Transfer of captive-bred *Placostylus hongii* snails to Limestone Island

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ABSTRACT

Populations of New Zealand's large indigenous land snails have been reduced to small scattered remnants by habitat destruction and predation. It is possible to rear some of these snail species in captivity, but it is important that they can then be released back into the wild to establish new populations. Eleven *Placostylus hongii* snails released from captivity onto Limestone Island, Whangarei Harbour, New Zealand on 5 August 2002 were monitored after release. All eleven snails died within < 0.25–1.63 years. The snails were equipped with harmonic radar transponders to facilitate finding them each time the island was visited. Six juveniles developed into adults, five after 0.25–0.47 years and one after 1.02–1.26 years on the island. A single newly hatched juvenile found on 13 August 2003 showed some breeding had occurred. The snails remained within 3 m of the small grove of trees where they were released. They moved 0.3–11.1 m between recaptures and were followed for total distances of 0.4–19.7 m with most displacements being uphill. Failure to establish was possibly due to a long dry period with high temperatures during the summer of 2003/04, together with soil that dried hard, thus preventing the snails from burrowing. Further research is needed to determine the causes of mortality in translocated snails and how these can be mitigated before further captive-rearing followed by translocation is considered.

Keywords: Mollusca, Bulimulidae, experimental translocation, conservation

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1. Introduction

The ultimate intention of captive-breeding for conservation management is to reintroduce the captive-bred animals to the wild. There are a number of reasons why reintroductions might be needed. The aim may be to re-establish a species where it has become extinct, to establish new populations or to supplement existing populations. In extreme cases, a species may no longer be able to survive in its natural environment because of human-induced changes, and captive individuals may be the only remaining members of that particular species (e.g. Coote et al. 2004; Hadfield et al. 2004). Whatever the reason for captive rearing of animals, it is important that they eventually be able to establish and sustain wild populations. In this study we document an experimental release of *Placostylus hongii* (Pulmonata: Bulimulidae) snails onto Limestone Island (sometimes called Limestone (Matakohe) Island) in Whangarei Harbour, Northland (Fig. 1) to determine if captive-bred individuals of this species can survive being released into the wild. Of the individual snails released, one had been maintained in a laboratory for 10 years after collection from the wild, and all the others were laboratory-reared (Stringer & Grant 2007).

Placostylus snails (sometimes commonly known as flax snails) were once widespread in Northland, northern New Zealand. This research and the associated captive-rearing were initiated because most populations of *P. hongii* snails have now been reduced to small scattered remnants by habitat destruction and introduced predatory mammals, particularly rodents (*Rattus* spp. and *Mus musculus*) and pigs (*Sus scrofa*) (Choat & Scheil 1980; Penniket 1981; Parrish et al. 1995). These large land snails (maximum shell length 85 mm, Powell 1979) are numerous on the Poor Knights Islands, which are mammal free, whereas only small numbers occur elsewhere on the east coast of Northland between

