Habitat use of *Tradescantia fluminensis* by *Powelliphanta traversi*

Rachel J. Standish*, Shaun J. Bennett and Ian A.N. Stringer

Ecology Group, Institute of Natural Resources, Massey University, Private Bag 11 222, Palmerston North, New Zealand

*Present address (& author for correspondence): Landcare Research, Private Bag 6, Nelson, New Zealand.

ABSTRACT

This study was initiated owing to concern that removal of the invasive ground cover, *Tradescantia fluminensis*, might adversely effect the rare, giant predatory land snail, *Powelliphanta traversi*. Of 18 sites surveyed in the Horowhenua District, seven sites provide habitat for *P. traversi* and do not contain *Tradescantia*. Five colonies of *P. traversi* are affected by *Tradescantia*, these are: Waiopehu Scenic Reserve, Prouse's Bush, Kimberley Scenic Reserve, Ohau River Bush, and Hillas Covenant. *Tradescantia* infestation at these sites varies from heavy (Prouse's Bush) to forest edge only (Hillas Covenant). Overall, *Tradescantia* affects a small proportion of snail habitat in the Horowhenua District. Our study of *P. traversi* at Prouse's Bush, using harmonic radar to follow long-term movements and cotton tracks for short-term movements, indicates that this snail commonly occurs under *Tradescantia*, sometimes exclusively, and that many of the snails move regularly between leaf litter and this weed. Moreover, *Tradescantia* provides an important refuge for juvenile snails at Prouse's Bush. Hence, removing *Tradescantia* from this site would have a detrimental impact on *P. traversi*. Graduated control of *Tradescantia* and concomitant replacement with native ground cover could be of mutual benefit to *P. traversi* and other ground-dwelling invertebrates.

Keywords: *Powelliphanta traversi*, *Tradescantia fluminensis*, endangered land snail, invasive weeds, snail distribution, Manawatu Plains Ecological District, weed control

 This paper may be cited as:

Standish, R.J.; Bennett, S.J.; Stringer, I.A.N. 2002: Habitat use of *Tradescantia fluminensis* by *Powelliphanta traversi*. *Science for Conservation 195A*. 26 p.

1. Introduction

The genus *Powelliphanta* (Powell) is endemic to New Zealand and contains ten species, including 34 subspecies, which are found from Mt Egmont and Lake Waikaremoana in the north to Resolution Island, Lake Monowai and the Mataura Ranges in the south (Meads et al. 1984). *Powelliphanta traversi* is endemic to the Horowhenua lowlands (Powell 1930, 1946). Geographic isolation has led to the evolution of several recognised taxa within the species, including *P. t. traversi*, with forms 'koputaroa', 'florida', 'latizona' and 'tararuaensis' (Powell 1930), and *P. t. otakia* (Powell 1946). Since European settlement, habitat fragmentation, habitat modification (e.g. drainage), shell collection and predation (e.g. rats, weka, hedgehogs) have each contributed to the decline of these taxa (Meads et al. 1984). Predation, particularly by rats in lowland areas, continues to jeopardise the survival of remaining populations of *P. traversi* (Meads et al. 1984; Walker 1997a). Within the Horowhenua lowlands, populations of *P. traversi* (all taxa mentioned above except *P. t. traversi* f.'tarauaensis' and f. 'latizona') are now confined to 12 sites at most (I. Cooksley, pers. comm.).

Sites containing lowland *P. traversi* are mostly small, modified forest remnants. Eight of the remaining populations are in remnants of less than 15 ha. These site characteristics, combined with their close proximity to towns, renders them prone to weed invasion (Timmins & Williams 1991). One weed that has successfully invaded many lowland remnants in the region, including sites containing *P. traversi*, is *Tradescantia fluminensis* Vell. (Commelinaceae; hereafter referred to as *Tradescantia*). *Tradescantia* was first introduced to the region to stabilise steep banks and as a popular ornamental plant. While it is not known to set seed in New Zealand (Healy & Edgar 1980), *Tradescantia* has spread widely, from material that has been dumped at forest remnants in garden refuse, or naturally via streams (Esler 1978). Livestock have also been known to disperse fragments (Ogle & Lovelock 1989). Fragments as small as 1 cm can successfully establish new plants (Kelly & Skipworth 1984). Once *Tradescantia* is introduced at a site, the high soil fertility (Ravine 1995) and moderate rainfall (Esler 1978) that generally occur within the Horowhenua district probably favour establishment.

Within a site, the extent of weed infestation appears to be determined by forest interior light levels, with the ground at forest edges and beneath canopy gaps most heavily infested (Kelly & Skipworth 1984; Maule et al. 1995; Standish et al. 2001). At high levels of infestation, *Tradescantia* forms a carpet which can out-compete native ground covers and seedlings (Kelly & Skipworth 1984; Standish et al. 2001). Clearly, where *P. traversi* and *Tradescantia* co-occur, invasion by *Tradescantia* threatens to disrupt the native habitat of *P. traversi*. First, the aims of our survey were to determine whether *Tradescantia* was established at sites where *P. traversi* occurs, or *P. traversi* inhabits *Tradescantia*-infested areas. *P. t. traversi* has been found in high densities underneath *Tradescantia* (Devine 1997). It has been suggested that *Tradescantia* fosters *P. t. traversi* survival (DOC 1996), although there is little evidence to support this claim. Second, we determined the likely effect of removing *Tradescantia* on *P. t. traversi* by detailing its habitat use at Prouse's Bush, Levin, lower North Island. As will be described, Prouse's Bush provides an ideal site to study *P. t. traversi* habitat use since it is an equal mix of *Tradescantia* and native ground cover (mostly leaf litter) and contains a large colony of *P. t. traversi*.

2. Incidence of *P. traversi* in *Tradescantia*-affected forest remnants

2.1 METHODS

A list of sites where *P. traversi* currently occurs, or has occurred in the recent past, was obtained through consultation with Ian Cooksley, Department of Conservation Area Manager, Waikanae. These sites were surveyed in February 1999, except those which had been visited by one of us previously (Prouse's Bush, Lake Papaitonga Scenic Reserve and Hillas Covenant). Prouse's (old) Queen Street property and Arapaepae Bush were not surveyed, since access to both was denied.

On arrival at each site, we first determined if *Tradescantia* was present. We inspected the entire forest floor of small (< 15 ha) accessible sites, and of likely sites of infestation (stream banks, forest edges) within large sites or sites with difficult access (Perawiti's Wetland, Koputaroa Scientific Reserve, Kimberley Scenic Reserve, Powell's Forest Reserve). If *Tradescantia* was absent, we did not actively search for *P. traversi*, particularly if its status was already known. However, snails or shells located in passing and the search effort (number of searchers × time spent searching = working hours) were recorded. If *Tradescantia* was present, we estimated its extent visually. Within *Tradescantia*, we searched for *P. traversi* within randomly placed 5 m × 2 m quadrats (number determined by size of habitat). Percentage cover and height in three categories (<30 cm; 30–50 cm and >50 cm of *Tradescantia*) was recorded in each quadrat. *Powelliphanta traversi* densities estimated by this method were expressed as number of live snails or shells per area. Live snails and empty shells were measured (maximum length) and replaced. Shell damage and the likely cause, using the guide of Meads et al. (1984), was noted for empty shells.

2.2 RESULTS

Detailed findings for each site are listed below and summarised in Table 1. Sizes of *P. traversi* collected are summarised in Table 2. Exact grid references are available from the DOC Area Manager, Waikanae.

TABLE 1. INCIDENCE OF *P. TRAVERSI* COLONIES AFFECTED BY *TRADESCANTIA*. *P. TRAVERSI* HAS BEEN RECORDED FROM ALL SITES LISTED, EITHER RECENTLY OR IN THE PAST (MISSING: PROUSE'S (OLD) QUEEN STREET PROPERTY AND ARAPAEPAE BUSH). THEIR CURRENT STATUS (THIS STUDY; I. COOKSLEY, PERS. COMM.) IS LISTED UNDER 'SNAILS PRESENT'. A SUMMARY OF OUR COLLECTIONS (SITES 1 TO 15) IS LISTED IN THE LAST FIVE COLUMNS. FIGURES IN BOLD AND PLAIN TYPE REFER TO COLLECTIONS IN *TRADESCANTIA* AND NATIVE HABITAT RESPECTIVELY. REFER TO TEXT FOR SEARCH EFFORT; (c) = CRUSHED AND '-' = NO DATA.

