Article

Re-establishment of *Partula tohiveana* tree snails in French Polynesia after 40 years of extinction in the wild

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Abstract The rapid decline of wild populations has resulted in complete extinction of many species. In some cases it has been possible to avoid extinction through the formation of *ex situ* conservation breeding populations. These have the aim of safeguarding the survival of the species and ultimately their reintroduction to the wild. In the case of *Partula* tree snails, four decades of conservation work has included *ex situ* breeding and reintroduction attempts. Most *Partula* tree snails of French Polynesia are categorised as Extinct on the IUCN Red List due to the introduction of invasive

predators. 10 species survive only in *ex situ* conservation breeding centres and attempts to reintroduce them have been underway since 2015. In 2024 a wild population of *Partula tohiveana* was located, formed as a result of reintroductions to Moorea island over the previous decade. This is the first Extinct in the Wild invertebrate species to have been re-established through interdisciplinary and coordinated *ex situ* and *in situ* conservation actions.

Keywords Extinct in the Wild, Mollusca, Partulidae, reintroduction

Introduction

Eighty-one species of animals and plants are currently categorised as Extinct in the Wild (IUCN, 2024), surviving only in specialised institutions such as *ex situ* conservation breeding centres, zoos or botanic gardens. In the case of the French Polynesian tree snails of the family Partulidae there is an exceptional concentration of such species. In the Society Islands the genus *Partula* comprises 51 species, of which at least 29 are extinct (possibly 34). Of the 17 species know to be extant , 10 survive only in captivity (IUCN, 2024).

Partulidae tree snails were a notable part of the Society Islands' fauna until the late 20th century. Globally, they were of note in the development of genetics, being the first organisms to be the focus of an attempt to demonstrate the reality of Mendelian genetics in wild species, with the pioneering work of Henry Crampton, and later the phenotypic inheritance studies of Bryan Clarke, James Murray and Michael Johnson (Johnson et al., 1993). Within the islands they were of significant cultural value in the manufacture of 'hei' necklaces, crowns and other ornaments. As highly abundant detritivores they were also presumably of great ecological significance (Gerlach, 2014), although this was never studied. All of these roles came to an end between 1982 and 1995 when almost all wild populations were eliminated by the introduced predator, the rosy wolfsnail *Euglandina* (Clarke et al., 1984; Gerlach, 2016). Two members of this species complex were introduced under the single species name *E. rosea* (Meyer et al., 2017) in a failed attempt to control populations of the invasive agricultural pest species, the giant African snail *Lissachatina fulica* (Gerlach et al., 2021). Subsequently a second invasive mollusc predator was identified, the New Guinea flatworm *Platydemus manokwari*. This has now become the primary predator in the islands, with *Euglandina* declining on all Society Islands (Gerlach et al., 2021).

Captive populations of 9 species of *Partula* had been established for genetics research in the 1960s and added to up until 1984. With the extinction of wild populations these became the basis of a conservation breeding programme (Clarke & Wells, 1992), first based at Jersey Wildlife Preservation

Trust and later as the Partulid Global Species Management Programme coordinated by the Zoological Society of London. Additional species were brought into the breeding programme in 1991–1995 as *Euglandina* spread through the islands. These were kept in stable, artificial conditions according to the EAZA Best Practice Guidelines, covering all aspects of care (Clarke, 2019). Not all were successfully bred, however by 2015 12 species, with 4 subspecies, were considered to be established *ex situ* (Coote et al., 2015).

Efforts to re-establish Extinct in the Wild species have had very mixed results although successful reintroduction has been documented in ten animals and three plants (Smith et al., 2023). In the case of *Partula*, reintroduction attempts first started in 1995 At this time fully wild re-establishment was considered impossible due to the persistence of *Euglandina* but it was thought that release into a predator-proof field exclosure might be viable. This was attempted in 1995 on Moorea island (Coote et al., 2004) with *Partula suturalis, P. taeniata* and *P. tohiveana* released into the '*Partula* reserve'. Although captive-bred snails of all three species adapted to the exclosure and bred, the releases were ultimately a failure due to repeated incursion by *Euglandina* as a result of insurmountable maintenance problems (Coote et al., 2004).