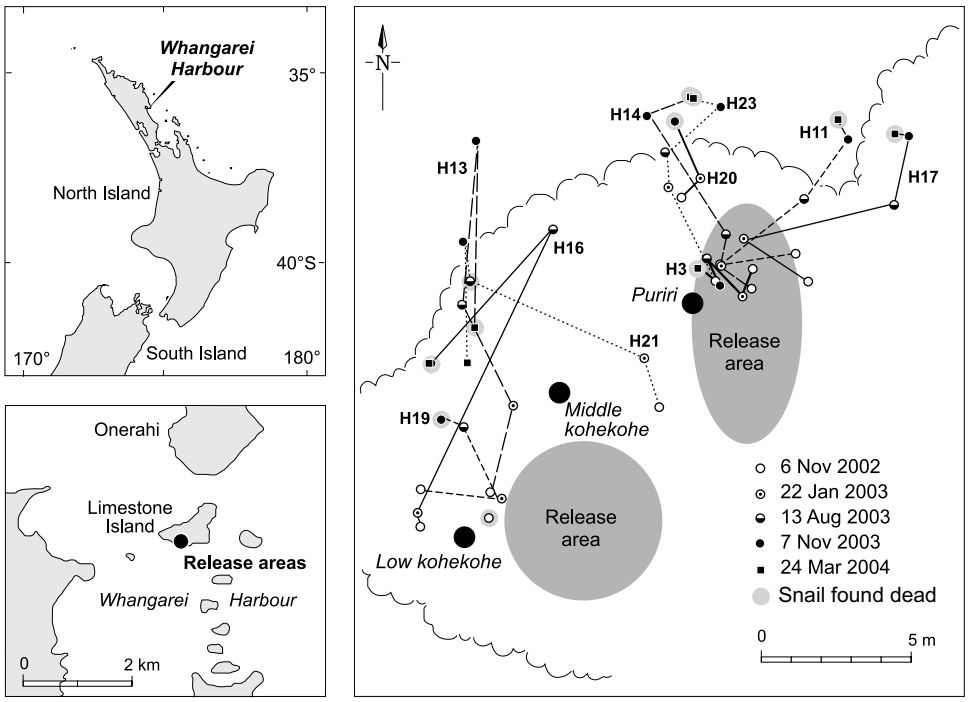

Figure 1. Movements of *Placostylus hongii* snails after release on Limestone Island, Whangarei Harbour, on 5 August, 2002. The snails' exact release locations were not recorded.

Whangarei Heads and the Bay of Islands, and on some northern islands (Brook & McArdle 1999). Populations of *P. hongii* snails are likely to recover only slowly after the removal of mammals because of their long developmental period and relatively low reproductive rate (Stringer et al. 2004a). There has, for example, been no appreciable increase in the numbers of this snail on Coppermine Island between 1977 and 2007, even though pacific rats (*Rattus exulans*), the only mammals once present there, were exterminated by poisoning on 28 August 1997 (Parrish et al. 2005; Lumis et al. 2007).

2. Previous transfers of *Placostylus* snails

Few details were recorded for most of the previous transfers of *Placostylus* snails. The first, of 100 *P. hongii* snails, was made by A.W.B. Powell from Archway Island, Poor Knights Islands to Motuhoropapa Island (sometimes called Motuhurakia), in The Noises group, in February 1934 (Powell 1938; Brook & McArdle 1999). Some snails still survive there, but have apparently not spread far from their release site. Motuhoropapa Island has undergone a series of eradications and reinvasions of Norway rats (*Rattus norvegicus*) since 1983–84, but it is now rat-free (Brook & McArdle 1999; Paul Keeling, Department of Conservation (DOC), pers. comm.).

Mr W.M. (Norm) Douglas placed some eggs of *P. ambagiosus keenorum* by a flax bush at his home in Tauraugaruru, Awhitu Peninsula, Auckland on 24 November 1976 and released two groups of five and four hatchlings in a valley near Karioitahi Beach, west of Waiuku on 2 January and 5 February 1977 respectively. These snails had hatched from eggs laid by a single adult collected from the east side of Maugapiko Hill, Spirits Bay, on 19 May 1976 and subsequently kept in a cage at his home. There are no records of whether any of these releases were successful.

The New Zealand Wildlife Service released four subspecies of *P. ambagiosus* onto islands in the Cavalli Islands group and Simmonds Islands group in 1984 and 1985 (Table 1). These snails were kept in outdoor cages at Kerikeri after being captured at the end of the Aupouri Peninsula in 1982 (summarised by Stringer & Grant 2007). The intention was to establish additional colonies on rat-free islands because it was thought that the parent colonies would not survive. No *P. a. watti* or *P. a. michiei* snails were found when the Cavalli Islands were surveyed in October 1985, but one empty *P. a. whareana* shell and some live juveniles were found on Horonui Island and one adult *P. a. pandora* snail with eggs was located near the release site on Motutakupu Island. Most snails had apparently moved from the release sites. Later, in 1989, nine live *P. a. pandora* snails were found on Motutakupu Island, and one live juvenile was found in 1992. No live snails or empty shells were found on Motu Puruhi Island (Simmonds Islands) when this was searched in March 1990 (New Zealand Wildlife Service file 33/5/37) (Parrish 1989; R. Parrish, unpublished data).

TABLE 1. NUMBERS OF *Placostylus ambagiosus* SNAILS RELEASED ONTO RAT-FREE ISLANDS BY THE NEW ZEALAND WILDLIFE SERVICE. THE SNAILS WERE CAPTIVE-REARED AT KERIKERI.

