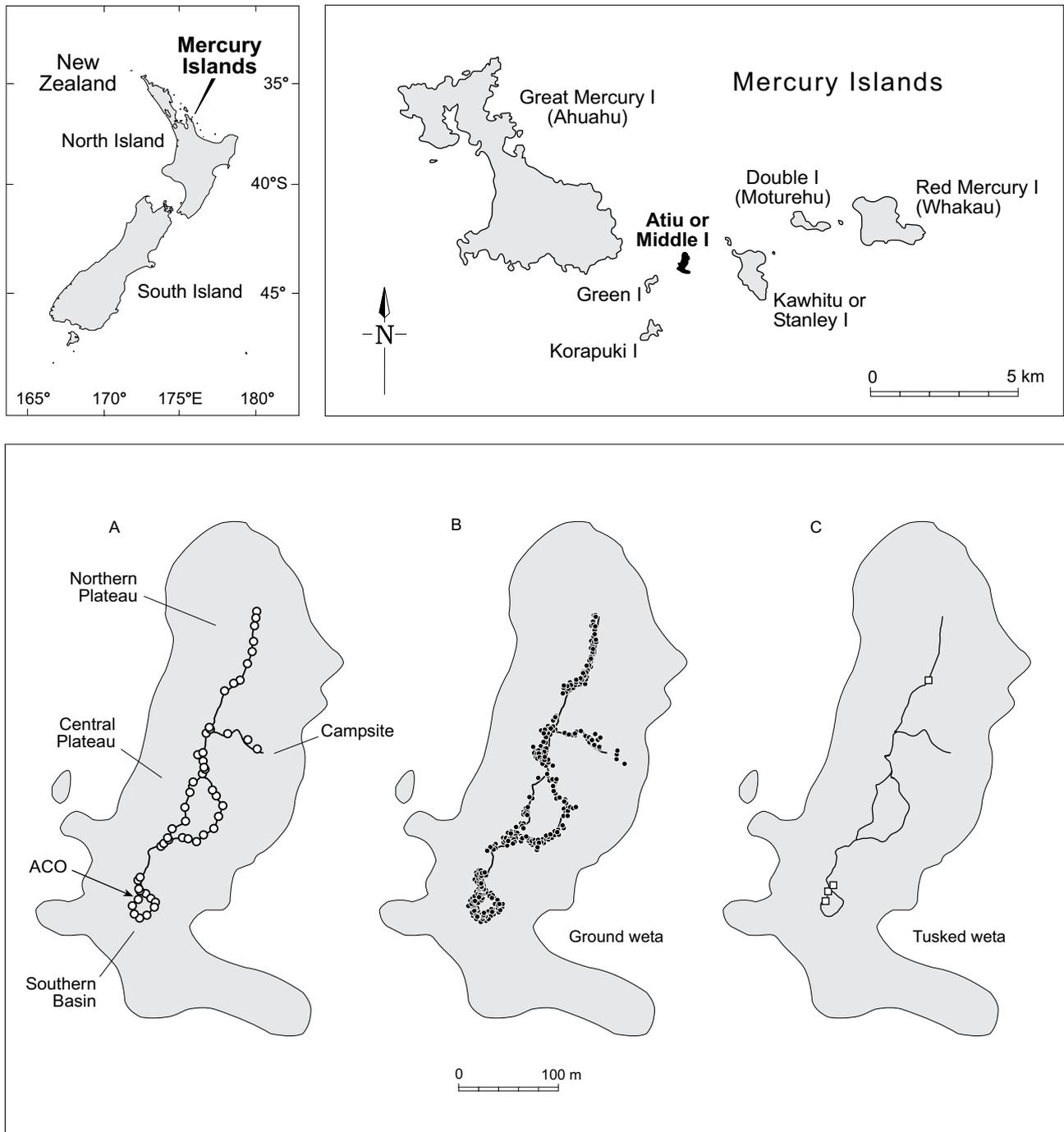


Figure 1. Map of the Mercury Islands showing Middle Island (official name now Atiu or Middle Island). **A.** Map of the path followed for searching at night showing the main regions of the island and positions of numbered trees (open circles) used as reference points for obtaining positions of weta. The region where artificial cover objects were placed is indicated at ACO. **B.** Positions where ground weta, *Hemiandrus pallitarsis*, were found (dots) in relation to the path. **C.** Positions where tussock weta, *Motuweta isolata*, were found (open squares) in relation to the path.

## 1.1 BACKGROUND

Mercury Islands tusked weta, *Motuweta isolata*, is the largest of three known species of tusked weta in New Zealand (Gibbs 2001). It is seldom seen because individuals usually remain in underground chambers and only emerge to feed on other invertebrates on the darkest nights, when there is no moon and it is calm, warm and damp (McIntyre 2001). This tusked weta has survived only on Middle Island, a 13-ha island in the Mercury Islands (Fig. 1), probably because introduced mammals never colonised it. Middle Island is the largest of four islands (including two rock stacks with some vegetation) in the Mercury Islands that rats never reached. None have fresh water streams, and Middle Island, which is also largely surrounded by cliffs, is accessible only when the sea is calm. It is clear that Maori visited Middle Island in the past, probably to collect seabird chicks for food. Today, thousands of seabirds breed on the island in burrows, wherever the soil is sufficiently deep, at such high densities that it is difficult to walk without damaging nests. Low coastal broadleaf forest with emergent pohutukawa (*Metrosideros excelsum*) trees grows on steeper slopes of the island, and a unique forest of milk tree (*Streblis banksii*), together with other broadleaf species, covers gently sloping areas on top of the island (Atkinson 1964; Cameron 1990). The forest floor is largely bare of vegetation. Leaf litter accumulates in some areas but is usually sparse under much of the forest for most of the year. Eleven species of reptile are recorded from Middle Island, together with a range of land and sea birds, and invertebrates (e.g. Gibbs 1989; Towns et al. 1990; Cameron 1990). Mercury Islands tusked weta were probably present on all of the larger Mercury Islands before Pacific rats (*Rattus exulans*) reached them, because these islands formed one large island about 6500 years ago when sea levels were lower (Hayward 1986; Towns 1994).

## 2. Methods

All procedures involving Mercury Islands tusked weta and the use of and amount of equipment placed on Middle Island were subject to approval by the Tusked Weta Recovery Group, set up by the Waikato Conservancy of the Department of Conservation.

### 2.1 DISTINGUISHING MERCURY ISLANDS TUSKED WETA FROM GROUND WETA

#### 2.1.1 Morphological features

Morphological features for distinguishing Mercury Islands tusked weta *M. isolata* from the ground weta *H. pallitarsis* were initially determined by examining and comparing all known preserved specimens (33) of *M. isolata*, one specimen of *H. pallitarsis* collected from Middle Island and held by M. McIntyre, University of Otago, Wellington, and 21 preserved specimens of *H. pallitarsis* collected

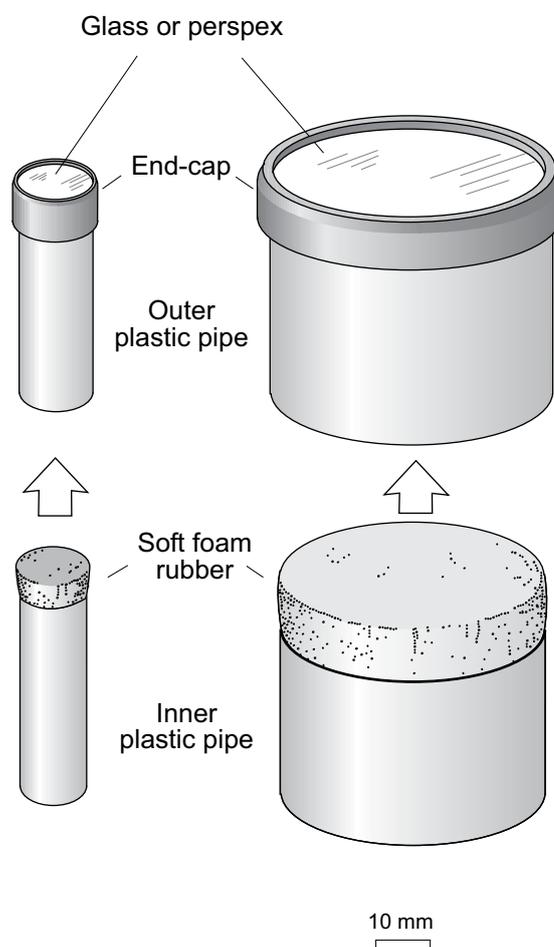
from elsewhere in the North Island of New Zealand and held by the Museum of New Zealand Te Papa Tongarewa, Wellington. A further 97 specimens of other species of *Hemiandrus* were also examined in the Museum of New Zealand.