Field surveys and reintroduction efforts from 2015 were led by the Partulid Global Species Management Programme's field conservationist Trevor Coote (Coote et al., 2015). In that year a further attempt at creating exclosures took place on Tahiti island. This was again unsuccessful, but during the construction of the reserve relict populations of *Partula clara* were found in *Inocarpus fragifer* woodland. This led to the proposal of the 'mape hypothesis', that these tall trees formed refugia for *Partula* as their bare, dry trunks could be a disincentive for *Euglandina* foraging. Following from this, Trevor Coote proposed that reintroductions onto such trees could be an alternative to the problematic reserves. Tree releases started in 2015 (Gerlach, 2016) and became the focus for the reintroduction programme. Releases continued every year with the exception of 2020–2022 when the Covid-19 pandemic caused a hiatus to the programme and restrictions prevented all field-work (Table 1).

These unprotected releases have proved simple to implement but difficult to evaluate. In many cases survival (as indicated by low numbers of dead shells and initial counts of living snails) has been good but released populations have mostly disappeared after a few months. However, in 2024 a population of wild-born *Partula tohiveana* was found on Moorea island, demonstrating that population re-establishment has been achieved in this species. Here we evaluate the process of its establishment.

Partula tohiveana , the 'Tohiea tree snail', is a relatively large sinistral partulid with a maximum shell length of 13.7 mm (Gerlach, 2016). It was naturally a restricted range species, originally found in upper parts of the valleys of Moorea's eastern ridge, particularly in association with the 'ie'ie or

climbing pandanus *Freycinetia demissa*, up to 4 m above the ground (Murray et al., 1982; Johnson et al., 1993). Despite its specialist ecology, and having passed through a captive bottleneck of just four animals (Gerlach, 2016), it now breeds very well in captivity and has been used as a 'starter' species for new conservation breeding collections. It is ovoviviparous, producing 16 young a year and reaching maturity at 6–12 months of age (Gerlach, 2016; Clarke, 2019). Despite the population bottleneck there is still some phenotypic variation, with at least two of the original four polymorphisms remaining (banded and unbanded).

Methods

Release methods

Prior to release all shipments of snails were screened for potential pathogens (Clarke et al., 2019; Flach et al., 2024) in order to maximise survival of released animals and to prevent importation of pathogens to French Polynesia. Snails were transported in a dormant, aestivating state according to a fixed protocol (Clarke et al., 2019). Snails were revived from aestivation on Tahiti with a very high success rate (<1% mortality).

Initially *Partula* species were released into the valleys where the captive stock had originally been collected. In the case of *P. tohiveana* this was the Afareaito valley (Fig. 1). This species was associated with *Freycinetia demissa* (Murray et al., 1982; Johnson et al., 1993) and trees supporting this plant were selected at three release points, with a fourth added subsequently. The first site, TOH1, was lost to a tree-fall shortly after release and no monitoring data are available. TOH2 has *Freycinetia* growing up *Inocarpus fragifer* trees (Plate 1a). This is the most easterly of the sites and is relatively dry; it has not been used since 2019. TOH3 has been the main release site in most years; it is the location of the 1995 *Partula* reserve (but the barriers have not been intact for the last two decades) and has very dense *Freycinetia*, both on the ground and on trees (Plate 1b). TOH4 comprises large trees with dense *Freycinetia* on steep ground. The steep slope makes monitoring impractical and it has only been used on two occasions.

At each release up to 100 snails were placed in plastic plant pots, one-third filled with soaked sphagnum moss and covered in clingfilm for transport. At the release sites the pots were attached to trees by garden wire. On release the clingfilm was removed and pots were sprayed with filtered water to encourage activity and rapid dispersal. Pots were left in place to allow gradual dispersal and to provide a site marker for monitoring purposes.