DATE	SUBSPECIES	No. REMOVED/ RELEASED	DETAILS
25 Jul 1984	*P. a. watti* or *P. a. michiei*	9 adults, 18 sub-adults, 15+ juveniles	Released on Nukutaunga Island, Cavalli Islands
	P. a. whareana	13 adults, 10 subadults, 9+ juveniles	Released on Horonui Island, Cavalli Islands
	P. a. pandora	5 adults, 6 subadults, 6+ juveniles	Released on Motutakapu Island, Cavalli Islands
Oct 1985	*P. a. keenorum*	10 adults, 52+ juveniles	Released on Motu Puruhi Island, Simmonds Islands

Two colonies of *P. a. paraspiritus* were successfully established in 1990 in an experimental wild-to-wild transfer near Cape Maria van Diemen. This involved moving 32 and 33 snails from the parent colony of several thousand individuals. The transfers were made to test whether new colonies could be established for conservation management purposes using wild-to-wild transfers of small numbers of snails (Sherley 1990). Rodent control was applied intermittently to both release sites and live snails were present in November 1998 (Stringer & Parrish 1998). These sites were then subject to an experiment to assess the effect of controlling rodents on snail populations which involved applying rodent control to only one site for some years and then reversing the treatment. Accordingly, rodent poisoning (bromodielone pellets in bait stations set on a 25 m × 25 m grid) was applied four times a year at one release site until early 2000 and no management was undertaken at the other site until November 2001, when the same rodent poisoning regime was applied there. Snail numbers increased at the site where poison was first applied and numbers were still high when they were last monitored in October 2004 (0.71 snails/m^2). However, snail numbers diminished to very low levels at the other site and never recovered after rodent control commenced: only one live snail was found there at the end of the experiment in October 2004 (0.013 snails/m^2; Stringer et al. 2004b).

Finally, seven captive-reared *P. ambagiosus paraspiritus* snails were released into an outdoor cage (2 m × 2 m × 2 m) containing food plants at DOC's Te Paki Field Centre, to test whether captive-bred snails could survive such a transfer. All died within a year from unknown causes, although it is likely that the cause of death was desiccation (Stringer & Grant 2003). The decision was then made to attempt the captive-to-wild transfer described below.

3. Methods

3.1 RELEASE SITE

Limestone Island in Whangarei Harbour was quarried for limestone until the early 1960s and largely cleared of trees for farming, but it is now being restored by a volunteer group, the Friends of Matakohe/Limestone Island Society. The restoration programme started in about 1989 with tree-planting. Cats (*Felis catus*), rats and brushtail possums (*Trichosurus vulpecula*) were eradicated by 1991, but mice are still present despite repeated attempts to remove them (Clapperton et al. 1992; Clark, 2001). The island is only about 100 m from the mainland and an average of seven predator invasions occur per year (K. Hawkins pers comm). The snails were released on the south side of the island within a small patch of broadleaf forest (230 m^2) comprising a few kohekohe (*Dysoxylum spectabile*), karaka (*Corynocarpus laevigatus*) and puriri (*Vitex lucens*) trees with an understory of kawakawa (*Macropiper excelsum*) and *Coprosma* species. The release site is surrounded by rank grasses within which planting of a variety of native trees and bushes commenced in 2003 (Fig. 1).

3.2 SOURCE AND DEVELOPMENTAL STATUS OF SNAILS

Eleven *Placostylus hongii* (four adults and seven large juveniles) were transferred to Limestone Island. One of the released snails (number H3, see below) was one of ten snails originally collected as an adult from Aorangi Island, Poor Knights Islands on November 8, 1992 for captive breeding. The other ten snails had been captive-bred in a laboratory at Massey University, Palmerston North from the snails collected from Aorangi Island (Stringer & Grant 2007).

Snails were considered to be adult when they exhibited a varix (when the edge of the shell aperture has become splayed outward and thickened). The terms 'adult' and 'juvenile' are used here in an operational sense as discussed by Stringer et al. (2004a) because it is likely that they become reproductively mature before the varix forms.

3.3 PREPARATIONS BEFORE RELEASE

Each snail was individually marked with numbers engraved through the periostracum of its shell, and had a harmonic radar transponder attached to its shell of so it could be found again. Each harmonic radar transponder consisted of a thin annealed strip of copper folded into a triangle with the ends joined through a diode (HP5082-2835) so that the diode lay along one edge of the triangle. The transponders were glued to the shells with 'Liquid nails' (Selleys Pty Ltd, Australia) (see Stringer et al. 2004a for further details). A hand-held harmonic radar unit (Type R5P1, RECCO, Sweden), which detected these transponders from a distance of 3–5 m, was used to locate the snails in the field.