Morphological differences identified by examining preserved specimens were confirmed by examining many of the ground weta and all tussock weta found on Middle Island during this study. Additionally, information from 21 captive-reared tussock weta was also used (Stringer et al. 2006). Examination of ground weta on Middle Island involved marking where they were found by inserting numbered white plastic tags into the soil and capturing them in numbered plastic jars. They were then taken to the campsite where they were measured, as described below, and examined under a binocular microscope to confirm that they lacked protibial tympanal organs. All were released at the sites where they had been found, usually later the same night, but some weta captured close to dawn were released the following night.

### 2.1.2 Measuring live weta

Morphological structures longer than about 13 mm were measured to the nearest 0.02 mm with calipers. Smaller structures were measured using a binocular microscope fitted with a linear eyepiece graticule. Weta were immobilised so that they could be measured under the microscope, using observation chambers made from standard domestic plastic water pipe and fittings (Fig. 2). Each chamber had a clear Perspex observation window held in place at the end of

Figure 2. Details of small and large observation chambers used to hold weta while they were measured. Weta were gently trapped against the glass by the foam rubber when the inner pipes are inserted into the outer pipes and pushed upwards.



the outer pipe with a plastic end-cap fitting which had most of the end drilled out. This end-cap formed a friction-fit with the outer pipe of the observation chamber, allowing easy access for cleaning. A pad of soft plastic foam, pushed partway into the end of an inner pipe, was used like a piston within a cylinder, to gently immobilise weta against the observation window. This foam plug was slightly larger than the outer pipe so it held its position by friction inside the outer pipe.

## 2.2 TRIALS OF SURVEY METHODS

### 2.2.1 Attractant trials

An attempt was made to test different foods for their attraction to Mercury Islands tusked weta by putting a variety of baits out at night, and subsequently observing what animals were on the baits or within 5 cm of them whenever a searcher passed by. Initially (24–27 November 1998), the baits were placed on plywood squares (75 mm × 75 mm) but these were replaced on 16 April 1999 with white plastic squares (75 mm × 75 mm) covered with cages (8 cm × 8 cm × 5 cm) of galvanised wire mesh (mesh 25 mm × 25 mm). The cages prevented tuatara and geckos from consuming the bait.

Three pitfall traps were set about 5 m apart alongside the track on the northern plateau (Fig. 1). This was the maximum number of traps allowed by the Tusked Weta Recovery Group because of a need to minimise catching endangered skinks, which are present on the island, together with giant centipedes (*Cormocephalus rubriceps* (Newport)) which prey on them (Townsend et al. 1990). Each pitfall trap consisted of a commercial paint tin (160 mm diameter opening, 190 mm high) sunk into the soil with the opening flush with the surface of the ground. A sheet of galvanized steel (250 mm × 250 mm) was positioned about 50 mm above the opening to keep rain and large seabirds out. Bait was placed on a leaf in the bottom of each tin after dark and the pitfall traps were checked again at intervals during the night. The bait was removed and the tins inverted after the final check each night.

### 2.2.2 Artificial cover objects

Ten concrete tiles (230 mm × 190 mm × 30 mm) were placed on the soil in the south basin within 3 m of the track (location indicated by ACO in Fig. 1A). This location was where Mercury Islands tusked weta were most frequently found in the past (M. McIntyre, pers. comm.). Each tile was held in place by two U-shaped pegs of galvanized wire that were pushed into the ground on either side of the tile and crossed over on top of the tile.

Ten plastic plant pot saucers (diameter 26 cm) were placed right way up and 3–4 m apart alongside the track in the south basin on 26 September 2000. The leaf litter was first removed and the soil broken up finely before a saucer was placed over it. Each saucer was fixed in place by placing a substantial rock onto it and driving two galvanized wire pegs into the ground through holes drilled opposite each other in the saucer base near the outer edge of the saucer.

All tiles and plastic plant pot saucers were lifted each time the island was visited and anything found under them was recorded.

### 2.2.3 Oviposition trials

Three oviposition trays were set up 5–8 m apart in the south basin on 30 November 1998. Three different substrates were used—one in each tray. These were sterilised commercial potting mix, washed beach sand, and soil from the south basin. The soil was replaced on 4 October 1999 with sterilised soil from Mt Eden after advice from Chris Winks (Landcare Research, Auckland, pers. comm.) that captive *M. isolata* weta preferred this for ovipositing in.

Each oviposition tray was a plastic tray 38 cm × 28 cm × 5 cm with a row of small holes drilled around the sides, 2 cm below the top, to allow rainwater to seep out and prevent the topmost layer of substrate from becoming water-logged. Each tray was placed level on a cleared area of soil, covered with galvanized wire mesh (25 mm × 25 mm) to prevent tuatara and seabirds digging into it, and held in place with wire pegs. The substrate was kept moist using a 1.5-L plastic drink bottle of water, with a small opening in the plastic screw cap. This was inserted into the substrate with the opening about 3 cm below the surface. Water was released from the bottle only when the level in the substrate fell below the level of the cap. These water bottles had usually emptied between visits to the island, and were then refilled, but the oviposition substrates were always quite moist. The oviposition trays also became partially covered with additional soil thrown up by seabirds while excavating their burrows, and this was carefully removed before the substrates were searched for tusked weta eggs. Searching was done by sorting through the substrate to a depth of 3 cm. Tusked weta eggs are black, 6–7 mm long, and have a maximum width of c. 2 mm (Winks et al. 2002).

## 2.3 WETA ACTIVITY

### 2.3.1 Search method

Searches were made for tusked weta on Middle Island mostly during moonless periods at night using powerful spotlights. A narrow path (c. 800 m long) was followed which covered the areas where tusked weta had previously been found (McIntyre 1994, 2001) (Fig. 1). Care was taken to keep strictly to the path except when catching weta, as this limited damage to sea bird burrows. When a sea bird burrow was accidentally broken into, the damaged portion was dug out to open the burrow and allow access by the birds. The path was also raked clear of leaves and sticks to help ensure that no animals were trodden on. Raking was done prior to or during the first search and was repeated when necessary.

The path had been previously marked with both high visibility marking tape and reflective tape. Individually numbered triangular pink track markers (Technical Plastics Ltd, Wellington) were added every 5–15 m by nailing them to trees. The positions of these were surveyed and they were subsequently used as reference points to plot the positions where Mercury Islands tusked weta and ground weta were found. Weta positions were obtained by measuring the distance (with a tape measure) and direction (to 0.5° using a Suunto KB14 compass) from the nearest track marker. The path was also divided into eight sections between path junctions or terminations for the purposes of recording data when searching at night.