Released snails were marked with enamel paint, using a different colour each year to enable release cohorts to be recognised. Adults, identifiable by the presence of an expanded lip at the shell aperture, were marked on the middle of the shell, young snails lacking any apertural lip were marked on the apex in order to distinguish life stages and to identify whether juveniles were maturing in the wild. In 2023 the enamel paint was replaced with ultra-violet reflective paint (Starglow UV neon, Glowtec Ltd.). Using an ultra-violet torch allowed marked snails to be detected to about 5 m above ground (Gerlach et al., 2023). In some species, problems arose with paint adhesion, either because of a dehiscent periostracum or a highly glossy shell surface. *Partula tohiveana* has a thin periostracum and a rough surface and no paint adhesion issues were experienced with this species.

Monitoring

Snails were monitored 24 hours after release and then frequently thereafter. Timing of monitoring varied due to availability of personnel and weather conditions. In 2015–2019 releases were monitored monthly until bad weather imposed gaps of three or more months. Restructuring of the release programme following the pandemic and Trevor Coote's death in 2021 resulted in changes in approach from 2023 onwards. The reduction in the number of release sites enabled monitoring to be more focussed, and the involvement of the French Polynesian government's Direction de l'environnement and the Fare Natura ecomuseum enabled more regular monitoring of all sites. Monitoring is now carried out on a schedule of 24 hours post release, weekly for the first month, fortnightly for the following month and monthly thereafter.

During monitoring the ground around release trees is searched for *Partula* shells which are recorded as adult or juvenile and the colour mark (if present) recorded. All dead shells are removed to prevent future double counting. All release trees and nearby vegetation are examined for the presence of snails, which are recorded in the same manner. These visual searches are limited to what can be seen from the ground; snails can occasionally be recorded to 5 m above ground (especially once UV marked), but effectiveness is inevitably reduced above about 3 m. Three approaches are used in attempts to detect snails in the forest canopy. In 2017 a GoPro HERO 6 camera was attached to a 3 m long pole, this did detect some snails, but the images were too poor to provide useful detail. In 2023 a drone (DJI Mavic Mini) was used, both using natural light and with an ultra-violet torch attached. Whist this did provide access to high levels of the canopy, navigation in complex forest was problematic and it proved impossible to fly the drone close enough to vegetation to allow useable imagery. Finally, a remote-controlled camera Olympus Tough TG-6, attached to a remotely controllable tripod head (ZIFON YT-800) on a 9 m telescopic monopod was used to directly access

the canopy. This gave high quality imagery but did not locate significant numbers of snails. Presence of predators is recorded although these are not searched for systematically.

In evaluating success, we have considered mortality, survival, maturation, reproduction and recruitment. Emigration has also been considered but data are very limited; only one shell has been found more than 5 m from a release point and all live snails have been within a similar radius. Mortality rates are indicated by numbers of dead shells, given in Table 1 as the percentage of released snails found dead. Survival is indicated by numbers of live snails recorded and the maximum number of days after release that live animals can be found. Maturation is demonstrated by finding animals (live or dead) that had been released as juveniles (with an apical paint mark) but had grown to full maturity, defined as having developed an expanded shell lip. Reproduction is indicated by the presence of unmarked animals and recruitment by finding unmarked adults. If several live unmarked adults are found simultaneously this is considered to be evidence of population establishment. Any such population will be a particular focus of monitoring in order to determine whether the numbers of individuals are increasing and the area occupied expanding, or whether the population is stable or contracting.

Unmarked (wild-born) snails can be individually identified from photographs on the basis of the position of colour bands, growth lines and irregularities on the shell surface.

Results

Mortality, survival and dispersal

The numbers of live and dead snails are summarised in Table 1. Recorded mortality in the first month was low (0–6.7%). In contrast, mortality after a year was high (8.9–39.1%), but varying widely between years. This variability probably reflects variation in monitoring opportunities and thoroughness in 2016–2019 and improved monitoring frequency since 2023 resulting in an increase in the proportion of shells recovered. The majority of snails disappeared quickly, but survival to at least a year was recorded in 2016 and 2023 (Table 1). Direct evidence of dispersal from the release site was seen in 2024 when one live marked juvenile was found 5 m from the nearest release pot after three days.