3.4 TRANSPORT AND RELEASE

The snails were released on Limestone Island on 5 August 2002. They were transported to the island in a ventilated plastic lunchbox containing damp paper and fallen karaka leaves (which had been washed). Care was taken to keep the lunchbox cool and to not expose it to direct sunlight. The snails were released, apertures down, in two clusters about 5 m apart. They were placed with the fronts of their shells slightly embedded in the soil, and then covered with leaf litter. Rain started to fall as the snails were being released, so the leaf litter was not watered. All materials used for transporting the snails were removed from the island.

3.5 MONITORING

Harmonic radar searches for the snails were made whenever the island was visited (6 November 2002, 22 January 2003, 13 August 2003, 7 November 2003, 24 March 2004). Each time the snails were retrieved, the maximum length of each shell and thickness of the varix, if present (taken at right angles to the plane of the aperture and halfway along the varix), were measured to 0.05 mm using callipers. The location of each snail was noted using the distance and direction from a marked tree. Live snails were replaced where they were found and empty shells were removed. Distances moved were normalised by log-transformation to obtain means and 95% confidence limits (95% CI).

4. Results

Four adult and seven juvenile snails were released from captivity onto Limestone Island on 5 August 2002. All were subsequently found each time the island was visited, except in August 2003, when one snail (H20) was not located. All juveniles grew after being released, including one (H18) that was found dead the first time the snails were found in November 2002. The varix of this snail had just started to develop. The remaining 6 juveniles all became adults between January and August 2003: five became adults 93–170 days after release and one became adult after 373–459 days. Three adults had died the third time they were checked in November 2003, and the remaining seven snails, all adult, were dead when located in March 2003 (Table 2).

The four snails that were released as adults showed increases in shell length of –0.6 to 0.11 mm/year, and their varices increased in width from –0.06 to 0.50 mm/year (median 0.0015 mm/year). Reductions in shell length were due to damage, whereas negative values in varix width arose because the varices were slightly uneven, so slight differences in where they were measured gave different values. In contrast, juveniles showed yearly increases in length that ranged from 0.2 to 23.9 mm/year, with the smallest snails tending to grow the fastest.

TABLE 2. CHANGES IN SHELL LENGTH AND VARIX WIDTH OF *Placostylus hongii* SNAILS AFTER RELEASE ON LIMESTONE ISLAND. ALL SNAILS WERE RELEASED ON 5 AUGUST 2002.

SNAIL NO.	STAGE AT RELEASE	LENGTH WHEN RELEASED (mm)	FINAL LENGTH (mm)	VARIX WIDTH AT RELEASE (mm)	FINAL VARIX WIDTH (mm)	MIN. PERIOD ALIVE (y)	DATE WHEN FOUND DEAD
H3	Adult	75.49	75.50	4.33	4.24	1.26	24 Mar 2004
H11	Adult	67.64	67.56	3.33	3.33	1.26	24 Mar 2004
H13	Adult	65.99	66.04	2.64	3.19	1.26	24 Mar2004
H14	Adult	67.63	67.60	3.43	3.44	1.26	24 Mar 2004
H16	Juvenile	65.39	65.65	–	1.05	1.02	7 Nov 2003
H17	Juvenile	61.40	61.79	–	1.86	1.26	24 Mar 2004
H18	Juvenile	56.92	60.51	–	–	<0.25	6 Nov 2002
H19	Juvenile	59.46	60.09	–	2.70	1.26	7 Nov 2003
H20	Juvenile	45.74	57.96	–	–	1.02	7 Nov 2003
H21	Juvenile	54.59	58.52	–	2.70	1.26	24 Mar 2004
H23	Juvenile	60.22	62.03	–	0.90	1.26	24 Mar 2004

4.1 MOVEMENTS OF THE SNAILS

Most snails remained within the clump of trees they were released under, but six moved up to 3 m beyond the canopy edge, where they were found resting on the ground under rank grass (Fig. 1). Two of the latter returned under the trees (snails H13, H21), whereas the others (H11, H14, H20, H23) remained in the grass and eventually died there. Snail H3 moved the least and remained within a few metres of its release point. The other snails travelled 3.2–19.7 m over the 1.38-year monitoring period and showed a significant tendency to move upslope from their release points ($F_{1,8} = 135$, $p < 0.01$; $r^2 = 0.94$) (Table 3). On each successive sample occasion, the snails had moved 0.3–11.1 m from their previous positions (sample intervals = 77, 86, 138, and 238 days). When found alive, they had moved (on average) 2.3 m (95% CI, 1.7–3.1 m) between samples, at an average displacement of 0.82 m per month (95% CI, 0.72–0.93 m) (Table 3). Although the sample size was small, no seasonal differences in snail movement were apparent because there were no significant differences between the distances they moved, their rates of movement (distance moved per month) or the proportions between successive sample periods of the total distances each moved.