### 2.3.2 Additional observations of tusked weta activity

Observations were also made of Mercury Islands tusked weta at the release sites after they had been translocated onto Red Mercury Island (Whakau) and Double Island (Moturehu). The translocations occurred between April 2000 and April 2001, and included releasing three pairs of half-grown weta into a predator-proof enclosure on Red Mercury Island in May 2000. Details of these translocations and of the predator-proof enclosure will be published elsewhere. The enclosure was modified from a design of Aviss & Roberts (1994). It was approximately square and occupied 22.5 m<sup>2</sup> of ground. The sides were fine nylon shade cloth topped with aluminium flashing to prevent animals climbing in or out, and wire netting formed a roof to keep birds out.

### 2.3.3 Meteorological measurements

Temperature and relative humidity (R.H.) were taken c. 1 m above the ground using a hand-held meter (Hanna Instruments model HI 8564; 0–60 ± 0.1°C, 10–95 ± 0.1% R.H.). These were taken, together with the time, whenever a Mercury Islands tusked weta was found, and at the start and end of each section of path searched at night. The latter readings were averaged over each night. Barometric pressure was taken at the start and end of each search and similarly averaged. Subjective descriptions of wind (calm, light, medium, strong) and rain (none, light, heavy) were taken whenever a change occurred. Daily readings of soil moisture and soil temperature were taken with an ‘Aqua-tel+S+T’ probe buried 10 cm below the surface and connected to a ‘Datataker’ 50 data-logger (Winks et al. 2002).

## 2.4 STATISTICAL ANALYSIS

All measurements of ground weta were made in the field, whereas the only comparable morphometric data available from tusked weta juveniles were taken from 21 captive-reared insects (Stringer et al. 2006). The latter data were neither from a random sample nor independent, so a comparative analysis with field-collected ground weta data can only give an indication of the differences that might exist.

Canonical variate analysis, principal component analysis and discriminant analysis of data were performed with SAS 8.1 (SAS Institute Inc., Cary, NC).

The relationship between the number of ground weta seen per hour and environmental conditions was determined with GRASP v3.0 (Lehmann et al. 2002). This is a generalised additive modelling procedure in S-Plus® 6.1 (Insightful Corp., Seattle) that uses spline-smoothing. A minimum adequate model was determined by both backward and forward selection using a quasi distribution with the *F*-test limit set at  $P = 0.05$ .

## 3. Results

### 3.1 DISTINGUISHING TUSKED WETA FROM GROUND WETA

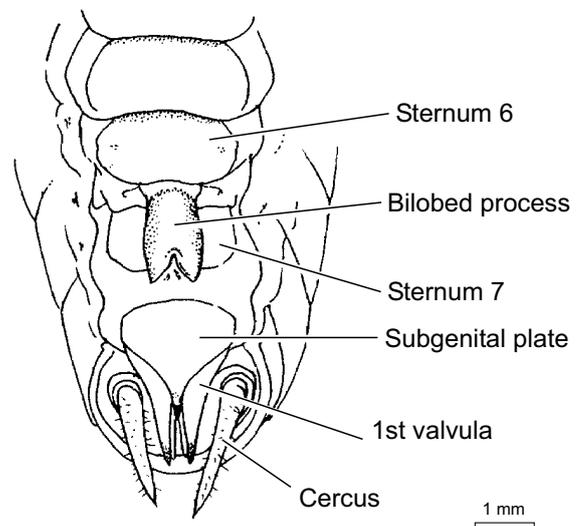
#### 3.1.1 Identifying species of weta in the field on Middle Island

Mercury Islands tusked weta (*M. isolata*) with bodies shorter than c. 28 mm are hard to distinguish from nymphal instars of the ground weta (*H. pallitarsis*) also found on the island. In adult male *H. pallitarsis*, the hypandrium projects slightly so it is visible from above, and the insect is darker coloured. Adult female *H. pallitarsis* are also a darker colour but their identity can be confirmed by the presence of a spanner-shaped structure (bilobed process) that arises from the 6th sternite (Fig. 3). This is used for positioning the male genitalia during deposition of a spermatophalx (Gwynne 2002). All adult *H. pallitarsis* found on Middle Island had body lengths (anterior of head to end of last abdominal segment) of  $22.0 \pm 2.8$  mm (mean  $\pm$  95% CI; range 16.5–27.0 mm). Thus, any anastostomatid found on Middle Island with a body  $> 30$  mm is a tusked weta.

In the field on Middle Island, ground weta could not be distinguished reliably from similar-sized tusked weta by using a hand lens (magnification  $\times 10$ ) to detect if tympanal organs were present (or not) because of the presence of a subgenual organ within the tibia of *H. pallitarsis*. This is located in the same position as the tympanal organs of *M. isolata*, but it is visible through the cuticle and appears as an oval area similar to a tympanal organ when viewed with a hand lens. Tympanal organs and subgenual organs can, however, be clearly distinguished when using a binocular microscope at low magnification ( $40\times$ ).

The following two consistent morphological differences were noted between *H. pallitarsis* from Middle Island and similar-sized *M. isolata* specimens. Firstly, *H. pallitarsis* lack protibial tympanic organs, whereas all 4th and older instar *M. isolata* (body length  $\geq 1.5$  cm) possess paired (anterior and posterior) tympanal organs on the protibiae. However, 1st and 2nd instar *M. isolata* lack tympanal organs, and most 3rd instars (94%) have anterior tympanal organs

Figure 3. Ventral view of the posterior end of the abdomen of an adult female *Hemidrus pallitarsis* from Middle Island. Note the bilobed process between the 6th and 7th sterna and the short ovipositor. Diagram by Liz Grant.



but usually lack posterior tympanal organs (the latter were present in 12.5% of specimens) (Stringer et al. 2006). Secondly, 3rd and older instars of *M. isolata* possess two postero-dorsal spines along the shaft of their mesotibiae whereas large nymphs and adults of *H. pallitarsis* have three (Fig. 4). Both species have two pairs of anterior-dorsal spines on their mesotibiae except for one specimen of *H. pallitarsis* which had three anterior-dorsal spines. The positions of these spines are here described as if the legs are held extended out from the body (see Lawrence et al. 1991). An alternative name for the postero-dorsal spines is the retrolateral spines (e.g. Field & Bigelo 2001). Two spines are present in the two preserved specimens of 1st instar *M. isolata* that were examined, but 33% of 2nd instar juveniles that were reared had only a single spine, so the second spine can appear during the first few moults (Stringer et al. 2006). In total, 40 juveniles of *H. pallitarsis* with body lengths > 1.5 cm were examined under a binocular microscope on Middle Island and all had three postero-dorsal spines along the shafts of their mesotibiae.

An examination of *H. pallitarsis* and other *Hemiandrus* species in the Museum of New Zealand, collected from elsewhere in New Zealand, revealed that although the arrangement of mesotibial spines can vary within a species, it is probably still a good character for distinguishing *H. pallitarsis* from *M. isolata* in the field on Middle Island. Thus, only 7.1% of the specimens of *Hemiandrus maculifrons* (Walker) out of all the specimens of *Hemiandrus* examined had the same pattern of mesotibial spines as did *M. isolata*. Twenty specimens of an un-named species of *Hemiandrus* from the Port Hills, Canterbury, did have paired anterior-dorsal and postero-dorsal mesotibial spines, but one of the postero-dorsal spines was situated proximally instead of distally as in *M. isolata*. Some 5% of the specimens of *Motuweta riparia* Gibbs had three posterior-dorsal mesotibial spines, and so this species could be confused with *H. pallitarsis*, but this arrangement of spines was never observed in known specimens of *M. isolata* (Table 1). Finally, all 11 *H. pallitarsis* weta found on Red Mercury Island had three anterior-dorsal and three posterior-dorsal mesotibial spines (IANS, unpubl. data), as did 4.5% of the specimens of *H. pallitarsis* in the Museum of New Zealand collection.