SITE	SNAILS PRESENT	*TRADESCANTIA* PRESENT	NO. OF LIVE SNAILS	WHOLE	SHELLS DAMAGED—CAUSE RAT	BIRD	OTHER
1 Perawiti's Wetland	n	n	0	0	0	0	0
2. Koputaroa Scientific Reserve	y	n	0	0	0	0	0
3. Blake's Swamp	y	n	1	3	0	14	1 (c)
4. Blake's Bush	y	n	0	1	1	0	0
5. Gardner's Bush	n	y	0	0	0	0	0
6. MacArthur Street Bush	n	y	0	0	0	0	0
7. Prouse's Bush	y	y	-	-	-	-	-
8. Waiopehu Scenic Reserve	y	y	**3**; 2	1	0	0	0
9. Lake Papaitonga Scenic Reserve	y	n	-	-	-	-	-
10. Brown's Bush	n	y	0	0	0	0	0
11. Kimberley Scenic Reserve	y	y	**2**	**3**;1	1	0	**1 (c)**
12. Powell's Forest Reserve	y	n	5	0	0	0	0
13. Ohau River Bush	y	y	**1**	**1**	0	0	0
14. Rushworth's Bush	n	y	0	0	0	0	0
15. MacIntosh's Wetland	y	n	0	2	0	0	0
16. Hillas Convenant	y	y	-	-	-	-	-
17. Hughes' Bush	n	y	0	0	0	0	0
18. Hutton's Bush	y	n	0	0	0	0	0
Total	12 sites	With snails 5	14	12	2	14	2

TABLE 2. MAXIMUM LENGTH OF LIVE, EMPTY AND DAMAGED (ESTIMATED) *P. T. TRAVERSI* SHELLS COLLECTED. FIGURES IN BOLD AND PLAIN TYPE REFER TO COLLECTIONS IN *TRADESCANTIA* AND NATIVE HABITAT RESPECTIVELY.

SITE	LIVE	EMPTY	DAMAGED
Blake's Swamp	30–40 mm	20–30 mm	14 bird-damaged (20–30 mm)
		30–40 mm	1 crushed (20–30 mm)
		40–50 mm	
Blake's Bush		45.7 mm	1 rat-damaged (40–50 mm)
Waiopehu SR	49.3 mm	12.2 mm	
	23.3 mm		
	13.0 mm		
	13.2 mm		
	22.7 mm		
Kimberley SR	**48.5 mm**	40.1 mm	1 rat-damaged (40–50 mm)
	54.8 mm	**50.3 mm**	**1 crushed (18.0mm)**
	49.0 mm	**20.5 mm**	
Ohau River Bush	**50.7 mm**	**45.1 mm**	
MacIntosh's Wetland	20–30 mm		
	40–50 mm		

Perawiti's Wetland

Size: 8 ha

Vegetation: Kahikatea treeland/flaxland/mixed broadleaved shrubland on floodplain

P. traversi record: *P. t. traversi* f. 'koputaroa', November 1993 (Ravine 1995)

Survey date: 4 Feb 1999

Searched by: RJS and SJB

Tradescantia: None found

Snails: None found in 1 working hour

Comments: Walker (1997a) does not include Perawiti's Wetland in her list of sites containing *P. t. traversi* f. 'koputaroa', despite Ravine (1995) reporting the presence of this snail. A potential source of *Tradescantia* is at Waiopehu Scenic Reserve, upstream of Perawiti's Wetland, although the stream is stop-banked at Perawiti's Wetland, which would probably prevent establishment. There is no road access to the site, so people are unlikely to dump garden refuse, another potential source of *Tradescantia*. *Tradescantia* could not establish in the flaxlands, since bare ground is absent.

Koputaroa Scientific Reserve

Size: 9.4 ha

Vegetation: Kahikatea/mixed broadleaved/*Carex virgata* treeland and raupo/flax/toetoe reedland on floodplain

P. traversi record: *P. t. traversi* f. 'koputaroa', May 1997 (Walker 1997a)

Survey date: 4 Feb 1999

Searched by: RJS and SJB

Tradescantia: None found

Snails: None found in 1 working hour

Comments: This site is the stronghold for *P. t. traversi* f. 'koputaroa' (Ravine 1995; Walker 1997b). *Tradescantia* is unlikely to disperse to this site since there is no road or stream access.

Blake's Swamp

Size: 2 ha

Vegetation: Raupo/mixed sedge gully

P. traversi record: *P. t. traversi* f. 'koputaroa' (I. Cooksley, pers. comm.)

Survey date: 17 Feb 1999

Searched by: HBH and SJB

Tradescantia: None found

Snails: One live *P. traversi* and 18 empty shells, three whole, 14 appeared bird-damaged and one crushed, in 0.33 working hour.

Comments: The large number of shells (especially small shells) found in a short time suggests that a population exists, although clearly bird predation is common. *Tradescantia* is unlikely to be introduced to this site. Excluding suburban gardens, there is no *Tradescantia* for a radius of 6 km around this site and there are no streams that offer routes for dispersal. Garden refuse is unlikely to be dumped, since there is no road access to the site.

Blake's Bush

Size:	4 ha
Vegetation:	Podocarp/broadleaved/mixed mahoe in gully
P. traversi record:	*P. t. traversi* f. 'koputaroa' (I. Cooksley, pers. comm.)
Survey date:	1 Feb 1999
Searched by:	RJS and SJB
Tradescantia:	None found
Snails:	Two empty shells in 1 working hour

Comments: The landowner, Collis Blake, is sympathetic to the conservation of *P. traversi* and maintains a fence around the site. Mrs Blake has never found a live snail, although several empty shells have been collected. *Tradescantia* is unlikely to be introduced to this site. Excluding suburban gardens, there is no *Tradescantia* for a radius of 6 km around this site and there are no streams that offer routes for dispersal. Garden refuse is unlikely to be dumped, since the site borders the owners' house and there was no *Tradescantia* in their garden.

Gardner's Bush

Size:	1 ha
Vegetation:	Pukatea/tawa/totara/mixed broadleaved forest in gully
P. traversi record:	*P. t. traversi* translocated colony (Powell 1946), now probably extinct (I. Cooksley, pers. comm.)
Survey date:	2 Feb 1999
Searched by:	RJS and SJB
Tradescantia:	Present, largely confined to several large patches at the forest edge, where it is the dominant ground cover. Its invasion into the forest is minimal. One isolated patch was found within the forest.
Snails:	None found in <10 m^2 of *Tradescantia* within the forest

Comments: *P. t. traversi* is now likely to be extinct at this site, and we recommend that snail conservation efforts be directed elsewhere.

MacArthur Street Bush

Size:	<1 ha
Vegetation:	Broadleaved scrub
P. traversi record:	*P. t. traversi* (I. Cooksley, pers. comm.)
Survey date:	1 Feb 1999
Searched by:	RJS and SJB
Tradescantia:	Dominant ground cover
Snails:	None found in 20 m^2 native habitat or 20 m^2 *Tradescantia* habitat

Comments: Three live snails have recently been observed at this site (I. Cooksley, pers. comm.), but it is uncertain if they remain, given the time we spent searching such a small area. *P. t. traversi* is now likely to be extinct at this site, and we recommend that snail conservation efforts be directed elsewhere.

Prouse's Bush

Size:	5 ha
Vegetation:	Titoki/tawa/mahoe forest
P. traversi record:	*P. t. traversi*
Tradescantia:	Covers 55% of forest floor
Snails:	Found in native habitat and *Tradescantia* habitat (refer to section 2)

Comments: Despite the degraded state of this forest remnant, its small size and close proximity to Levin, it supports a relatively large *P. traversi* colony. We suggest revegetation with hand weeding as a combined method to control *Tradescantia*. The ultimate aim of tree planting would be to shade out the *Tradescantia*. Revegetation would require monitoring to ensure plants were not overgrown by *Tradescantia*; as the canopy cover of the site improves with revegetation, snail-favoured ground cover (e.g. ferns) could then be planted in areas from which *Tradescantia* had been removed. Given that *Tradescantia* provides half the ground cover at this site, it would be wise to control sections of *Tradescantia* at a time (keeping bare ground to a minimum). This method would be better achieved with few people, to reduce the risk of trampling snails. An additional preventive measure would be to collect and cage snails during initial revegetation efforts. Any work at this site would need the approval of the site administrators, the Horowhenua District Council.

Waiopehu Scenic Reserve

Size:	15 ha
Vegetation:	Tawa/mahoe forest on terrace tread
P. traversi record:	*P. t. traversi* (I. Cooksley, pers. comm.)
Survey date:	1 Feb 1999
Searched by:	RJS and SJB
Tradescantia:	Present along the edge of the stream, and as several small patches along the main walking track that cuts through the reserve. It was also present along most of the roadside edges of the reserve, but does not penetrate the bush more than a few metres at most.
Snails:	One live and one whole empty shell in native habitat in 0.5 working hour. Four live snails in 40 m^2 of *Tradescantia* habitat (30–50 cm high); three were directly under *Tradescantia* and one was under *Asplenium bulbiferum*.

Comments: This site is the type locality for *P. t. traversi* (Powell 1930). Clearly, *Tradescantia* habitat is used by *P. t. traversi* at Waiopehu Scenic Reserve. Currently, *Tradescantia* occupies all the high light areas available. Further invasion by *Tradescantia* would occur only after canopy damage allowing light to infiltrate to the forest floor (Kelly & Skipworth 1984; Maule et al. 1995; Standish et al. 2001). Soil disturbance promoting high soil nitrogen, such as that which occurs after tree fall, would also promote growth of *Tradescantia* (Maule et al. 1995). Successful control of *Tradescantia* would require a large initial effort, since it is well established over a large area. After initial *Tradescantia* eradication, constant monitoring would be required to ensure it does not reestablish, since the stream provides an obvious means of re-introduction from other infested sites.