TABLE 3. DISTANCES MOVED BY *Placosylus hongii* SNAILS AFTER RELEASE ON LIMESTONE ISLAND. THE LAST MOVE IS THE DISTANCE DEAD SNAILS WERE FROM WHERE THEY WERE LAST FOUND ALIVE.

SNAIL NO.	No. TIMES FOUND	DISTANCE MOVED PER MONTH WHEN ALIVE (RANGE, m)	LAST MOVE (m)	TOTAL DISPLACEMENT UPSLOPE (m)	TOTAL DISTANCE MOVED (m)
H3	5	0.29–0.41	0.83	0.03	4.4
H11	5	0.56–1.00	0.73	4.75	9.55
H13	5	0.59–2.09	6.58	6.06	19.66
H14	5	0.17–1.78	1.52	6.71	8.91
H16	4	0.12–1.78	6.2	5.75	17.67
H17	5	0.78–1.03	0.36	5.29	10.67
H18	1	–	–	–	–
H19	4	0.43–0.98	0.68	2.6	6.02
H20	3	0.39	2.19	2.73	3.17
H21	5	0.50–0.98	1.22	1.62	13.86
H23	5	0.18–1.45	0.83	6.41	4.4

5. Discussion

This transfer failed because all of the snails died prematurely. Their total adult life-spans, including time in captivity, ranged from about 0.7 to 10.3 years (Stringer & Grant 2007). On the Poor Knights Islands, however, this species has an estimated adult lifespan of 30 years or more (Stringer et al. 2004a). The environment on Limestone Island appeared to be suitable for these snails, at least in the short term, because 64% survived for 1.26–1.63 years and all of the juveniles grew after being released. Only one snail (snail H20) was small enough for its growth—measured as the change in shell length—to show a linear increase. This is probably the normal growth pattern for this species, because the shells of captive snails show a linear increase in length until the shell is about 90% adult size. Growth then slows progressively and, after a variable period, the shell acquires a varix, at which time increase in length virtually ceases (Penniket 1981; Stringer & Grant 2007; W.M. Douglas, unpubl. data). The shell of snail H20 increased in length at a rate of 23.9 mm/year after release. This was faster than five of the six juvenile *P. hongii* snails of similar size (shell lengths 38–51 mm; growth rates 6.9–24.3 mm/year) followed on the Poor Knights Islands (Stringer et al. 2004a). This growth was also faster than that for one snail of comparable size (H11; 22.8 mm/year) when it was in captivity before being released (Stringer & Grant 2007). It was also faster than that of six of the seven *P. hongii* snails kept in a cage indoors after they were collected from the Poor Knights Islands (growth rate 5.6–12.6 mm/year; Penniket 1981). Such rapid growth indicates that conditions on Limestone Island were probably suitable for the snails, at least initially. Furthermore, the single hatchling snail that was found indicates that the snails should be able to breed there. What, then, caused the deaths of these snails? We suggest that the main reason for their demise was a hot dry period combined with particular features of the island's soil. The last seven *P. hongii* snails died on Limestone Island during the summer of 2003/04, when there was

very low rainfall and many days when no rain fell and the maximum temperature exceeded 27°C (Tables 4 and 5). When the empty snail shells were found, no rain had fallen for the previous 23 days, the clay soil was hard and deeply cracked and even the deepest levels of leaf-litter were dry and brittle. We suspect that the soil was too hard for the snails to push the apertures of their shells into. As a result, they could not protect themselves from desiccation. *Placostylus* snails do not form a protective epiphragm in desiccating conditions, as do many other land snails, and only the hatchlings seal their edge of their shell apertures to objects such as leaves (Penniket 1981). Instead, larger individuals typically bury the front of their shells in the soil to reduce water loss during dry weather. Such behaviour enables *P. a. paraspiritus* snails to live on sand in dense vegetation and for *P. a. michiei* snails to survive the hot, dry conditions under low sparse vegetation during summer at Surville Cliffs, North Cape, New Zealand (Sherley et al. 1998).