Maturation

Adults that had been released as young were found in 2016 (1), 2018 (5), 2019 (1) and 2023 (10).

Reproduction

Evidence of reproduction was given by records of unmarked snails (shells and/or live animals). The first wild-born snail was found on 29th September 2016 (a new-born) and the first half-grown juvenile was found on 9th August 2017, resulting from the first release the year before. The first wild-born adult was found on 24th September 2018 (Plate 2). Wild-born animals have been found in increasing numbers since early 2023 (Fig. 2).

Recruitment

Adult unmarked shells have been found regularly since 2020, indicating successful recruitment (Plate 2). There was a large increase in unmarked shells from 2023. Single live adults of *P. tohiveana* were found on two occasions in 2018. During surveys over three days in 17th–21st September 2024 a population of unmarked individuals was located, comprising 4 different adults and 13 juveniles (Table 2, Plate 3). Further unmarked individuals were found in October 2024.

Discussion

The data on the releases of *Partula tohiveana* show that released animals adapted well to the natural environment despite having spent around 20 generations in relatively stable, artificial conditions. Breeding occurred in the first year, and recruitment was demonstrated from 2018 onwards. Only single wild-born adults were found until September 2024 when a resident population was detected in the release site. The discovery of a population of wild-born *P. tohiveana* demonstrated that captive-bred *Partula* can be re-established in the wild. The presence of multiple wild-born adults does not necessarily constitute a viable long-term population and we recognised this to be merely the first step in recovery. Evidence of expansion will be needed to confirm long-term establishment and this is now the focus of monitoring for this species. In time monitoring data will reveal whether the population is continuing to expand in numbers and area, is remaining stable or declining. The 2025 releases are planned to take place in similar habitat 20 m from this population in order to evaluate investigate whether the population will continue to grow in the absence of further augmentation. *Partula* conservation has always been adaptable and future management will continue to be adjusted in the light of monitoring results.

In this particular case, it is notable that population establishment has occurred despite the presence of the invasive predators that caused the original extirpation of partulid populations. Trevor Coote's 'mape hypothesis' proposed that it might be possible to re-establish partulids on tall trees where there could be vertical separation between predators on or near the ground, and partulids high in the trees (Coote et al., 2015). 'High' was not specified, but given that *Euglandina* often climb, it was hoped

that released *Partula* could be established some 4 m above the ground: high enough to reduce predation but still be visible. The *Freycinetia demissa* that *P. tohiveana* is associated with grows as a climber on forest trees to well above this height, and also sprawling on the ground. The re-established population has so far been found almost exclusively in the low vegetation, with all but one individual being less than 1 m above ground level. This would be expected to make them very vulnerable to predation, and *Platydemus manokwari* flatworms are occasionally found in the act of predating the snails. *Euglandina* are also present in the area, although now only found as isolated individuals. Population establishment in the presence of predators may have been possible due to the complexity of the vegetation. Although flatworms have been found in the low growing vegetation, the ground has only sparse litter and the vegetation structure is extremely complex. This gives many alternative routes for a predator to explore, reducing the likelihood of a successful pursuit of a snail.

At present there is no evidence of population re-establishment on the taller forest trees with no recent sightings of released or wild-born snails outside of the TOH3 release point. Monitoring snails on these trees has proven very difficult. The UV reflective paint increases detection distance but it is still difficult to see snails more than 5 m above ground. Due to the complexity of the habitat, it was impossible to fly the drone close enough to the leaves to enable clear visualisation and sufficiently thorough surveying. Use of cameras on long poles have had some success in extending monitoring range. The GoPro did detect snails at about 4–5 m above ground but proved too unstable to enable clear images or extensive surveying. The remotely controlled camera improved imagery, but still no significant populations have been detected above 5 m. In the case of *P. tohiveana* this may be a reflection of their ecology as historical records show them to have been a species that inhabited relatively low-vegetation (Murray et al., 1982).