Lake Papaitonga Scenic Reserve

Size:	50.9 ha not including islands
Vegetation:	Tawa/titoki forest and swamp land
P. traversi record:	*P. t. traversi* and *P. t. traversi* f. 'florida' (SJB, unpubl. data)
Tradescantia:	Not found, but has been reported in the past (I. Cooksley, pers. comm.)
Snails:	5.13 ± 0.65 per 100 m^2

Comments: This site contains one of the largest remaining populations of lowland *P. traversi* (Meads et al. 1984). The most likely means of *Tradescantia* dispersal to the site is via the public (the reserve has a high public use). However, establishment is unlikely since the site is visited regularly by DOC staff who can eradicate any *Tradescantia* they find. Moreover, Lake Papaitonga Scenic Reserve is afforded some protection from *Tradescantia* establishment by its size. *Tradescantia* is unlikely to invade or become the dominant ground cover in areas of closed-canopy forest.

Brown's Bush (a.k.a. McLeavey Road Bush)

Size:	<1 ha
Vegetation:	Mixed broadleaved forest
P. traversi record:	*P. t. traversi* f. 'florida'(?) but no sightings of live snails since the 1940s (I. Townsend, pers. comm.)
Survey date:	2 Feb 1999
Searched by:	RJS, SJB and JIT
Tradescantia:	Present around the periphery, extends into the bush in places
Snails:	None found in 10 m^2 native habitat or 20 m^2 *Tradescantia* habitat

Comments: The only evidence of *P. traversi* in recent times has been one empty shell (I. Townsend, pers. comm.). Two keen naturalists who have visited the site regularly over the last decade have not seen any live snails (I. Townsend and D. Mudge, pers. comm.). Ian Townsend (JIT) would probably have come across *P. traversi* if they were present, since he sorts through leaf litter looking for carabid beetles. *P. traversi* is likely to be extinct at this site, and we recommend that snail conservation efforts be directed elsewhere.

Kimberley Scenic Reserve

Size:	77 ha
Vegetation:	Tawa/mixed broadleaved forest on terrace tread and totara/tawa forest on floodplain
P. traversi record:	*P. t. traversi* and *P. t. traversi* f. 'florida' (I. Cooksley, pers. comm.)
Survey date:	2 Feb 1999
Searched by:	RJS and SJB

Tradescantia:	Present as large discontinuous patches along the Florida Road edge of the reserve, and also along the walking track that extends into the reserve from Florida Road. Does not appear to be present along the southern banks of Ohau River, which bisects the reserve, although the entire bank was not inspected. It is the most dominant ground cover in the long, narrow section of bush extending west from the picnic area on the northern side of the river. This area does not contain snails (I. Cooksley, pers. comm.).
Snails:	One whole empty and one rat-damaged shell in native habitat in 0.5 working hour; no snails or shells found within *Tradescantia* at the Florida Road edge in 0.3 working hour. Two live snails, three whole empty shells and one crushed shell, in 10 m^2 of <30 cm *Tradescantia* along track in forest.

Comments: This site is the largest of the forest remnants containing *P. traversi*. Only sites located at the foothills of the Tararua Range are buffered by larger tracts of forest. *Tradescantia* is unlikely to invade or become the dominant ground cover in areas of closed-canopy forest. Perhaps more significantly, this site appears to serve as a source of *Tradescantia* to sites downstream. It is one of the first remnants to flank the Ohau River as it flows down from the Tararua Range, and several remnants downstream contain *Tradescantia*, including Ohau River Bush. The areas containing the most significant infestations of *Tradescantia* (Florida Road edge of reserve, narrow section of bush on northern side of river) do not contain snails. Despite the relative scarcity of *Tradescantia* habitat within the forest interior, *P. traversi* was found within it.

Powell's Forest Reserve (a.k.a. Florida Road Reserve)

Size:	At foothills of Tararua Range, at least 40 ha
Vegetation:	Tawa/broadleaved forest
P. traversi record:	*P. t. traversi* f. 'florida'
Survey date:	4 Feb 1999
Searched by:	RJS and SJB
Tradescantia:	None found along pasture-side edge of forest
Snails:	Five located in April 1998 in one working hour

Comments: This site is the type locality for *P. t. traversi* f. 'florida' (Powell 1930; referred to as 'Florida Road Reserve' in Meads et al. 1984). Access to this relatively remote site is via private land. For these reasons, *Tradescantia* is unlikely to be introduced to the site.

Ohau River Bush

Size:	1 ha
Vegetation:	Swamp maire/pukatea/mahoe treeland on floodplain and tawa/mahoe forest on terrace riser
P. traversi record:	*P. t. traversi* f. 'florida' (Ravine 1995)
Survey date:	1 Feb 1999
Searched by:	RJS, SJB and JIT
Tradescantia:	Present on the riverbank, extending up the riser in a few places

Snails:	One live snail and one empty undamaged shell in *Tradescantia* in 1.5 working hour; none found in 20 m^2 of *Tradescantia* habitat (> 50 cm maximum height) on river bank
Other snails:	Two live *Wainuia*, one empty *Wainuia* shell and c.55 eggs (probably *Wainuia*) in 20 m^2 of *Tradescantia* habitat (> 50 cm maximum height)

Comments: *P. traversi* occurs in *Tradescantia* at Ohau River Bush. *Wainuia* and a ground weta were also found in *Tradescantia*. The population of *P. traversi* has declined in the last five years in comparison with the population of live snails encountered by Ravine (1995). Ravine also found 60 rat-chewed shells and did not observe *Tradescantia* established in November 1993. It would be difficult to eradicate *Tradescantia* from this site as it could potentially re-invade from Kimberley Scenic Reserve, located upstream. Moreover, the site has been used as a rubbish dump and it is not known whether its status as a 'Recommended Area for Protection' (Ravine 1995) has changed this. Access to the *Tradescantia*-infested riverbank is difficult via the steep terrace riser (and parking is a problem).

Rushworth's Bush (a.k.a. Hasselwood's Bush)

Size:	2 ha
Vegetation:	Tawa/titoki/rewarewa forest
P. traversi record:	*P. t. traversi* (f. 'florida'?)
Survey date:	3 Feb 1999
Searched by:	RJS and SJB
Tradescantia:	*Tradescantia* is the most dominant ground cover
Snails:	None found in native habitat in 0.3 working hour; none found in 40 m^2 of *Tradescantia* habitat (<30 cm/30–50 cm height)
Other snails:	Two live *Rhytida* and five empty *Rhytida* shells were found in 40 m^2 of *Tradescantia* habitat (<30 cm height)

Comments: *P. traversi* has been found at this site by Dan Hasselwood, the previous landowner, but no snails or shells have been found by the current owners since they bought the property in 1996 (S. Rushworth, pers. comm.). *Rhytida* snails were found in *Tradescantia* habitat. *Tradescantia* is well established on the banks of a stream that runs along the southern end of the bush, and occurs throughout the bush interior. It would be difficult to eradicate *Tradescantia* from this small, heavily infested site.

MacIntosh's Wetland

Size:	3 ha
Vegetation:	Blackberry (*Rubus fruticosus*)/raupo (*Typha orientalis*)/ *Carex secta* wetland
P. traversi record:	*P. t. otakia*
Survey Date:	17 Feb 1999
Searched by:	HBH, SJB and S. MacIntosh
Tradescantia:	None found, but was once present (S. MacIntosh, pers. comm.)
Snails:	No live snails and two empty whole shells were found in 0.5 working hours

Comments: Since *P. traversi* has been observed recently at this site and no *Tradescantia* was located, our search efforts were minimal. The owner tries to ensure that *Tradescantia* is kept out of the wetland (S. McIntosh, pers. comm.). Control of *Tradescantia* will have to be sustained for long-term eradication, since it may re-invade after flooding from a strip of *Tradescantia*-infested bush nearby.

Hillas Covenant (a.k.a. Rahui Road)

Size:	3 ha
Vegetation:	Pukatea/tawa forest on terrace tread
P. traversi record:	*P. t. otakia* (Walker 1997a)
Tradescantia:	Present on roadside edge of remnant
Snails:	*P. t. otakia* present (Walker 1997a)

Comments: This forest remnant is a stronghold for the rare *P. t. otakia*, referred to as 'Rahui Road' in Meads et al. (1984). The site was last surveyed in May 1997, when seven live snails were located in 125 m^2 of leaf litter (Walker 1997a). The snail colony is perched atop a steep-sided hillock bordered by a stream on three sides. *Tradescantia* extends to the stream's edge on the stream bank opposite the colony. The areas containing snails and *Tradescantia* are separated by the stream and the steep sides of the hillock. However, neither the stream nor the steep topography are barriers to *Tradescantia* spread (e.g. Monro's Bush).