Although moisture and temperature are the most important environmental factors that affect terrestrial mollusca (e.g. Egonmwan 1991; Hommay et al. 2001; Cook 2001), it is unlikely that high temperatures and low rainfall caused the deaths of the two juveniles that died during the second-to-last sampling period. This period had the highest average rainfall and the lowest number of rainless days during the study (the longest period without rain was seven days) and moderate temperatures (Tables 4 and 5). The snails were also on steep, well-drained slopes

TABLE 4. RAINFALL AT WHANGAREI AIRPORT AFTER *Placostylus bongii* SNAILS WERE RELEASED ON LIMESTONE ISLAND ON 5 AUGUST 2002. THE METEOROLOGICAL STATION WAS 2.1 km NORTH OF THE SNAIL RELEASE SITE. DATA COURTESY OF NIWA.

PERIOD ENDING	MEAN RAINFALL (mm)	No. DAYS NO RAIN (%)	No. DAYS 0–< 1 mm RAIN (%)	No. DAYS 1–10 mm RAIN (%)	No. DAYS > 10 mm RAIN (%)
6 Nov 2002	2.53	41 (43.6%)	18 (19.1%)	28 (29.8%)	7 (7.4%)
22 Jan 2003	3.50	43 (56.6%)	10 (13.2%)	16 (21.1%)	7 (9.2%)
13 Aug 2003	4.43	90 (44.3%)	37 (18.2%)	5 (24.6%)	26 (12.8%)
7 Nov 2003	4.63	31 (36.0%)	16 (18.6%)	28 (32.6%)	11 (12.8%)
24 Mar 2004	2.44	86 (61.9%)	23 (16.5%)	23 (16.5%)	7 (5.1%)

TABLE 5. MAXIMUM TEMPERATURES AT WHANGAREI AIRPORT AFTER *Placostylus bongii* SNAILS WERE RELEASED ON LIMESTONE ISLAND ON 5 AUGUST 2002. THE METEOROLOGICAL STATION WAS 2.1 km NORTH OF THE SNAIL RELEASE SITE. THE TABLE GIVES THE NUMBER OF DAYS WHEN THE LISTED MAXIMUM TEMPERATURE WAS REACHED. DATA COURTESY OF NIWA.

PERIOD ENDING	NUMBER DAYS (% PERIOD)			
	> 27°C	23–27°C	19–22°C	< 19°C
6 Nov 2002	0	3 (3.2%)	38 (40.4%)	53 (56.4%)
22 Jan 2003	1 (1.3%)	32 (41.6%)	40 (51.9%)	4 (5.2%)
13 Aug 2003	5 (2.5%)	47 (23.3%)	78 (38.6%)	72 (35.6%)
7 Nov 2003	0	1 (1.2%)	34 (39.5%)	51 (59.3%)
24 Mar 2004	29 (20.9%)	60 (43.2%)	47 (33.8%)	3 (2.2%)

where they could not have drowned, so the reasons for their deaths remain unknown. We can only speculate that they may have contracted a disease from the introduced *Cantareus aspersus* snails which were also present at the release site, or that they succumbed to parasitism or invertebrate predators, although we know of no recorded instances of these affecting *Placostylus* snails. Potential predators or parasites present in New Zealand range from carabid beetles, spiders and parasitic flies to Ciliophorans and microsporidians (Harris 1992; Barker 2004 and references therein). If harmful invertebrates were present, then they would have had easier access to the snails through the shell apertures during the dry periods when the soil was too hard for the snails to burrow into.

On islets in the Poor Knights Islands, *P. hongii* survives in areas as small as 50 m^2 (pers. obs.; Brook & McArdle 1999), so the size of the patch of trees where the snails were released was unlikely to be limiting, especially as the leaves of most of the plant species present are eaten by this snail species. They also survive dry hot summers on these islets, in conditions that are comparable with those experienced by *P. a. michiei* on Surville Cliffs. However, the snails on these islets are able to burrow into the soil because it is made friable by the activities of burrowing seabirds.