The scarcity of observations of live snails outside of the dense *Freycinetia* may be due to rapid and wide early dispersal. This pattern of movement seems to be typical of reintroduced or translocated snails; in the Hawaiian tree snail *Achatinella concavospira* it has been found that released animals start by dispersing 2.5-7.0 m (maximum of 14.1 m) from the release point, but within 2–4 months have established stable home ranges within (Hee, 2024). Early rapid dispersal was initially seen as being desirable, and a requirement for survival in the presence of predators (Coote et al., 2015). It may however result in over-dispersed populations, reducing the potential for breeding and population establishment, and contributing to the lack of evidence of success in small-scale releases of several *Partula* species. Mass releases may overcome the over-dispersion and enable establishment in the two species released in the largest numbers on Moorea: *P. tohiveana* and *P. taeniata*. The latter is one of the most adaptable *Partula* and one of the few species to persist in the wild (categorised as

Critically Endangered). Since 2019 releases of this species have been successful in re-establishing additional populations.

Thanks to decades of effort from the international zoo community it is possible to produce tree snails in large numbers and relatively easy to transport them to field sites. The greatest difficulty in the reintroductions has proven to be the monitoring of small animals in extremely complex habitat. This requires considerable effort and has only been possible thanks to the dedication of people on the ground. Monthly monitoring of the populations within a narrow radius of the release sites is practical for a large part of the year, although breaks in monitoring are inevitable due to extreme weather conditions. Monitoring population expansion will be additionally challenging and will require more of an exploratory approach, probably as an annual survey.The re-establishment of populations of the Critically Endangered *Partula taeniata* was an important observation in that it demonstrated that release of captive-bred snails can be effective. The discovery of a population of wild-born *P. tohiveana* was a more significant event for the *Partula* conservation programme as it showed for the first time that an Extinct in the Wild snail can be re-established. It is also notable that wild extinction for this species occurred 40 years ago (1984) The captive lineage last received input from the wild in 1984 and passed through a captive bottleneck of four individuals in 1988 (Gerlach, 2016). Despite likely inbreeding caused by the bottleneck and having spent multiple generations in relatively constant, artificial conditions, the snails have retained sufficient adaptability to survive, adapt and breed. This makes it hopeful that the remaining Extinct in the Wild *Partula* and wider species can also be established.

Author contributions Fieldwork: JG, TA, CB, MD, KH, EL, SM, AO, PPK, AR, RT; programme management: SA, DC, KG, PPK; conservation breeding: SA, DC, JE, DF, SH, PPK; writing: JG; critical revision and correction: all authors

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Conflict of interest None.

Ethical standards Handling and transport of animals in the *Partula* conservation programme are covered by agreement between the Direction de l'environnement, French Polynesia and the Partulid Global Species Management Programme. The programme abides by the Oryx guidelines on ethical standards.

Data availability The authors confirm that the data supporting the findings of this study are available within the article.