Currently, invasion into the forest interior (and hence into the area containing snails) is unlikely, since light levels are too low under the relatively intact forest canopy. However, *Tradescantia* could invade further if a combination of the following were to occur: (1) Canopy damage, leading to increased light levels within the forest, and hence growth of *Tradescantia*; (2) DOC workers servicing the rat bait stations accidentally spread *Tradescantia* fragments via their boots; or (3) A flood event dispersed *Tradescantia* fragments to the colony-side of the stream. The small size of this site makes it particularly susceptible to canopy damage. Increased light levels would need to accompany events (2) and (3) for *Tradescantia* to invade further.

Hughes' Bush

Size:	4 ha
Vegetation:	Podocarp/broadleaved forest on terrace tread, gully and terrace riser
P. traversi record:	*P. t. otakia* probably extinct at this site (Meads et al. 1984)
Survey date:	3 Feb 1999
Searched by:	RJS and SJB
Tradescantia:	Present on stream bank, at forest edges and within forest
Snails:	None found in 60 m^2 of *Tradescantia* habitat (<30 cm height)

Comments: A road separates this site and Hillas Covenant. Together, they are the type locality for *P. t. otakia*, although this study and previous snail surveys suggest that *P. t. otakia* has disappeared from Hughes' Bush (Meads et al. 1984; I. Cooksley, pers. comm.). We recommend that snail conservation efforts be directed elsewhere.

Hutton's Bush

Size: 10 ha

Vegetation: Podocarp/broadleaved forest

P. traversi record: *P. t. otakia* (I. Cooksley, pers. comm.)

Survey date: 3 Feb 1999

Searched by: SJB and RJS

Tradescantia: None found

Snails: None found in 0.75 working hour

Comments: *P. t. otakia* is still present at this site (K. Walker, pers. comm.) though difficult to locate (Meads et al. 1984; present study).

2.3 DISCUSSION

Currently, there are five *P. traversi* colonies affected by *Tradescantia*: Waiopehu Scenic Reserve, Prouse's Bush, Kimberley Scenic Reserve, Ohau River Bush and Hillas Covenant. The degree of *Tradescantia* infestation among these sites varies from heavy (Prouse's Bush) to forest edge only (Hillas Covenant). We found *P. traversi* in *Tradescantia* regardless of the extent of infestation (percentage habitat available), except where the snail colony was separate from the site of weed infestation (Hillas Covenant).

Tradescantia provides a favourable habitat for *P. traversi*. Thick swards of *Tradescantia* are likely to provide some protection from desiccation (particularly at the relatively dry Prouse's Bush) and predation, at least for juvenile snails. Clearly, any attempt to remove *Tradescantia* from these sites can only be carried out after prior consideration of *P. traversi*. The most sensitive situations, where a mistake could lead to loss of *P. traversi*, are at those sites where *Tradescantia* is a significant or dominant ground cover and its removal would constitue a significant habitat loss and disturbance, i.e. Waiopehu Scenic Reserve and Prouse's Bush. Furthermore, the level of infestation at these sites indicates a degraded forest canopy which would need repair if the site were to remain weed-free. Of the sites surveyed, Waiopehu Scenic Reserve and Prouse's Bush require the most work to become *Tradescantia*-free. Without intervention, they are likely to degrade further, allowing *Tradescantia* to invade further.

We recommend that *Tradescantia* be removed from Hillas Covenant as soon as practicable, while the extent of infestation is relatively small and isolated from the snail colony. The site would need to be monitored for re-establishment of *Tradescantia* since it is present in all the surrounding forest remnants linked by road (Ravine 1995). We suggest that a different approach be taken at Kimberley Scenic Reserve, where *Tradescantia* is present but unlikely to invade areas of closed-canopy forest. Leaving this site untouched might be the best option. It would be difficult to eradicate *Tradescantia* from the area within Kimberley Scenic Reserve thought to be a source for sites downstream. Given the likelihood of re-establishment at Ohau River Bush (i.e. downstream of Kimberley Scenic Reserve, small size of site), it might not be feasible to eradicate *Tradescantia* from this site. If *Tradescantia* provides some protection from predation there, it is perhaps better left. Certainly, the benefits of rat control would outweigh those of weed control for *P. traversi* conservation at this site.

Tradescantia is regarded as a serious threat to nature conservation (Meurk 1996) because of its ability to prevent native forest regeneration (Kelly & Skipworth 1984; Standish et al. 2001). However, any impact of *Tradescantia* on *P. traversi* is likely to be neutral or beneficial, and its removal is likely to adversely affect the survival of these rare and endangered snails unless a simultaneous effort is made towards providing alternative habitat. This may present a conundrum for conservation management, similar to the case of gorse, which has replaced native manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) as the major early successional shrub over much of the New Zealand lowlands (Blaschke et al. 1981), but which provides suitable habitat for giant weta (Sherley & Hayes 1993). However, this conundrum is minor since dense *Tradescantia* currently affects only two of the twelve *P. traversi* colonies in the Horowhenua District.

3. *Powelliphanta t. traversi* habitat use in a *Tradescantia*-affected forest remnant

3.1 METHODS

The movement, density, size-frequency distribution and mortality of *P. t. traversi* snails were examined in relation to habitat type at Prouse's Bush. Residential properties, farmland, and industrial businesses surround the site. The canopy is dominated by tawa (*Beilschmiedia tawa*) and titoki (*Alectryon excelsus*), with some rewarewa (*Knightia excelsa*) and mahoe (*Melicytus ramiflorus*) (Ravine 1995), and is degraded in places. Some understorey cover is provided by karaka (*Corynocarpus laevigatus*) and kawakawa (*Macropiper excelsum*). *Tradescantia* was the dominant ground cover at Prouse's Bush, covering 55% (2.77 ha) of the total area. The remaining area (2.53 ha) was covered by native leaf litter, or less commonly by *Tradescantia* and leaf litter (i.e. where *Tradescantia* had recently established, and at the edges of large *Tradescantia* patches), which will be referred to as 'combination' habitat.

3.1.1 Long-term snail movements

Long-term (2 years) snail movements were monitored using transponders which were attached to the shell, and a harmonic radar for locating transponded snails (Lövei et al. 1997). This method minimises habitat disturbance during searches by allowing the user to locate the snail within c. 0.25 m². Transponded snails were relocated each month between July 1998 and July 2000, except for October 1999, and May and June 2000. Individual snails were followed for different lengths of time depending on when they were first found and when they died or disappeared, so movements were converted to daily displacements for comparison. Each time a snail was located, its habitat was categorised as 'leaf litter', '*Tradescantia*' or a 'combination'.

3.1.2 Home ranges

Successive positions of snails were mapped using Sigma Plot (Jandel Corporation 1994), and home range estimates made using the adaptive kernel method (Kie et al. 1996). A logarithmic transformation was used to normalise the data when daily movements and home ranges of snails were compared within leaf litter, *Tradescantia* and combination habitat. Snail movements and home ranges were compared using a general linear model (SAS 1996). Because movement data were repeatedly collected from individual snails, there was the potential for some correlation between the movements of individual snails. This was reduced by fitting a term for each individual to the general linear model used for movement analysis (i.e. 1 for 50% and 2 for 90% home ranges). Home ranges for individual snails were defined as the estimated 50% and 90% areas they occupied during the time their movements were recorded. The association of habitat type and snail size (for 2 mm intervals of maximum length (ML) from 34 to 56 mm) with home range size were tested using a two-factor ANOVA.

3.1.3 Short-term movement

Short-term (24–72 hours) movements were followed by attaching a spool and thread to the shell. Short-term snail movements were followed in leaf litter, *Tradescantia* and combination habitat on a total of 29 dates between March 1999 and February 2000. Twenty snails with transponders and five without transponders were used in this study. When a snail moved, the amount of thread pulled out and the distance between the snail's initial and final positions were measured to the nearest millimetre.

3.1.4 Snail density, distribution and mortality

Searches for snails were carried out in areas of leaf litter and *Tradescantia fluminensis* to compare the density and distribution of snails in these habitats. Different-sized areas were searched on several occasions in each habitat, up to 100 m² in leaf litter or 25 m² in *Tradescantia*, and live snail and empty shell densities expressed as means per unit area of the habitat searched. The size-frequency distributions (ML) of live snails and empty shells found in the two habitats were also compared using Fisher's exact test (SAS 1996). Snail mortality was recorded over the 2-year period of the study and, where possible, the cause of mortality was determined using Meads et al. (1984) as a guide.

3.2 RESULTS

3.2.1 Long-term movement

Transponders were attached to the shells of 40 *P. t. traversi* individuals (ML 34.7–55.5 mm). Of these, 23 snails were originally found in leaf litter, 16 in *Tradescantia*, and one in combination habitat. All 40 snails were relocated at least once, and 30 were relocated five times or more (Table 3). The greatest number of times one snail was relocated was 19, over 662 days (snail 12).