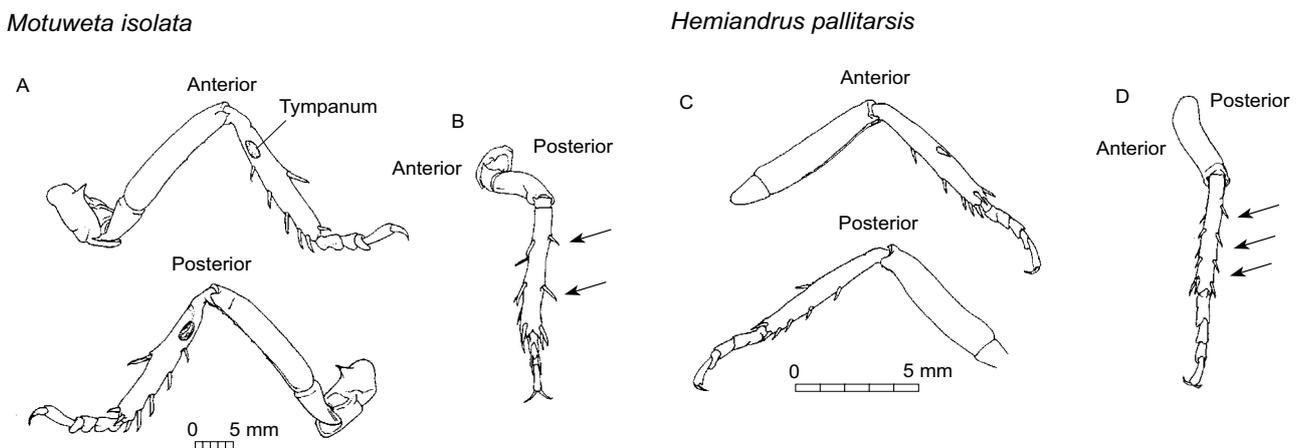


Figure 4. Diagrams of the left prothoracic and left mesothoracic legs of tussock weta, *Motuweta isolata*, and ground weta, *Hemiandrus pallitarsis*, from Middle Island, showing anterior-lateral and posterior-lateral spines mentioned in the text (arrows). Both anterior and posterior views of the prothoracic legs are shown. Diagrams by Liz Grant.

### 3.1.2 Distinguishing tusked weta from ground weta on Middle Island using morphometric data

Discriminant analysis using measurements from all Mercury Islands tusked weta (*M. isolata*) in captivity and from live ground weta (*H. pallitarsis*) caught on Middle Island indicated that these species can often be distinguished morphometrically (Table 2). The measurements used were total head length (to tip of mandible), length from mandibular boss to vertex, and lengths of the pronotum, protibia, mesotibia, metatibia, metafemur and cercus. When only measurements from *M. isolata* of comparable size to *H. pallitarsis* were used (12–30 mm body length), then *H. pallitarsis* were correctly identified with more than 90% accuracy using the arrangement of mesotibial spines described above as the confirmatory criterion (Table 2). First instar *M. isolata* weta that hatched in the laboratory had body lengths of 8.2–10.2 mm (mean  $9.5 \pm 0.5$  mm,  $\pm 95\%$  CI; Stringer et al. 2006), so the two weta found on Middle Island with body lengths of 6.1 mm and 7.7 mm were probably *H. pallitarsis*.

TABLE 1. PROPORTIONS OF TUSKED WETA (*Motuweta isolata*) AND GROUND WETA (*Hemiandrus pallitarsis*) WITH DIFFERENT DORSAL MESOTIBIAL SPINE PATTERNS.

Note: Spine patterns are shown schematically with proximal uppermost and distal lowest. Anterior and posterior positions are indicated as the left and right of the ranges (0–0 etc.) respectively. Data are from specimens in the Museum of New Zealand collection, plus all other known preserved specimens of *M. isolata*. *n* = number of specimens.

SPECIES	<i>(n)</i>	MESOTIBIAL SPINE ARRANGEMENT							
		Proximal	0–0	0–1	0–0	0–1	0–0	0–1	1–1
		Medial	0–0	0–1	1–0	1–1	1–1	1–1	1–1
		Distal	0–0	1–1	1–0	1–0	1–1	1–1	1–1
		PERCENTAGE OF INDIVIDUALS							
<i>Hemiandrus pallitarsis</i>	(22)	0.0	0.0	0.0	0.0	0.0	95.5	4.5	
<i>Hemiandrus fiordensis</i>	(4)	0.0	0.0	0.0	0.0	0.0	100.0	0.0	
<i>Hemiandrus maculifrons</i>	(14)	0.0	0.0	0.0	0.0	7.1	92.9	0.0	
<i>Hemiandrus</i> unidentified	(79)	1.3	15.2	1.3	25.3	0.0	57.0	0.0	
<i>Motuweta isolata</i>	(33)	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
<i>Motuweta riparia</i>	(19)	0.0	0.0	0.0	0.0	94.7	5.3	0.0	
<i>Antisoura monstrosus</i>	(3)	100.0	0.0	0.0	0.0	0.0	0.0	0.0	

TABLE 2. SUMMARY OF CLASSIFICATIONS OF MERCURY ISLANDS TUSKED WETA (*Motuweta isolata*) AND GROUND WETA (*Hemiandrus pallitarsis*) USING DISCRIMINANT ANALYSIS WITH MEASUREMENTS TAKEN FROM CAPTIVE-BRED JUVENILE TUSKED WETA WITH BODY LENGTHS OF 12–30 mm, AND GROUND WETA FOUND ON MIDDLE ISLAND.

Note: The resubstitution method using a quadratic discriminant function was employed. Measurements used were total head length and lengths of mandibular boss to vertex, pronotum, protibia, mesotibia, metafemur and cercus. *n* = number of specimens.

MEASUREMENTS	GROUND WETA ( <i>Hemiandrus pallitarsis</i> )			TUSKED WETA ( <i>Motuweta isolata</i> )		
	CORRECTLY CLASSIFIED (%)	WRONGLY CLASSIFIED (%)	<i>n</i>	CORRECTLY CLASSIFIED (%)	WRONGLY CLASSIFIED (%)	<i>n</i>
All sclerites	100.0	0.0	15.0	99.2	0.8	115.0
All sclerites except total head, boss to vertex, and cercus lengths	90.2	9.8	51.0	99.2	0.8	120.0
Pronotum, protibia, metafemur	89.8	10.2	49.0	98.8	1.2	86.0

Total head length and distance from mandibular boss to vertex were taken from only 15 specimens of *H. pallitarsis* on Middle Island because these measurements were difficult to take accurately in the field. When these head measurements were not considered, stepwise discriminant analysis indicated that only the lengths of the pronotum, protibia, and metafemur were required, in order of importance, to adequately separate the two species (Table 2; Fig. 5). Principal component analysis indicates that the two species do separate reasonably well, but good separation also occurs when all measurements except those of the head are considered (Fig. 6).

## 3.2 TRIALS OF SURVEY METHODS

### 3.2.1 Attractant trials

No tusked weta were observed near tinned cat food ('Chef' chicken & tuna), tinned tuna, honey, washed kumara (*Ipomea batatas*) peel, or peanut butter when these were put out after nightfall and checked 3 h 16 min to 7 h 47 min later (Table 3). No weta were caught in pitfall traps baited with tinned cat food ('Chef' jellymeat), tinned pears or honey, and peanut butter (tested either separately or in combinations) when these were checked 4–8 h after being set out at dusk (Table 4). This trial was discontinued after three nights because of the risk of trapping rare skinks (protected under the Wildlife Act 1953) together with giant centipedes (*C. rubiceps*) which eat the skinks.

TABLE 3. ANIMALS ATTRACTED TO BAITS ON MIDDLE ISLAND. BAITS WERE SET AFTER DARK AND REPEATEDLY CHECKED DURING THE NIGHT.