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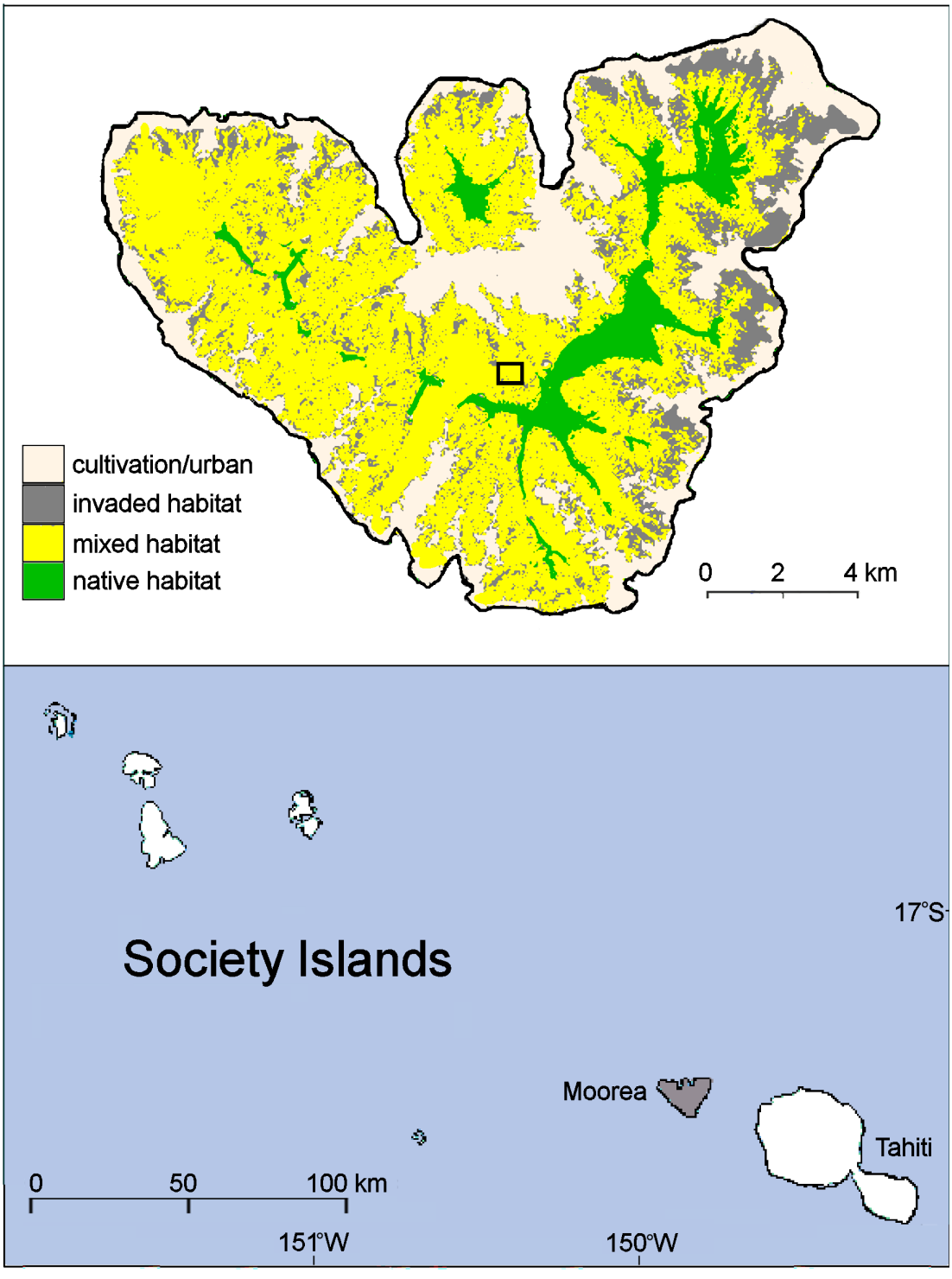
TABLE 1. Summary of *Partula tohiveana* releases and monitoring results to the end of 2024

Release point	Number of snails released by year							Total
	9/2016	9/2017	9/2018	5/2019	4/2023	9/2023	9/2024	
TOH1	47	0	0	0	0	0	0	47
TOH2	146	0	0	234	0	0	0	380
TOH3	446	814	766	35	976	555	1581	5079
TOH4	0	204	0	471	0	0	0	675
Total	639	1018	766	740	976	555	1581	6181
Number of dead shells found by end of year								
2016	12	-	-	-	-	-	-	
2017	145	113	-	-	-	-	-	
2018	169	196	45	-	-	-	-	
2019	173	204	76	161	-	-	-	
2020	182	204	76	171	-	-	-	
2021	188	209	96	189	-	-	-	
2023	196	217	135	205	357	87	-	
2024	196	218	137	208	400	123	136	
Percentage mortality after								
1 month	0	2.6	2.3	0.7	6.7	0.9	3.4	
1 year	8.9	12.9	9.8	23.4	39.2	20.5	-	
Days to last live sighting	500	355	178	172	556	207	-	