However, the longest time one snail was followed was 692 days, during which it was relocated 17 times (snail 6). The greatest total distance moved by a snail with a transponder was 214.42 m (over 627 days) by snail A4 and included three movements between leaf litter and *Tradescantia*. The smallest total distance was 0.05 m (over 66 days) by snail 18 before it died. On average, the direct displacement between the first and last positions of a snail relocated more than once (n = 37) accounted for 38% of the total movement between these two positions (range 3–100%; Table 3).

TABLE 3. SUMMARY OF LONG-TERM MOVEMENTS OF *P. T. TRAVERSI* SNAILS.

SNAIL	NO. OF RELOCATIONS	NO. DAYS FOLLOWED	MEAN DISPLACEMENT (m)	TOTAL DISTANCE TRAVELLED (m)	OVERALL DISPLACEMENT (m)	% TOTAL DISTANCE EXPLAINED BY OVERALL DISPLACEMENT	ORIGINAL SIZE (MAX. DIAMETER) (mm)
*12	19	662	1.59	30.25	6.97	23.04	34.68
6	17	692	4.35	73.99	2.43	3.28	37.68
*13	17	532	7.53	128.03	46.22	36.10	43.14
*2	16	600	3.50	55.98	25.57	45.68	44.00
16	16	594	1.96	31.38	16.65	53.06	39.92
*11	16	503	2.92	46.70	13.39	28.67	37.32
*A4	15	627	14.29	214.42	87.59	40.85	39.66
30	14	538	4.42	61.87	3.07	4.96	48.36
*5	14	491	8.79	123.11	6.60	5.36	46.82
*17	14	483	1.80	25.23	12.24	48.51	50.52
*19	14	483	3.42	47.94	12.46	25.99	43.86
*B2	14	463	2.65	37.07	10.62	28.65	44.44
D3	13	402	6.88	89.48	11.36	12.70	53.23
32	12	434	3.87	46.50	3.93	8.45	46.28
D2	12	402	5.47	65.64	8.95	13.63	51.32
*D1	12	359	4.65	55.79	14.29	25.61	43.68
31	11	380	4.16	45.76	10.39	22.71	51.60
4	11	347	5.99	65.92	13.06	19.81	49.18
B1	10	313	2.33	23.34	9.48	40.62	43.68
61	9	397	1.89	17.05	7.30	42.82	47.14
*60	9	373	5.77	51.93	14.13	27.21	47.35
3	9	295	5.39	48.51	12.83	26.45	50.25
10	9	285	1.22	11.00	6.68	60.73	44.18
8	8	379	6.85	54.78	10.30	18.80	44.80
34	8	373	7.35	58.84	4.83	8.21	45.33
35	8	373	4.70	37.57	4.25	11.31	44.36
*50	8	286	1.33	10.65	2.10	19.72	46.99
*A1	6	198	0.62	3.75	2.06	54.93	47.70
D4	5	214	6.18	30.88	8.03	26.00	54.86
33	5	150	1.91	9.56	6.19	64.75	44.66
72	3	157	2.25	6.76	6.20	91.72	48.72
7	3	98	2.95	8.86	6.58	74.27	53.50
14	3	88	0.31	0.94	0.51	54.26	48.72
*71	2	157	0.19	0.37	0.20	54.05	47.48
Qb10	2	130	1.82	3.64	2.86	78.57	51.55
18	2	66	0.03	0.05	0.05	100.00	36.90
*70	2	68	1.09	2.18	2.16	99.08	53.74
D5	1	34	0.29	0.29	0.29	100.00	55.53
Qb5	1	30	82.91	82.91	82.91	100.00	38.89
15	1	22	0.49	0.49	0.49	100.00	48.92

* Snails determined to have moved between habitats.

In total, 371 long-term movements were recorded (Table 4). Of these, 199 were by snails in leaf litter, 121 in *Tradescantia* and 10 in combination habitat. On 39 occasions, a snail had moved from one habitat to another. The remaining two movements were by two snails that had moved from one patch of *Tradescantia* to another, and could have only done so by travelling over leaf litter, but these were excluded from analyses. The fact that only ten consecutive relocations were made in combination habitat was probably due to the small amount of combination habitat at Prouse's Bush compared with leaf litter and *Tradescantia*.

The average distance between relocations was greatest for movements when a snail changed habitat, followed by movements in leaf litter, *Tradescantia*, and combination habitat (Table 4). However, when a snail changed habitat, it was relocated less frequently than snails that remained in leaf litter or *Tradescantia*. Consequently, mean daily displacement was actually greatest for movements in leaf litter, followed by movements between habitats, in *Tradescantia*, and in combination habitat (Table 4). A general linear model fitted to the log-transformed daily displacement data showed a highly significant difference in daily displacement among snails ($P < 0.01$) and among movements within and between the different habitats (i.e. leaf litter, *Tradescantia*, combination and between habitats; $P < 0.01$). Thus, even when variation among individual snails was accounted for, there were still highly significant differences in daily displacement among movements within and between habitats. However, the model only accounted for 34% of the variation ($R^2 = 0.34$). Hence, while differences among individual snails and habitats were significant, these factors

TABLE 4. COMPARISON OF LONG-TERM MOVEMENTS BY SNAILS IN THREE HABITATS AND WHEN A SNAIL CHANGED HABITAT. ALL DISPLACEMENT MEASURES REFER TO DISTANCE IN METRES. 'MEAN NO. DAYS' SHOWS THE AVERAGE TIME BETWEEN RELOCATIONS. MEANS ARE ± SE.

	LEAF LITTER	*TRADESCANTIA*	COMBINATION	CHANGE	TOTAL
No. movements	199	121	10	39	371
Range of displacements	0.05–28.13	0.05–18.71	0.01–1.08	0.11–44.55	0.01–44.55
Mean no. days	36.10 ± 1.33	35.68 ± 1.21	39.90	38.64 ± 2.90	36.18
Mean displacement	5.48 ± 0.55	2.71 ± 0.52	0.35 ± 0.13	7.21 ± 1.67	4.42
Mean daily displacement	0.201 ± 0.03	0.064 ± 0.01	0.031 ± 0.02	0.169 ± 0.03	0.15

TABLE 5. HABITAT CHANGES MADE BY 15 TRANSPONDED SNAILS. A CHANGE IN HABITAT WAS SHOWN BY SUCCESSIVE RELOCATIONS IN A DIFFERENT HABITAT TYPE.

CHANGE IN HABITAT	NO. OBSERVATIONS	NO. SNAILS
Tradescantia to combination	7	6
Tradescantia to leaf litter	9	8
Leaf litter to combination	6	6
Leaf litter to *Tradescantia*	8	6
Combination to *Tradescantia*	5	4
Combination to leaf litter	4	4

alone were not sufficient to explain the majority of the variation in daily displacement.

Mean daily displacements for movement within and between habitats were compared with Tukey's procedures (SAS 1996) to establish significant differences ($P < 0.05$). There was no significant difference in mean daily displacement among movements in leaf litter, between habitats, and *Tradescantia* habitat. Mean daily displacements of all three were significantly greater than for movements by snails in combination habitat but, again, combination habitat was of a limited size and few observations were made ($n = 10$).

Movement between habitats occurred on a total of 39 occasions. Of these, movement from *Tradescantia* into leaf litter was undertaken by more *P. t. traversi* (eight snails), more often (nine movements) than any other change in habitat (Table 5). Only 15 snails were involved in all 39 changes in habitat. Five snails changed habitat just once, but six changed habitat three times or more. Snail 19 was the most active, changing habitat six times in 483 days (including all three habitats).

3.2.2 Home range

Home range estimates, for 50% and 90% of total excursion area, were calculated for 36 and 27 snails respectively. Mean 50% and 90% home ranges in decreasing order were for snails that were observed: to have changed habitat, remained in leaf litter or remained in *Tradescantia* (Table 6). A general linear model fitted to the data showed no significant effect of habitat, snail size or habitat snail size interaction on areas of the 50% home range ($P > 0.05$). However, for 90% home range areas, there was a significant effect of habitat ($P < 0.05$) and snail size ($P < 0.05$), and no significant interaction effect between these two factors ($P > 0.05$). The mean 90% home ranges for snails that changed habitat and for those only found in leaf litter were significantly greater than for snails always found in *Tradescantia* ($F_{2,15} = 5.16$, $P < 0.05$; Table 6).

3.2.3 Short-term movement

For snails with cotton spools attached, a total of 97 paired observations of thread length and displacement were made: 10 in combination habitat, 31 in *Tradescantia* and 56 in leaf litter. However, movement was observed on only 39 instances (38% of total): two in combination habitat, nine in *Tradescantia* and 28 in leaf litter. For these movements, the mean amount of thread pulled out was 28.3 cm compared with a mean displacement of 20.7 cm (Table 7). For 19 movements (49%), displacement was equal to the amount of thread pulled out.

TABLE 6. MEAN (± SE) HOME RANGE SIZES (M^2) AND SAMPLE SIZES (*n*) FOR SNAILS USING LEAF LITTER, *TRADESCANTIA*, AND BOTH HABITATS. THE VALUES SHOWN WERE CALCULATED USING THE ADAPTIVE KERNEL METHOD (KIE ET AL. 1996).