BAIT	DATES TESTED	NO. OF OBSERVATIONS	ANIMALS PRESENT	NO. OF TIMES BAITS LOST
Tinned cat food	16–17 Apr 99; 24–27 Nov 99	17	1 tuatara, 1 harvestman	2
Honey	16–27 Apr 99	23	1 tuatara, 1 large centipede, many ants	2
Kumera peel	16–17 Apr 99	2	0	0
Peanut butter	18–24 Apr 99; 24–27 Nov 99	31	7 ground weta, 1 spider, many ants	
Tinned tuna	18–24 Apr 99	18	1 cave weta	0

TABLE 4. ANIMALS CAUGHT IN PITFALL TRAPS DURING THE NIGHT ON MIDDLE ISLAND. PITFALL TRAPS WERE BAITED AFTER NIGHTFALL AND REPEATEDLY CHECKED DURING THE NIGHT.

BAIT	DATES TESTED	NO. OF OBSERVATIONS	ANIMALS PRESENT
Jellymeat	11–12 Sep 99; 5–7 Oct 99	4	1 diving petrel, many amphipods and slaters
Peanut butter	11–12 Sep 99; 5–7 Oct 99	4	1 spider ( <i>Aparua</i> sp.)
Tinned pears	11–12 Sep 99	2	0
Honey	6–7 Oct 99	2	0
Jellymeat, honey and peanut butter	5–6 Oct 99	3	1 spider ( <i>Cambridgea</i> sp.), 1 amphipod, 1 slater

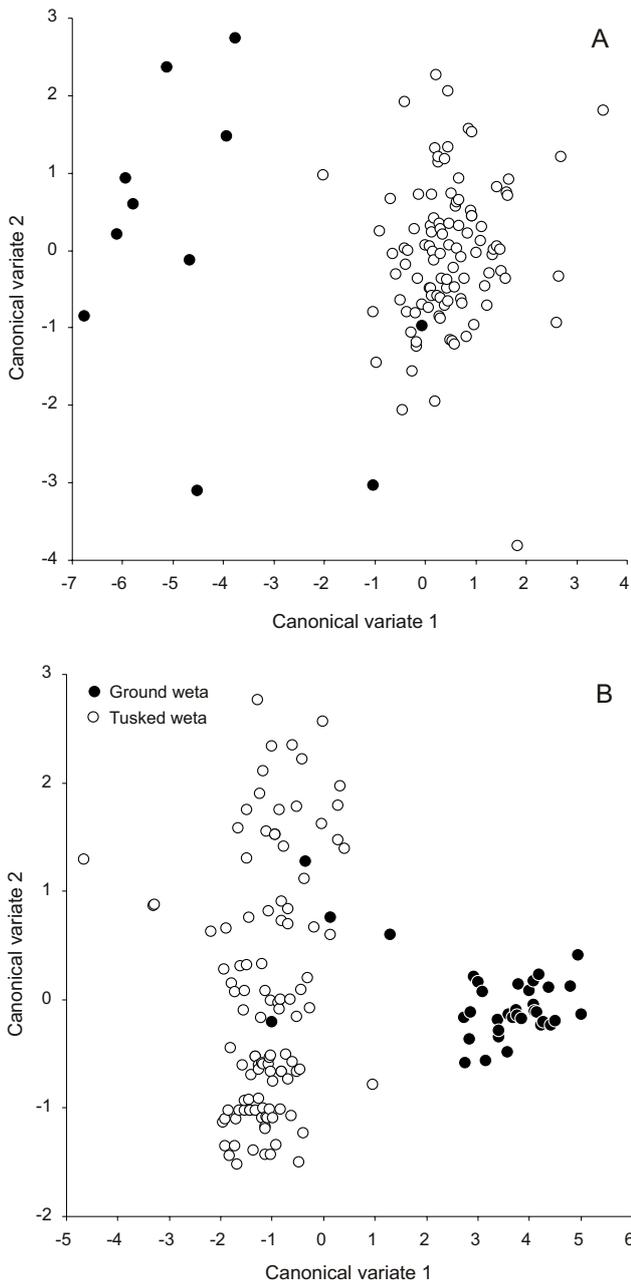


Figure 5. Canonical variate analysis of captive tusked weta, *Motuweta isolata*, and ground weta, *Hemiandrus pallitarsis*, from Middle Island. **A.** Measurements used are lengths of the pronotum, protibia, mesotibia, metatibia and metafemur. **B.** Measurements used are lengths of the pronotum, protibia and metafemur.

### 3.2.2 Oviposition trial

Notusked weta eggs were found in the oviposition substrates during the entire study, but a small ground weta (body length 9 mm) was found in the tray of beach sand on two consecutive occasions (Table 5). On both occasions this was in a vertical burrow rather than in a shallow ovoid chamber such as tusked weta construct. Other invertebrates found in the oviposition substrates are listed in Table 5.

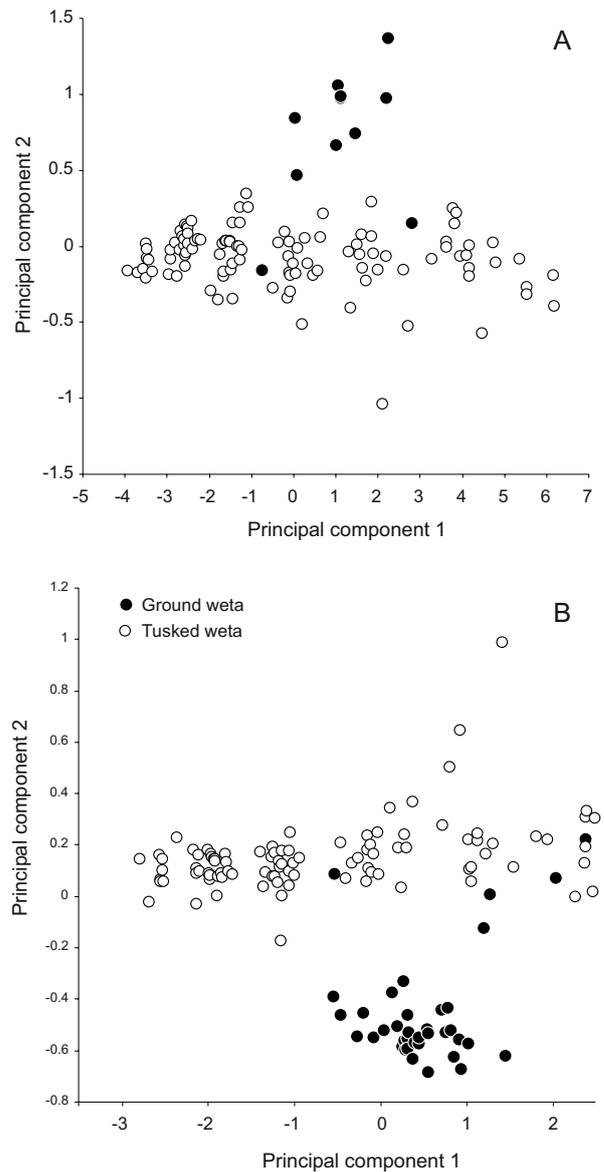


Figure 6. Principal component analysis of pooled morphometric data from similar-sized tusked weta, *Motuweta isolata*, and ground weta, *Hemiandrus pallitarsis*, (metafemur lengths 8–30 mm). **A.** Measurements used are lengths of the pronotum, protibia, mesotibia, metatibia, and metafemur. Principal components 1 and 2 accounted for 98.5% of the variation. **B.** Measurements used are lengths of the pronotum, protibia and metafemur. Principal components 1 and 2 accounted for 99.4% of the variation.

TABLE 5. INVERTEBRATES FOUND IN THREE OVIPOSITION TRAYS DURING REPEATED VISITS TO MIDDLE ISLAND. EACH SUBSTRATE WAS PRESENTED IN A SINGLE OVIPOSITION TRAY.