360 TABLE 2. Records of individual unmarked *Partula tohiveana* in 2024; adults shown in Plate 3

		Survey date				
		17/9/24	18/9/24	21/9/24	15/10/24	22/10/24
Adult 1	Banded adult	+	+			
Adult 2	Unbanded young adult		+			
	Unbanded large juvenile		+	+		
	Unbanded juvenile		+			
	Banded large juvenile		+			
	Banded juvenile		+			
	Banded juvenile		+			
Adult 3	Unbanded adult			+		+
	Unbanded subadult			+		
Adult 4	Banded adult			+		
	Banded subadult			+		
	Banded subadult				+	+

FIG. 1. Map of Moorea showing the location of the release area (black square) and of Moorea in the Society Islands. Habitat categories modified from Meyer et al. (2015)



365 FIG. 2. Numbers of individual wild-born *Partula tohiveana* found as dead shells and live animals. Breaks indicate periods without monitoring.

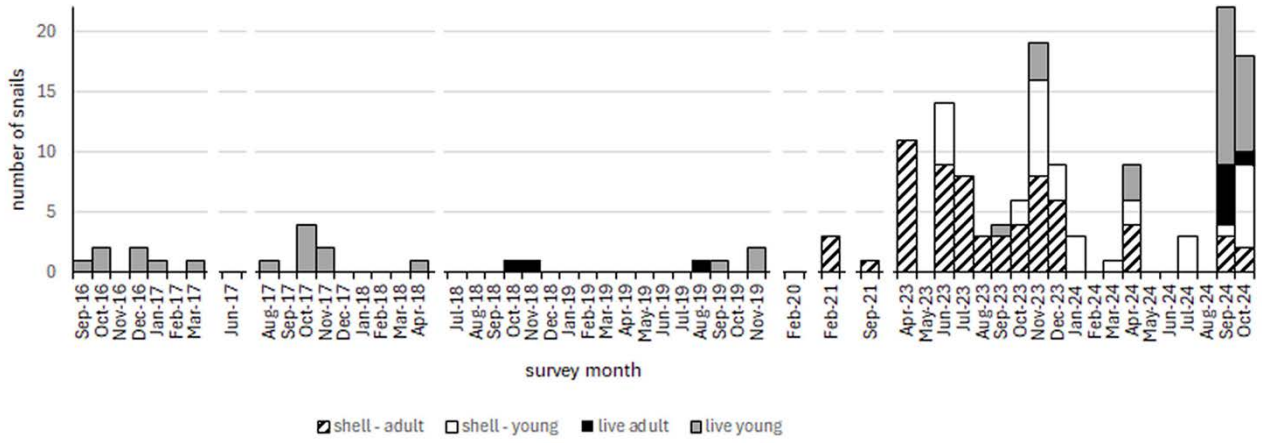


PLATE 1. Two of the sites used for *P. tohiveana* releases: a – site used in 2016 only (TOH2), b – the main release site (TOH3) used in every year. Arrows show release points.

PLATE 2. Live wild-born *Partula tohiveana* observed early in the reintroduction programme: a) first large young snail, 9th August 2017, b) first live adult, 24th September 2018 (photo: T. Coote), c) large young, 13th October 2017, d) second live adult, 14th October 2018, e) same snail on 8th November, f) third live adult, 16th August 2019 (photos: T. Coote). Scale bar 1 cm.