HOME RANGE	LEAF LITTER	*TRADESCANTIA*	LEAF LITTER AND *TRADESCANTIA*
50%	24.65 ± 5.18 ($n = 16$)	6.18 ± 3.87 ($n = 6$)	130.25 ± 104.79 ($n = 14$)
90%	171.35 ± 31.52 ($n = 13$)	43.91 ± 21.06 ($n = 3$)	610.14 ± 337.25 ($n = 11$)

Snails in leaf litter moved proportionally more often (50%) and further (33 cm mean thread length) than snails in *Tradescantia* (29%, 17 cm) or a combination (20%, 15 cm). When a snail did move, movement was regularly in a single direction with little deviation in each habitat (proportion of movements explained by displacement = 49%). However, there were also two instances when a snail made several changes in direction, or even backtracked, and no displacement was observed. Linear regression of thread length and displacement accounted for 81% of the variation (adjusted R^2) (n = 39 paired observations).

3.2.4 Snail density and distribution

Many more live snails were found in *Tradescantia* (54) than in leaf litter (11) during searches (Table 8). Only slightly more empty shells were found in leaf litter (48) than in *Tradescantia* (43). A general linear model fitted to the log-transformed density data revealed the difference in live snail density between leaf litter and *Tradescantia* to be non-significant (P = 0.065). The model did find a significant difference in the density of empty shells between the two habitats (P = 0.049). However, neither model was able to provide a very good fit to the data (R^2 = 0.10 and 0.12 respectively). This was probably due to the large number of searches where no live snails or empty shells were found.

The size-frequency distribution of live snails differed between leaf litter and *Tradescantia* habitats (Fig. 1; n = 29 and 57 respectively; Fisher's exact test P < 0.01), but there was no difference in the size-frequency distribution of empty shells between habitats (Fig. 2; n = 43 and 43 respectively; Fisher's exact test P > 0.05). Mean maximum shell length was smaller for live snails and empty

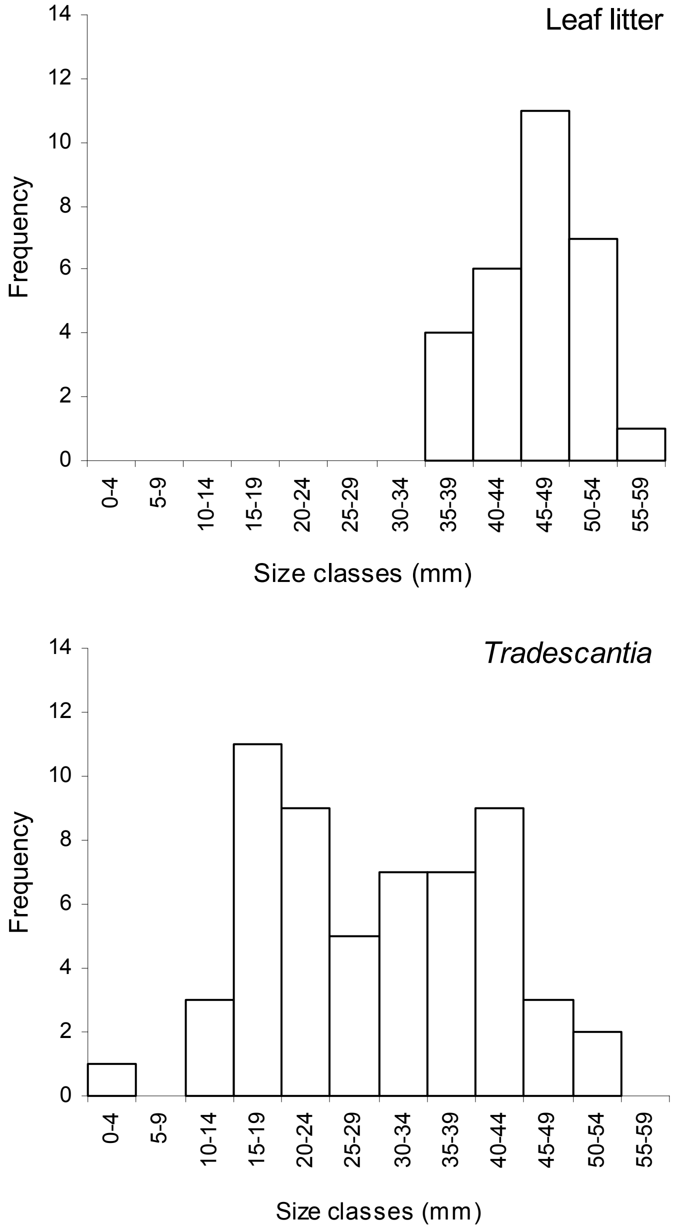
TABLE 7. SUMMARY OF SHORT-TERM MOVEMENTS IN LEAF LITTER AND *TRADESCANTIA* BY *P. T. TRAVERSI* SNAILS. THREAD LENGTH AND DISPLACEMENT MEASURES ARE SHOWN IN METRES.

PARAMETER	MEASURE	LEAF LITTER	*TRADESCANTIA*	COMBINATION	TOTAL
No. of movements		28	9	2	39
Range	Thread length	0.03–1.30	0.05–0.41	0.11–0.12	0.03–1.30
Range	Displacement	0–0.72	0–0.33	0.11–0.12	0–0.72
Mean	Thread length	0.32	0.17	0.15	0.28
Mean	Displacement	0.23	0.13	0.15	0.21

TABLE 8. DENSITY OF LIVE *P. T. TRAVERSI* AND EMPTY SHELLS IN LEAF LITTER AND *TRADESCANTIA* AT PROUSE'S BUSH.

	LEAF LITTER	*TRADESCANTIA*
Area searched	285 m²	293 m²
No. live snails	11	54
No. empty shells	48	43
No. searches with no live snails	5	11
No. searches with no shells	2	17
Mean live snail density ± SD	0.05 ± 0.07 m^{-2}	0.25 ± 0.47 m^{-2}
Mean shell density ± SD	0.17 ± 0.18 m^{-2}	0.12 ± 0.21 m^{-2}

Figure 1. *Powelliphanta t. traversi* size-frequency distributions (ML) in leaf litter (n = 29) and *Tradescantia* (n = 57) at Prouse's Bush.

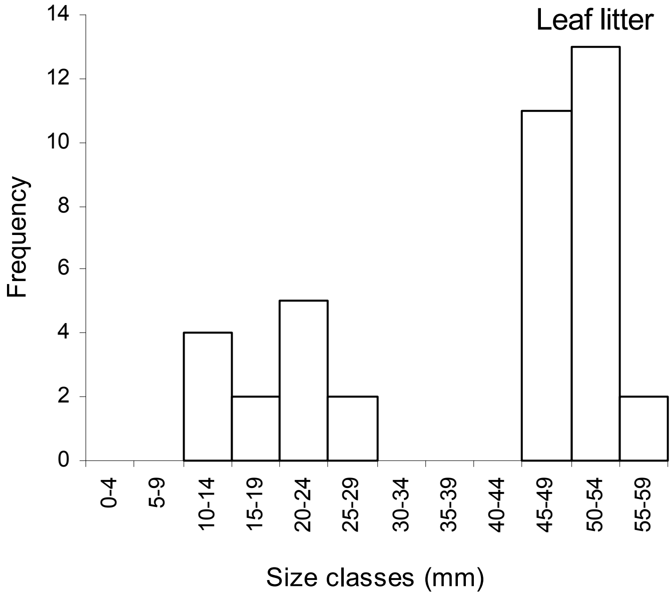


shells found in *Tradescantia* (29.8 mm and 31.2 mm, respectively) than for those found in leaf litter (47.2 mm and 49.5 mm respectively). Furthermore, live snails in leaf litter were all greater than 35 mm (Fig. 2.1). By comparison, live snails found in *Tradescantia* had a greater range of sizes, including snails as small as 4.9 mm. The size-frequency distribution of empty shells was bimodal for both habitats, with an absence of empty shells of between 30 and 35 mm in length (Fig. 2).

3.2.5 Snail mortality

Twenty-four transponded snails (59% of total transponded) died between August 1998 and July 2000. Of these, causes unrelated to predation accounted for 13 deaths (54% of total) in leaf litter, seven (29%) in *Tradescantia* and three (13%) in combination habitat. The remaining death was the result of rat predation in *Tradescantia*. Five of the seven deaths that occurred in *Tradescantia* took place during the summer months.

Figure 2. Size-frequency distributions (ML) of empty *P. t. traversi* shells found in leaf litter (n = 43) and *Tradescantia* (n = 43) at Prouse's Bush.