	POTTING MIX	BEACH SAND	SOIL (MIDDLE ISLAND)	SOIL (Mt EDEN)
Number of observations	11	11	4	7
Ground weta	0	2	0	0
Geophilomorph centipedes	22	28	5	11
<i>Aparua</i> sp.	1	2	1	0
Amphipoda	8	0	0	34
Earthworms	26	0	0	9
Other invertebrates	1 millipede	1 symphylan, 3 millipedes, 1 caterpillar, 1 scutigermorph centipede		1 scolopendromorph centipede, 1 flatworm, 1 symphylan

### 3.2.3 Artificial cover objects (including oviposition trays)

No weta were found under the concrete slabs, the plastic plant pot saucers, or the oviposition trays, and no tusked weta eggs were found in any of the oviposition substrates (soil, potting mix, sand). A variety of other invertebrates were found under these objects, although slaters (isopods), ants, and amphipods were most often encountered (Table 6), sometimes in numbers of over 30 under a single object. The large predacious scolopendromorph centipede, *C. rubiceps*, was often found under oviposition trays, whereas the mygalomorph spider *Aparua* sp. and silverfish (Iepismatids) were more commonly found under plant pot saucers (Table 6).

## 3.3 WETA ACTIVITY

### 3.3.1 Activity of tusked weta at night

Only four clearly identifiable tusked weta (*M. isolata*) were found in 284 hours of searching at night on Middle Island (Table 7). This was done during 65 nights between October 1989 and April 2003. A total of 16 observations were taken from tusked weta and their progeny after they were released from captivity as half-grown nymphs onto Double Island and Red Mercury Island (Table 8).

A total of 15 tusked weta were observed actively moving about on warm (15.7–20.5°C), humid nights (R.H. >79%) when there was little or no wind and the remaining four were active at temperatures of 11.5–14.1°C (Tables 7 and 8). All except one were active when there was no moon. The exception was the first tusked weta found on Middle Island, and this was seen just before the moon (c. quarter moon) went behind a hill (Tables 7 and 8). This occurred when the soil was still saturated with water three nights following a cyclone.

Three of the four tusked weta found on Middle Island were in the southern basin, in the area identified by M. McIntyre (pers. comm.) as being the most likely place to find them (Fig. 1C). The other, on the northern plateau, was also in an area where M. McIntyre had often found them previously.

TABLE 6. PROPORTION OF TIMES INVERTEBRATES WERE PRESENT UNDER ARTIFICIAL COVER OBJECTS.

OBJECT	OVIPOSITION TRAYS	CONCRETE TILES	PLANT POT SAUCERS
No. of objects	3	10	10
No. times checked	11	11	5
Slaters (Isopoda)	61%	56%	68%
Amphipoda	33%	16%	8%
Ants (Formicidae)	0%	22%	54%
<i>Cormocephalus rubriceps</i>	36%	3%	14%
<i>Aparua</i> sp.	0%	4%	18%
Lepismatidae	0%	8%	16%
<i>Mimopeus opaculus</i>	7%	1%	0%

TABLE 7. TIME OF NIGHT AND METEOROLOGICAL CONDITIONS WHEN TUSKED WETA (*Motuweta isolata*) WERE FOUND ON ATIU OR MIDDLE ISLAND. R.H. = RELATIVE HUMIDITY.

DATE	TIME	PLACE	SEX	STAGE	TEMP. (°C)	R.H. (%)	BAROMETRIC PRESSURE (hPa)	NOTES
01 Dec 1998	02:21	South Basin	M	10th instar juvenile	16.8	87.4	1000	Moon just setting, still; heavy rain 12 h previously
15 Apr 1999	22:00	North Plateau	F	10th instar adult	17.5	95.4	987	Heavy rain ceased at midnight, brisk westerly
16 Apr 1999	02:00	South Basin	M	11th instar adult	15.9	94.1	985	Rain stopped midday, clear and still
26 Jan 2001	03:17	South Basin	F	7th instar juvenile	19.2	88.1	993	Clear night, light westerly; ground dry, no rain since before 21 Jan 2001; barometer dropping slowly

### 3.3.2 Activity of ground weta at night

A total of 717 ground weta (*H. pallitarsis*) were seen on Middle Island during most nights (86%). This represented a catch rate of 2.5 ground weta per search hour. All were on the ground except for four that were found 0.4–1.6 m above the ground on tree trunks. Most of those on the ground were on the track (72.4%) or up to 1 m from it (20.1%), and few were seen beyond this, although the furthest was found 9 m from the track (Fig. 1B). They occurred almost everywhere the track went on Middle Island, but they were clearly more frequently found in the Southern Basin, along the eastern branch of the track on the Central Plateau, on the track up from the campsite, and at the southern end of the Northern Plateau (Fig. 1B).

Ground weta, apart from the small ones found in an oviposition tray, were all located during night searches. They usually became motionless when first illuminated and then walked or hopped away after a few minutes. One was observed eating a slater, and another adult-sized ground weta was seen being carried away in the jaws of a large *C. rubiceps* centipede.

When modelled with GRASP, the number of weta seen per hour was significantly correlated with the mean soil moisture and the mean soil temperature recorded over 24 hours, and with the mean air temperature during the search period. The partial responses for the number of ground weta found per hour were non-linear

TABLE 8. TIME OF NIGHT AND METEOROLOGICAL CONDITIONS WHEN TUSKED WETA WERE FOUND ON RED MERCURY ISLAND (WHAKAU) AND DOUBLE ISLAND (MOTUREHU). R.H. = RELATIVE HUMIDITY.

PLACE	DATE	TIME	SEX	DEVELOPMENTAL STAGE	ORIGIN	TEMP. (°C)	R.H. (%)	NOTES	
Red Mercury enclosure	22 Apr 2001	19:45	M	10th instar adult	Released half-grown	15.7	87.2	Clear and still; ground wet, rained heavily previous day and night	
			F	11th instar adult	Released half-grown				
			F	11th instar adult	Released half-grown				
			F	11th instar adult	Released half-grown				
	25 Apr 2001	22:25	M	10th instar adult	Released half-grown	11.5	87.5	Removed from hole during day, facing hole containing female; ground wet	
Red Mercury release site	24 Apr 2001	19:00	M	Adult	Released half-grown	14.1	79.4	Clear and still; ground wet	
			F	Adult	Released half-grown	14.1	79.4	Clear and still; ground wet	
			F	11th instar adult	Released half-grown	13.0	83.0	Clear and still; ground moist	
	02 Mar 2003	22:03	M	8th instar	1st generation progeny on island	20.5	>95	Clear and still; rained in morning	
	03 Mar 2003	22:55	F	6th instar juvenile	1st generation progeny on island	19.4	91.0	Overcast and calm; light rain just stopped	
			23:05	M		8th instar juvenile	18.4	91.1	Overcast and calm; light rain early in night
			22:45	F		9th instar juvenile	19.4	91.0	
			23:10	F		9th instar juvenile	17.8	91.0	
			23:20	M		9th instar juvenile	17.8	91.1	
Double Island	05 Mar 2003	22:00	F	9th instar juvenile	1st generation progeny on island	-	-	Partly overcast; SE breeze	
	30 Mar 2003	21:05	F	8th instar juvenile	1st generation progeny on island	19.0	>95	Clear and still	

for all three environmental factors (Fig. 7) and the model accounted for 81% of the deviance. Mean soil temperature during a 24-h period affected the number of ground weta found per hour the most (Fig. 8), with a non-linear relationship that increased with temperature, although there was no change in the number of weta seen between 15.8°C and 16.6°C. The highest numbers of weta were also seen when the mean soil saturation level was between 10% and 20%, whereas the least important factor was the mean air temperature during the searches. The plot of this latter response was S-shaped when rotated 90° clockwise, with high numbers of weta observed below 8°C and between 17–18°C, and the lowest numbers at c. 12°C. Mean saturation vapour deficit or mean relative humidity during the search period and rainfall had no detectable effect on the number of ground weta seen at night. Rain fell on only 7 of the 55 days included in the analysis and this may have been too small a number for a relationship to be determined.