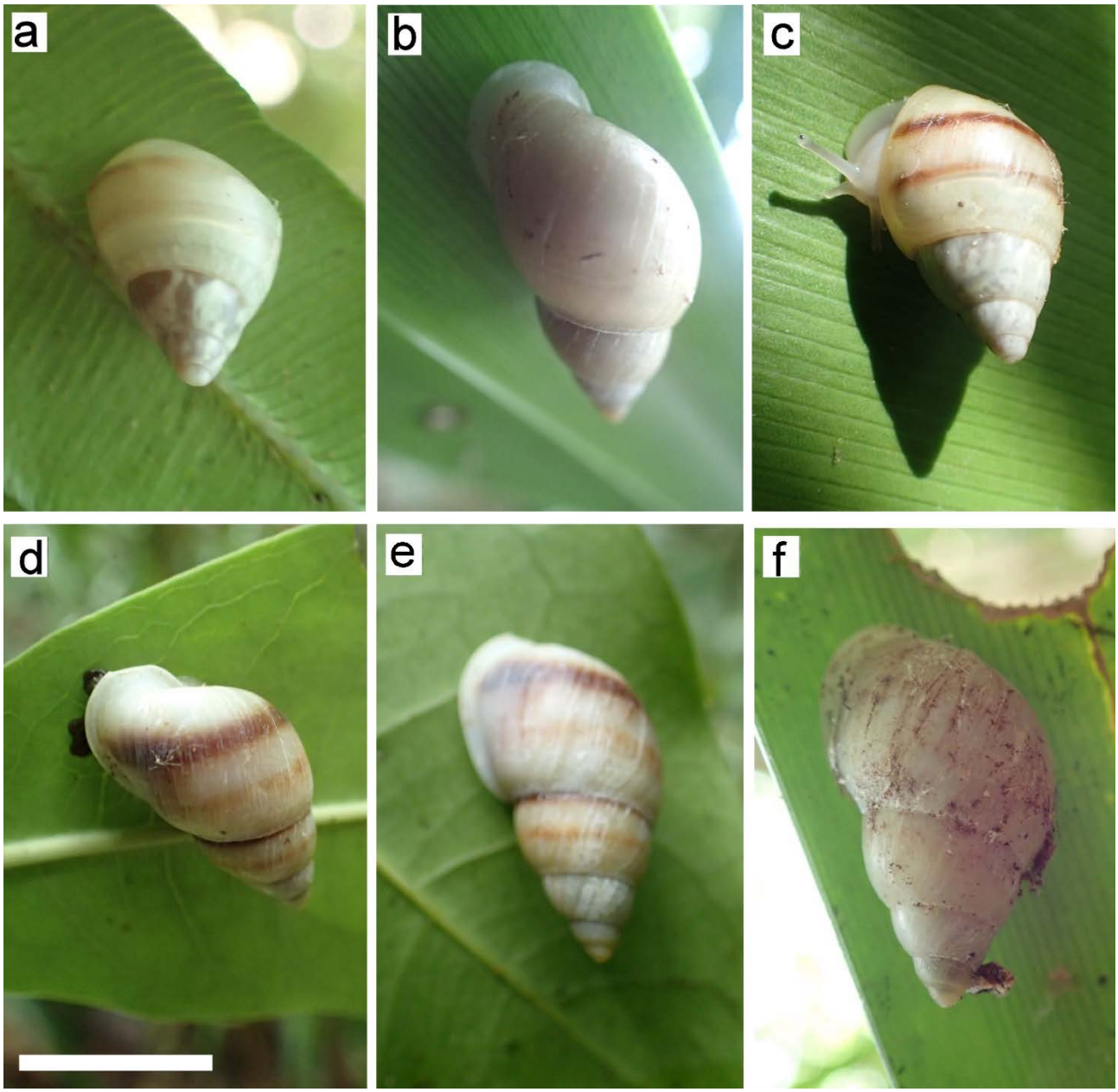


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PLATE 3. Four different live wild-born adult *P. tohiveana* found in September 2024; a) mature adult, 17th September 2024; b) young adult with partially developed shell lip, 18th September 2024; c) mature adult, 21st September 2024; d) young adult, 21st September 2024 (photos: J. Gerlach). Scale bar 1 cm.