3.3 DISCUSSION

Homing behaviour has been proposed or demonstrated for some mollusca (e.g. Cook et al. 1969; Gelperin 1974; Pollard 1975; Cook 1977; Peake 1978; Lorvelec 1990; Coad 1998), while Devine (1997) reported *P. t. traversi* as maintaining a home range. At Prouse's Bush, territories within *Tradescantia* are as common as territories within native habitat, showing a substantial overlap in native/ *Tradescantia* habitat use by *P. t. traversi*. In addition, there is a great deal of variation in home range size between snails, and sometimes the home ranges of several snails overlap; this is similar to findings for *Paryphanta busbyi busbyi* (Coad 1998).

The recent investigation by Devine (1997) of *P. t. traversi* at nearby Lake Papaitonga Scenic Reserve provides a useful comparison for this study. The largest distance travelled during a single night at Prouse's Bush (1.30 m) was much smaller than for *P. t. traversi* at Lake Papaitonga (5.58 m, Devine 1997), but nightly movements of many snails at Prouse's Bush appeared to have a single orientation—a phenomenon already noted for *P. t. traversi* (Devine 1997), and also *Paryphanta b. busbyi* (Coad 1998) and *Oxychilus helveticum* Blum (Verdcourt 1947). Despite this, movement in one direction would rarely be the case other than over short distances (Verdcourt 1947). Our study supports this conclusion and shows that displacement can only be expected to explain a certain percentage of the actual distance a snail has travelled. Caution is needed over longer periods, when the actual distance not explained by displacement may become sizeable.

Tradescantia appeared to have an effect on home range, since snails that were only ever found in *Tradescantia* had smaller home range sizes than those only ever found in leaf litter. Some snails regularly moved between the two habitats and sometimes moved relatively large distances over short periods. Therefore, although the average distances moved daily were not significantly different between litter and *Tradescantia*, overall dispersal by snails in *Tradescantia* was less than in leaf litter and for those that moved between habitats. This may have been related to differences between habitats (i.e. it is harder for snails to move in *Tradescantia* than in leaf litter) and/or snails in each habitat. Live snails were significantly larger in leaf litter, so they may have had a greater tendency to disperse further than smaller snails in *Tradescantia*. However, Pomeroy (1969) showed that juvenile *Helicella virgata* were more active and moved further than adults, and Verdcourt (1947) did not consider size to be an influencing factor (within a species) on the speed of a snail, since resistance to motion would increase with size and muscular power.

Verdcourt (1947) considered the rate of snail dispersal to be influenced by the actual speed of the snail, but considered that this factor was in turn dependent on atmospheric conditions, nature of the surface, internal state of the animal and food supply. Devine (1997) showed that movements of *P. t. traversi* are mostly nocturnal, and that activity is primarily determined by moisture-related factors. Casual observations suggested that soil moisture beneath *Tradescantia* was generally greater than under leaf litter (Bennett 2001). A small amount of temperature data (11 days) suggested temperature was only slightly lower on average under *Tradescantia* (6.7°C) than under leaf litter (7.1°C) at Prouse's Bush (S. Bennett, unpubl. data). Despite little apparent difference in temperature, if moisture is greater in *Tradescantia* than in leaf litter, there may be no need for snails under *Tradescantia* to disperse as far as those in leaf litter to find favourable conditions.

Tradescantia supports a greater snail density than does leaf litter at Prouse's Bush. Coad (1998) found a correlation between the density of *Paryphanta b. busbyi* and the relative abundance of their earthworm prey, and Verdcourt (1947) considered that food abundance would play a considerable role in snail dispersal, with snails not needing to leave habitats that provide an ample food supply. Furthermore, it has been shown that high prey density affects behavioural patterns and the speed of movement of some carabid beetles, including increased patch residence times (Wallin 1991; Wallin & Ekbom 1994). The smaller home ranges of *P. t. traversi* in *Tradescantia* may therefore reflect similar responses to prey densities if earthworms are more abundant under *Tradescantia*.

Many *P. t. traversi* snails found in leaf litter at Prouse's Bush had a thickened peristome, but snails found under *Tradescantia* typically did not. Thickening of the aperture lip is believed to represent growth under less favourable conditions; growth of the peristome occurs at the same point rather than a normal progression of the aperture lip (K. Walker, pers. comm.), resulting in a reduction in aperture size. Such a response may retard water loss by eliminating convective transfer (Machin 1975) under increased evaporative pressures brought about by the degraded state of Prouse's Bush. Activity of terrestrial snails is generally governed by moisture-related factors (e.g. Pomeroy 1969; Machin 1975; Pollard 1975), so the state of the bush may also explain the difference between the mean daily average for *P. t. traversi* movements in leaf litter at Prouse's Bush (0.201 m/day) and Lake Papaitonga (0.293 m/day, Devine 1997), where vegetation is generally less degraded (S. Bennett, pers. obs.).

The reason for the significant difference in live snail sizes between the two habitats is unclear, but may also be related to the state of the bush. Water is lost by evaporation from all exposed surfaces (including the shell) of a terrestrial pulmonate's body and is affected by environmental parameters such as humidity, temperature and wind speed (Machin 1975). Such factors are in turn affected by fragmentation, with smaller remnants more affected owing to proportionally greater edge effects (Saunders et al. 1991). At Prouse's Bush, no live snails smaller than 35 mm were ever found in leaf litter whereas the majority of snails found under *Tradescantia* were smaller than 35 mm. Furthermore, the largest empty shell and live snail were found in leaf litter. Smaller snails are at more risk from desiccation than larger snails owing to their proportionally larger surface/volume ratio, and nearly twice as many snails followed with harmonic radar died in leaf litter as in *Tradescantia*. This suggests environmental conditions under *Tradescantia* may be more suitable for smaller snails.

DOC has not favoured removal of *Tradescantia* from some sites because of a perceived benefit to *P. traversi* snails (DOC 1996). This possibility has been recognised by the Horowhenua District Council (Strong 2000), which administers Prouse's Bush and as yet has not undertaken any steps to control the weed. The abundance of *P. t. traversi*, the apparent maintenance of home ranges in areas of *Tradescantia* and the presence of small snails in areas of this weed at Prouse's Bush (when none were found in leaf litter) support the suggestion that these snails may benefit either from *Tradescantia* or by an environmental factor that its presence indicates. Devine (1997) found that karaka (*Corynocarpus laevigatus*) was associated with areas of high *P. t. traversi* abundance at Lake Papaitonga, leading him to suggest that karaka may reflect good snail habitat. Similarly, vigorous growth of *Tradescantia* is considered to indicate high-fertility soils (Ogle & Lovelock 1989; Atkinson 1997), which may also be preferred by *P. t. traversi*.

Predation by introduced species is another serious threat to *P. traversi* snails (Climo 1975; Meads et al. 1984), but it is unclear whether *Tradescantia* influences predation on *P. t. traversi*. Blackbirds (*Turdus merula* L.) and song thrushes (*Turdus philomelo*s Brehm) are known predators of smaller *P. t. traversi* (Meads et al. 1984), and bird-damaged shells were found in litter. No shells were found under *Tradescantia*, and it seems likely that these birds would find it difficult to locate snails in areas of this weed. The same cannot be said for rat predation. The only snail with a transponder known to be lost to predation was killed by a rat in *Tradescantia*. The aperture and outer whorl were removed, damage characteristic of predation by a Norway rat (*Rattus norvegicus* Berkenhout) (Meads et al. 1984). Another live snail found in *Tradescantia* had survived an attack to its aperture and the only certain rat-damaged shells were found in *Tradescantia*. All had damage consistent with Norway rat predation. Norway rats are commensal with humans in most towns and cities (Moors 1990), but one dead rat found at Prouse's Bush was identified as a ship rat (*Rattus rattus* L.).

The effects of rats and birds on *P. t. traversi* at Prouse's Bush appear to be minor compared with depredations suffered by snails at Lake Papaitonga (S. Bennett, pers. obs.). Domestic cats (*Felis catus* L.) were seen at Prouse's Bush and may restrict rodent and bird numbers. In addition, rodent numbers may have been affected by poison in bait stations adjacent to one side of Prouse's Bush. No rats were recorded using tracking tunnels in leaf litter and *Tradescantia*, but mouse tracks were recorded from one tunnel in *Tradescantia* and from another next to an area of *Tradescantia*.

4. Conclusion

Powelliphanta t. traversi commonly occurs under *Tradescantia*, sometimes exclusively, and there are regular movements of snails from leaf litter into areas of this weed. The sites which contain *P. traversi* and *Tradescantia* are Waiopehu Scenic Reserve, Prouse's Bush, Kimberley Scenic Reserve, Ohau River Bush and Hillas Covenant. The first two forest remnants listed would certainly benefit from a restoration programme. *Tradescantia* does not dominate the ground cover at Kimberley Scenic Reserve or Hillas Covenant, and is not likely to, since much of the forest canopy is intact, although Hillas Covenant is small and therefore susceptible to canopy damage. It would be impractical to try to eradicate *Tradescantia* from Ohau River Bush since it is likely to reinvade from sources upstream.