The time of year was ignored in the above analysis, because the number of nights sampled were too unevenly distributed either on a monthly or seasonal basis to obtain meaningful results. The size distribution of the ground weta that were measured (420) did, however, clearly vary with time of year. Small ground weta (mean body length 5.9 mm,  $n = 3$ ) were first found in November and this cohort could be followed as it increased in size over the following months until by April it overlapped with a cohort of larger weta from the previous year. Most adults were present from February to September and few were seen in November (Fig. 9). The only indications of the time of year when mating takes place were two adult females that were observed with spermatophores, one in February

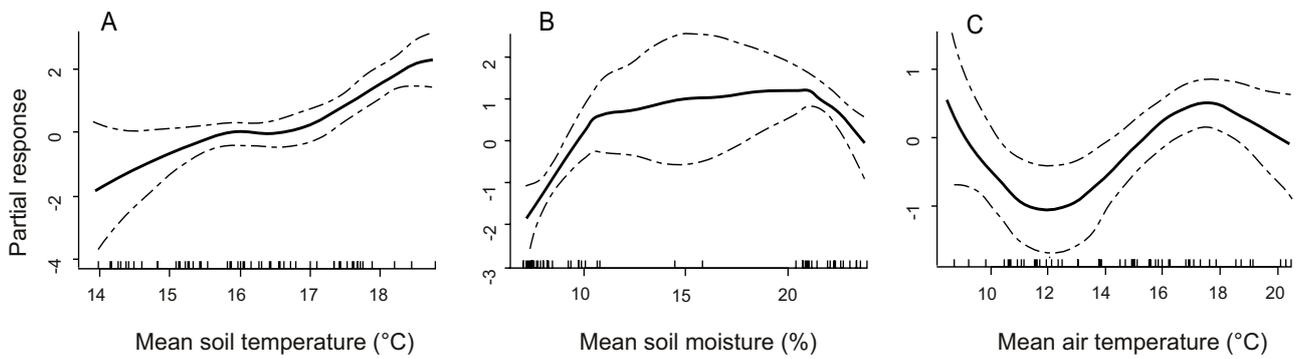


Figure 7. Partial response curves for environmental factors that significantly correlated with the number of ground weta, *Hemiandrus pallitarsis*, seen at night on Middle Island when modelled with GRASP. **A.** Mean daily soil temperature. **B.** Mean daily soil moisture (%). **C.** Mean air temperature during the night. Results are expressed as the additive contribution made by a variable to the model using spline-smoothing with four degrees of freedom. Dashed lines represent  $\pm 2$  SE curves. Rugplots show predictor values used.

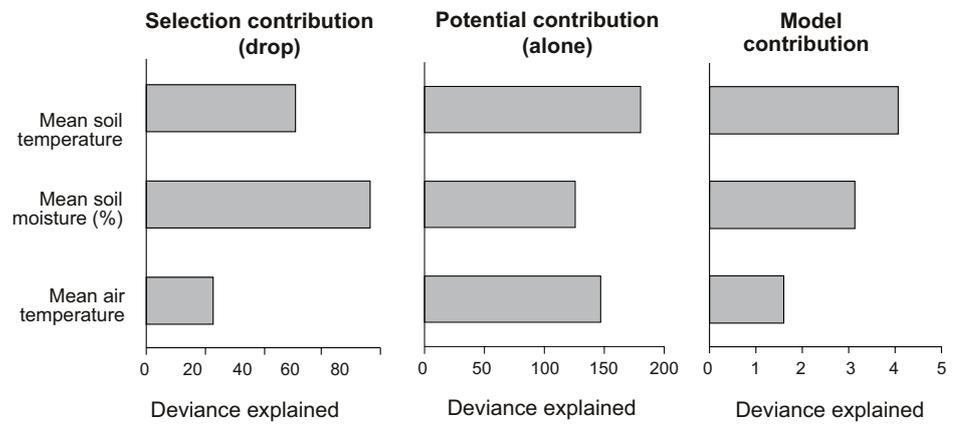


Figure 8. Relative contributions of environmental variables to the GRASP model of numbers of ground weta, *Hemiandrus pallitarsis*, seen per hour at night. The drop contribution is the difference in explained variance between the model when that variable is excluded. The alone contribution is the deviance explained by the model with only that variable in the model. The model contribution gives an indication of the contribution of each variable within the model.

2000 and one in January 2001. All adults observed in April were male ( $n = 23$ ) and all observed in October were female ( $n = 12$ , none measured), whereas the sex ratio was approximately equal during the other months when adults were observed.

## 4. Discussion

### 4.1 DISTINGUISHING TUSKED WETA FROM GROUND WETA

The presence of paired tympanal organs on the front legs of Mercury Islands tusked weta (*M. isolata*) clearly differentiates them from ground weta (*H. pallitarsis*), yet these are not always a good characteristic to use for identification because they can be missing in tusked weta with overall body lengths smaller than about 1.5 cm (the size of tusked weta up to 3rd instar). Tympanal organs are also absent

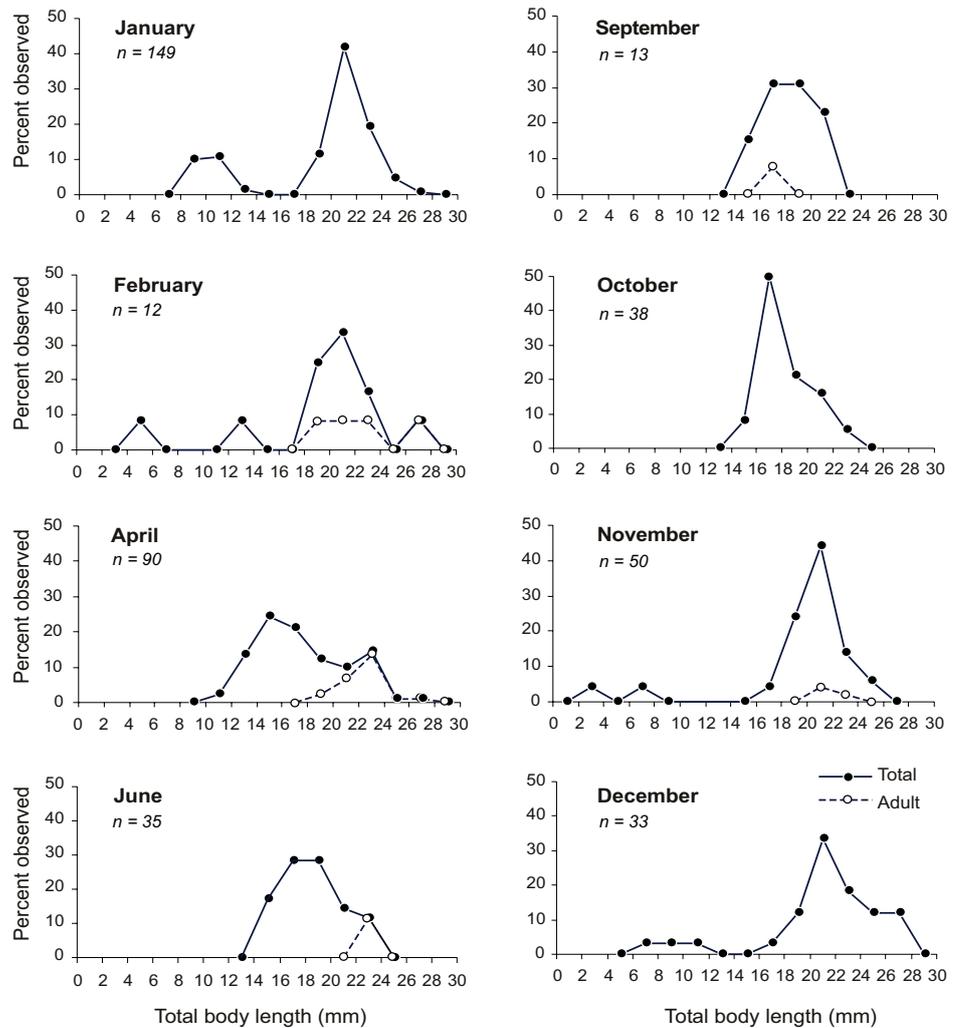


Figure 9. Seasonal variation in body size of ground weta, *Hemianthus pallitarsis*, found on Middle Island. (Numbers found for each month are summed over all years.)