Calcium can affect the distribution of some snails, but in this case the vegetation growing on the soils of Limestone Island is likely to be high in calcium, so that calcium limitation is unlikely to have been a problem for the snails (e.g. McLaughlan 1951; Oosterhoff 1977; Wäreborn 1979; Ireland 1991; Johannessen & Solhoy 2001). Disturbance and soil pH can also affect both the distribution and density of snails (Martin & Sommer 2004). Disturbance to the site was minimal because we used harmonic radar to find the animals. Soil pH may have negatively affected the snails, but we did not collect soil pH data either at the release site or, for comparative purposes, at other locations where this species occurs. Soil pH does affect the density of snails (Martin & Sommer 2004) and soil on limestone might vary from acidic to alkaline depending on factors such as the leaching rate and vegetation growing on it (e.g. Etherington 1981; Heine et al. 1987). Limestone Island was once mined, so limestone dust may also have made the soil more alkaline than it normally would have been (Etherington 1978; Clarke 2001).

Tracking the snails with harmonic radar made it possible to follow all of them as they dispersed following their release and this provided detailed information on both their movements and survival. It is unlikely that the harmonic transponders attached to the shells contributed to the deaths of the snails, because we have used the same transponders with *Placostylus* snails since 1997, and many have survived for at least 7 years. For example, we attached harmonic radar transponders to 43 adult *P. a. michiei* snails in 1998, and all 40 that were found again were alive when last searched for in 2004 (unpubl. data). Different transponder designs have also been used with *Paryphanta busbyi* snails (Rhytididae) (Stringer et al. 2002) and a variety of other land snails (e.g. Devine 1997; Bennett 2001; Gililland 2006; Kiriazi et al. 2007; Hall & Hadfield, in press).

6. Conclusions and recommendations

We can only speculate on what caused the deaths of the snails in this study, and those in the previous attempt to establish laboratory-bred *Placostylus* snails into an outside cage at DOC's Te Paki Field Centre (Stringer & Grant 2003). Further research is needed to determine what the causes of mortality were and how they could be mitigated before captive-rearing followed by translocation is considered again. Laboratory-rearing does enable large numbers of snails to be reared relatively quickly (juveniles with shells 30–50 mm long can be reared within 2–3 years), but is relatively expensive because of labour costs (Stringer & Grant 2007). Laboratory-rearing is clearly not a viable conservation management option at present because the snails do not survive when returned to the wild. We suggest that should there be a need to captive-breed these snails in future, then the use of large outdoor cages should be investigated. *Placostylus ambagiosus* snails have been successfully captive-bred in outdoor cages in the past (as mentioned earlier), although there are few details of how it was done (Wildlife Service files 33/2/6, 33/5/37, 33/5/70). We suggest transferring the snails directly from the wild into large outdoor cages containing suitable mature food plants and a sprinkler system to ensure that the leaf-litter is kept moist. The cages should be constructed using a mesh size smaller that 5 mm to prevent hatchling snails, which are arboreal, from escaping. The advantage of captive-rearing in outdoor cages is that it should involve minimal attention from personnel, so it is likely to be less costly overall. The disadvantage is that the snails may grow more slowly than in the laboratory and require a longer period before they are of a suitable size for release.

Overall, the indications are that *P. hongii* snails are best released as either large juveniles or as adults, because small juveniles may experience a higher mortality in the wild. Our results are inconclusive because of the small numbers of snails followed. However, all four of the adult snails and four of the five large juveniles (shell lengths > 90% adult size) that were released on Limestone Island survived for 1.3–1.6 years, whereas two of the three smallest snails survived for shorter periods (H20, 79% adult shell length, 0.5–1.3 years; H18, 89% mean adult length, < 0.25 years). Stringer et al. (2004a) also report that juvenile *P. hongii* snails have a higher mortality rate than adults on the Poor Knights Islands and the mortality details of snails collected for captive-breeding also support this. All of the small juvenile *P. hongii* snails taken into captivity by Stringer & Grant (2007) died, whereas the largest juvenile survived for 2.9 years and became an adult, and the three adults survived for 6.3–7.2 years.

Finally, we recommend the use of harmonic radar for monitoring when it is desirable to follow each individual snail. Our experience suggests that it could be particularly useful for snails that are hard to find or when there are relatively few individuals and it is important to follow each one. For this project, monitoring using other methods would have involved considerably more search effort and it is likely that some of the snails, particularly those in the grass adjacent to the trees, would not have been found. Systematic searching through leaf-litter would

have created considerable habitat disturbance, whereas using harmonic radar allowed the area that needed to be searched to be narrowed down to about 30 × 30 cm for each snail. These small areas were the only areas of the habitat to be disturbed (apart from the disturbance associated with our walking through the study area).

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