Our most important finding was that *Tradescantia* provides refuge for juvenile and sub-adult snails at Prouse's Bush. *P. traversi* recruitment has rarely been observed; Devine (1997) did not record a live *P. t. traversi* smaller than 17.63 mm ML at Lake Papaitonga and we have observed recruitment rarely at the same site. Additionally, in three searches for *P. t. otakia* in 1987, 1990 and 1997 (Walker 1997a), live juveniles (< 24 mm ML) were found only during the 1987 search. The presence of juvenile snails at Prouse's Bush indicates that this population persists despite ongoing threats. *Tradescantia* may be *more* attractive to snails at this site than at other sites we have visited owing to the abnormally dry and compacted state of the leaf litter, which means that we can not assess the role of *Tradescantia* in *P. traversi* recruitment generally. Nevertheless, it is clear that removal of *Tradescantia* will have a deleterious effect on *P. t. traversi* at this site.

Tradescantia is a suitable habitat for *P. t. traversi*, but also appears to be more suitable for juvenile recruits and sub-adults than native habitat at Prouse's Bush. Irrespective of whether a refuge from predation or desiccation, recruitment appears to be a regular event in *Tradescantia*, whereas it has not occurred for some time in leaf litter. For this *K*-selected, naturally rare snail, whose recovery from a more threatened status (i.e. very low population size) depends on regular recruitment, these observations are of prime conservation significance. It is ironic, but not unusual (cf. Sherley & Hayes 1993), that an invasive weed should provide some benefit to a rare and endangered native species.

5. Acknowledgements

We thank Ian Cooksley for his valuable contribution to this study and Greg Sherley, Colin Miskelly and Alastair Robertson for their valuable contributions to the research proposal and planning stages. Thanks to the landowners who allowed us access to forest remnants on their property, and to the Horowhenua District Council for allowing us access to forest remnants under its jurisdiction. Thanks also to Ian Townsend (JIT) and Hayden Hewitt (HBH) for assistance in the field.

6. References

Atkinson, I. A. E. 1997: Problem weeds on New Zealand islands. *Science for Conservation 45*. Department of Conservation, Wellington, New Zealand. 58 p.

Bennett, S.J. 2001: The effects of introduced predators and the invasive weed *Tradescantia fluminensis* (Vell.) (Commelinaceae) on the land snail *Powelliphanta traversi* traversi (Powell) (Gastropoda: Pulmonata: Rhytididae). MSc thesis, Massey University (unpublished), 101 p.

Blaschke, P.M.; Hynter, G.G.; Eyles, G.O.; Van Berkel, P.R. 1981: Analysis of New Zealand's vegetation cover using land resource inventory data. New *Zealand Journal of Ecology 4*: 1–14.

Climo, F. 1975: Molluscs. Large Land Snails. *New Zealand Natural Heritage 5*: 1862–1866.

Coad, N. 1998: The kauri snail (*Paryphanta busbyi busbyi*): Its ecology and the impact of introduced predators. MSc thesis, University of Auckland (unpublished), 150 p.

Cook, A.; Bamford, O. S.; Freeman, J. D. B.; Teidman, D. J. 1969: A study of the homing habit of the limpet. *Animal Behavior 17*: 330–339.

Cook, A. 1977: Mucus trail following by the slug *Limax grossui* Lupu. *Animal Behaviour 25*: 774–781.

Devine, C. D. 1997: Some aspects of behaviour and ecology of the land snail *Powelliphanta traversi traversi* Powell (Rhytididae: Rhytidinae). MSc thesis, Massey University (unpublished), 137 p.

DOC 1996: Wellington conservancy conservation management strategy for Wellington 1996–2005. Department of Conservation, Wellington, New Zealand.

Esler, A.E. 1978: Botany of the Manawatu. Government Printer, Wellington, New Zealand.

Gelperin, A. 1974: Olfactory basis of homing behaviour in the giant garden slug, *Limax maximus*. *Proceedings of the National Academy of Sciences of the United States of America 71*: 966–970.

Healy, A.J.; Edgar, E. 1980: Flora of New Zealand, Volume 3. Government Printer, Wellington, New Zealand.

Jandel Corporation 1994: Sigma Plot v. 1.02. Jandel Corporation, San Rafael, California, USA.

Kelly, D.; Skipworth, J. P. 1984: *Tradescantia fluminensis* in a Manawatu (New Zealand) forest: I. Growth and effects on regeneration. *New Zealand Journal of Ecology 22*: 393–397.

Kie, J.G.; Baldwin, J.A.; Evans, C.J. 1996: CALHOME: a program for estimating animal home ranges. *Wildlife Society Bulletin 24*: 342–344.

Lorvelec, O. 1990: Homing by the snail *Helix aspersa*. *Biology of Behaviour 15*: 107–116.

Lövei, G. L.; Stringer, I. A. N.; Devine, C. D.; Cartellieri, M. 1997: Harmonic radar—A method using inexpensive tags to study invertebrate movement on land. *New Zealand Journal of Ecology 21*: 187–193.

Machin, J. 1975: Water relationships. Pp. 105–163 in Fretter, V.; Peake, J. (Eds) Pulmonates Volume 1. Functional Anatomy and Physiology. Academic Press, London.

Maule, H. G.; Andrews, M.; Morton, J.D.; Jones, A.V.; Daly, G.T. 1995: Sun/shade acclimation and nitrogen nutrition of *Tradescantia fluminensis*, a problem weed in New Zealand forest remnants. *New Zealand Journal of Ecology 19*: 34–46.

Meads, M. J.; Walker, K.J.; Elliot, G.P. 1984: Status, conservation, and management of the land snails of the genus *Powelliphanta* (Mollusca: Pulmonata). *New Zealand Journal of Zoology 11*: 277–306.

Meurk, C.D. 1996: Time bombs in the land—a nature conservation perspective. *Weed Identification News 18*. Landcare Research, New Zealand.

Moors, P. J. 1990: Norway rat. Pp. 192–206 in King, C.M. (Ed.) The handbook of New Zealand mammals. Oxford University Press, Auckland, New Zealand.

Ogle, C.; Lovelock, B. 1989: Methods for the control of wandering Jew (*Tradescantia fluminensis*) at 'Rangitawa', Rangitikei District, and notes on other aspects of conserving this forest remnant. *Science and Research Internal Report 56*. Department of Conservation, Wellington, New Zealand.

Peake, J. 1978: Distribution and ecology of the Stylommatophora. Pp. 429–526 in Fretter, V.; Peake, J. (Eds): Pulmonates Volume 2A. Systematics, Evolution and Ecology. Academic Press, London.

Pollard, E. 1975: Aspects of the ecology of *Helix pomatia* L. *Journal of Animal Ecology 44*: 305–329.

Pomeroy, D. E. 1969: Some aspects of the ecology of the land snail, *Helicella virgata*, in South Australia. *Australian Journal of Zoology 17*: 495–514.

Powell, A. W. B. 1930: The Paryphantidae of New Zealand: their hypothetical ancestry, with descriptions of new species and a new genus. *Records of the Auckland Institute and Museum 1*: 17–55.

Powell, A. W. B. 1946: The Paryphantidae of New Zealand. No. V. further new species of *Paryphanta*, *Wainuia*, and *Rhytida*. *Records of the Auckland Institute and Museum 3*: 99–136.

Ravine, D.A. 1995: Manawatu Plains Ecological District: survey report for the Protected Natural Areas programme. Department of Conservation, Wanganui, New Zealand. 352 p.

Saunders, D.A.; Hobbs, R.J.; Margules, C.R. 1991: Biological consequences of ecosystem fragmentation: a review. *Conservation Biology 5*: 18–32.

Sherley, G.H.; Hayes, L.M. 1993: The conservation of giant weta (*Deinacrida* n. sp. Orthoptera: Stenopelmatidae) at Mahoenui, King Country: Habitat use, and other aspects of its ecology. *New Zealand Enotomologist 16*: 55–68.

SAS/STAT 1996: Release 6.12 for Windows. SAS Institute, North Carolina, USA.

Standish, R.J.; Robertson, A.W.; Williams, P.A. 2001: The impact of an invasive weed *Tradescantia fluminensis* on native forest regeneration. *Journal of Applied Ecology 38*: 1253–1263.

Strong, C. 2000: Bush reserves of Levin management plan. Horowhenua District Council (unpublished), 12 p.

Timmins, S. M.; Williams, P.A. 1991: Weed numbers in New Zealand's forest and scrub reserves. *New Zealand Journal of Ecology 15*: 153–162.

Verdcourt, B. 1947: The speed of land mollusca. *Journal of Conchology (London) 22*: 269–270.

Walker, K. 1997a: Monitoring the effect of rodent poisoning on *Powelliphanta traversi otakia*—May 1997. File Note for Department of Conservation, Nelson/Marlborough Conservancy (unpublished).

Walker, K. 1997b: Techniques for monitoring populations of *Powelliphanta* land snails. *Ecological Management 5*: 53–63.

CONTENTS

HABITAT USE OF *TRADESCANTIA FLUMINENSIS* BY *POWELLIPHANTA TRAVERSI*

By Rachel J. Standish, Shaun J. Bennett and Ian A.N. Stringer