on regenerated protibia (although such limbs can usually be identified, they are often noticeably shorter than those that develop normally; Stringer et al. 2006). It is also difficult to determine with confidence (using a hand lens) whether tympanal organs are present or not on weta with body lengths  $\leq 2$  cm because the subgenual organs in ground weta look superficially like tympanal organs, as described above. Positive identification of tympanal organs in small weta is only reliable if a dissecting microscope is used, and this is often impractical in the field. The arrangement of mesotibial spines can, however, be used to distinguish all except the first two nymphs of tusked weta from ground weta. All Mercury Islands tusked weta (*M. isolata*) examined that were older than 4th instar had two antero-dorsal and two postero-dorsal spines along the shaft of their mesotibiae whereas ground weta (*H. pallitarsis*) from Middle Island have three postero-dorsal spines (Fig. 4). The number of such spines does vary within some species of *Hemianthus* as well as in *M. riparia* (Table 1), and the mesotibial spine pattern in species of *Hemideina* (Anostomatidae) is known to be particularly variable (Field & Bigelow 2001). However, all anostomatid weta found on Middle Island with three postero-dorsal mesotibial spines and a body length of  $\geq 1.5$  cm lacked protibial tympanal organs when examined under a binocular

microscope and so were *H. pallitarsis*. These spines are clearly visible using a hand lens, and therefore provide a ready and reliable means of identifying ground weta in the field on Middle Island. Possession of two pairs of these spines does not necessarily indicate that a weta with a body length < 1.5 cm is a tusked weta (*M. isolata*), because some spines are likely to be missing in the early juvenile instars of ground weta (*H. pallitarsis*). This follows because some protibial spines can be missing in the early instars of *M. isolata* (Stringer et al. 2006), and this may also apply to ground weta. These spines certainly appear during postembryonic development of a cockroach (Tanaka & Kitamura 1992), but it is not known how widespread this process is amongst orthopteroid insects. Weta < 1.5 cm in length cannot be reliably identified as Mercury Islands tusked weta (*M. isolata*) if they have only two postero-dorsal mesotibial spines, but they are ground weta (*H. pallitarsis*) if they have three. Fortunately, weta this small were rarely found in the field.

Morphometric analysis also results in errors of identification between the two weta species (Table 2). Some misclassifications can be expected if measurements were taken from individuals with regenerating limbs, because growth of both the regenerating limb and the contra-lateral limb are affected, together with other parts of the body (Stringer et al. 2006) (Figs 5 and 6). Most errors were ground weta misclassified as tusked weta, and it seems likely that ground weta commonly lose limbs on Middle Island where predators are numerous, whereas this happened rarely amongst captive-reared tusked weta (Stringer et al. 2006). However, only one of the ground weta that was grouped amongst the tusked weta clearly had smaller than expected hind leg measurements indicating that its misclassification was probably due to regeneration. Reasons for the other misclassified ground weta were unclear.

Finally, the use of this discriminant analysis for distinguishing between tusked and ground weta on Middle Island should be applied with caution, as previously noted. A higher proportion of misclassifications can almost certainly be expected when measurements are used from tusked weta in the wild. This follows because the only available data for tusked weta were repeated measures from captive-reared insects that originated from one male and two female parents. Thus the data were not a random sample nor were they independent, so the discriminant analysis almost certainly shows less variability than if the data had been collected from a wild population. However, until suitable field-collected data are obtained, this is the best available morphometric method for distinguishing between the two weta species.

## 4.2 TRIALS OF SURVEY METHODS

The failure to detect tusked weta by any of the alternative survey methods tried may not necessarily indicate that they do not work because it is likely that the population of tusked weta on Middle Island was very small during this research. Only four tusked weta were seen there during 65 nights of searching between 1998 and 2003, whereas McIntyre (2001) recorded 239 during 118 nights between 1991 and 1994. This was despite the use of very similar search methods. In addition, oviposition trays and artificial cover objects were certainly successful for monitoring the translocated populations of tusked weta on Red

Mercury Island and Double Island (IANS & R. Chappell, unpubl. data). However, the areas where these artificial cover objects were used on Double Island and Red Mercury Island probably had high local densities of these weta because 84 and 50 were released there, respectively, when the artificial cover objects were being used.

### 4.3 WETA ACTIVITY

The few observations taken of *M. isolata* weta on Middle Island support the findings of McIntyre (2001) that they are most likely to be active above ground when it is warm, humid. These were also the conditions when most of the other invertebrates and reptiles on Middle Island appeared, subjectively, to be most frequently active. However, there were too few observations of tusked weta (*M. isolata*) to determine what the relationship was between the number seen and the meteorological conditions, the time of year, or the number of other animals that were active.

Previous reports showed that the number of *H. pallitarsis* caught in pitfall traps elsewhere on the North Island of New Zealand has a significant positive correlation with increasing temperature (McColl 1975; Moeed & Meads 1985). These responses were averaged over many days (14 d for McColl 1975; unspecified for Moeed & Meads 1985) so they are not easily reconciled with the complex partial response that numbers seen per hour have with temperature in the present study even though this was also positive between temperatures of 12°C and 18°C (Fig. 7). In addition, Moeed & Meads (1985) reported that activity of ground weta was unaffected by rainfall and a similar response seems likely in the present study.

However, both of the above studies with pitfall traps measured activity over a longer time scale than in the present study, and most of the observations taken in the present study were made during moonless periods of the night which may have biased the results.

The large numbers of ground weta found on Middle Island suggest that tusked weta of comparable size should also have been found if they were active because both species of weta are similar in both shape and colouration. Furthermore, tusked weta grow twice as large as ground weta, so larger specimens should have been even more easily seen. The fact that they weren't indicates that there were probably few tusked weta on the island during the period of the study, as mentioned above. It is, however, also possible that the two weta species may have different reactions to light and that the spotlights used for searching may have affected how many weta were found. Tusked weta, for example, may have a stronger avoidance response to light than ground weta and may react more quickly to artificial light by hiding. This is supported by the discovery by McIntyre (2001) that tusked weta are usually seen on the darkest nights when there was no moon, whereas ground weta were frequently found in moonlight and soon after dusk during the present study. Light avoidance could explain why only large instars of tusked weta were found during the present study, as these would have more difficulty hiding under fallen leaves than smaller individuals when they detected light from approaching spotlights. The search method used was

based on that employed by McIntyre (pers. comm.) except that the spotlights used in the present study were more powerful. Light avoidance is also a likely explanation for why most ground weta were found on or very close to the track which was raked clear of leaves. They were often observed trying to hide under nearby fallen leaves when dimly illuminated, so those further from the track may have been able to find cover faster because shadows cast by leaves and sticks lengthen with distance from the light source used on the track.

Changes in the size classes of ground weta (*H. pallitarsis*) during the year (Fig. 9) suggest that juveniles probably take about a year to develop into adults, and that the adult may live up to 9 months. However, the full developmental period of the juvenile is likely to be longer than the observed period, because adult female *H. pallitarsis* weta care for both the eggs and early instars in their burrows (Gwynne 2004). Thus *H. pallitarsis* probably has a lifespan of at least 1.5 to 2 years on Middle Island, and it is likely to be similar to the reported lifespans of other ground weta (see review by Stringer & Cary 2001).

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