

From 61 species to five: endemic tree snails of the Society Islands fall prey to an ill-judged biological control programme

Trevor Coote and Éric Loève

Abstract Following the well documented extinctions of many species of endemic tree snail (family Partulidae) throughout French Polynesia, field surveys were undertaken on four islands in the Society archipelago to provide up to date information for the international conservation programme for this group of invertebrates. These surveys have confirmed the loss of all species of *Partula* in the wild on the Society Islands other than Tahiti. Thirty-three species have been lost from Raiatea, thereby eliminating one of the most outstanding examples of island evolutionary radiation. On Huahine the disappearance of *P. varia* and *P. rosea*, used for making *lei* (shell jewellery), had an economic and social effect on the local community: many of the women of the villages lost their livelihoods, and the artisan's association folded. The seven species of *Partula* on Moorea were extinct in the wild by the mid 1980s, terminating

almost 100 years of biological research. It now seems that the remnant populations of *Samoana attenuata* discovered only 5 years ago are the only species of partulid still surviving beyond Tahiti on the Society Island group. The mixed species populations in the Te Pari area of Tahiti-Iti are still extant, but the predatory snail *Euglandina rosea* has now spread to the last valley on the Peninsula that did not have previous evidence of predator activity. On Tahiti-Nui populations of partulid, without the predator, were found near the crest of Mount Tahiti above Orofero Valley. Partulidae are clearly a highly threatened family of invertebrates, and in need of the most intense conservation focus.

Keywords Biological control, extinctions, Mollusca, *Partula*, Partulidae, Polynesia, snails, Society Islands.

Introduction

Tree snails belonging to the family Partulidae, endemic to many of the high islands of the Pacific, have been the subject of classic studies in population biology and evolutionary ecology (Crampton 1916, 1925, 1932; Murray & Clarke, 1980; Murray *et al.*, 1992; Johnson *et al.*, 1993) and formed a component of Polynesian culture in the making of *lei* (shell jewellery). The family contained over 120 species in three genera, half of which were found in French Polynesia, notably the Society Islands: the windward islands of Bora Bora, Huahine, Raiatea and Tahaa, and the leeward islands of Moorea and Tahiti (Fig. 1). Unfortunately many of the species have become extinct due to the disastrous, and ultimately futile, introduction of a predatory snail species from Florida, *Euglandina rosea*, as a biological control agent against a previously introduced crop pest, the giant African snail *Achatina fulica* (Clarke *et al.*, 1984; Murray *et al.*, 1988; Cowie, 1992). Most species within the family are now either under threat or extinct because of the

continuing spread of the predator. Fifteen of the original 61 species (Appendix) from French Polynesia are currently being maintained in captive collections in Europe and North America.

In 1991 a field mission to the Society Islands, 'Operation Partula', was launched to gather information on the current status of both the indigenous and alien species. As expected only dead shells were found on Moorea, and it was necessary to make rescue collections from Raiatea, where a large part of the island was infested with *E. rosea*. Collections were also made of the three species of *Partula* from Huahine, although *E. rosea* had not yet reached the island at that time. A 1-day survey on Bora Bora confirmed that the island's single species of *Partula* and *Samoana* were almost certainly extinct.

By 1992 surveys across Raiatea located live *Partula* in the absence of the predator at only four locations, and all other locations were either devoid of *Partula*, or contained *Partula* populations in the presence of *E. rosea* (Gerlach, 1994). Further surveys in 1994 (Pearce-Kelly *et al.*, 1995) failed to locate living partulids on either Raiatea or Tahaa, and found that the introduction of *E. rosea* to Huahine sometime during the previous 2 years was threatening the three species of *Partula* on the island, individuals of which were then collected for captive breeding.

Trevor Coote (Corresponding author), c/o Zoological Society of London, Regents Park, London, NW1 4RY, UK. E-mail: trevor.coote@zsl.org

Éric Loève, BP 110659, Mahina, Tahiti, French Polynesia.

Received 22 December 2001. Revision requested 5 June 2002.

Accepted 8 October 2002.

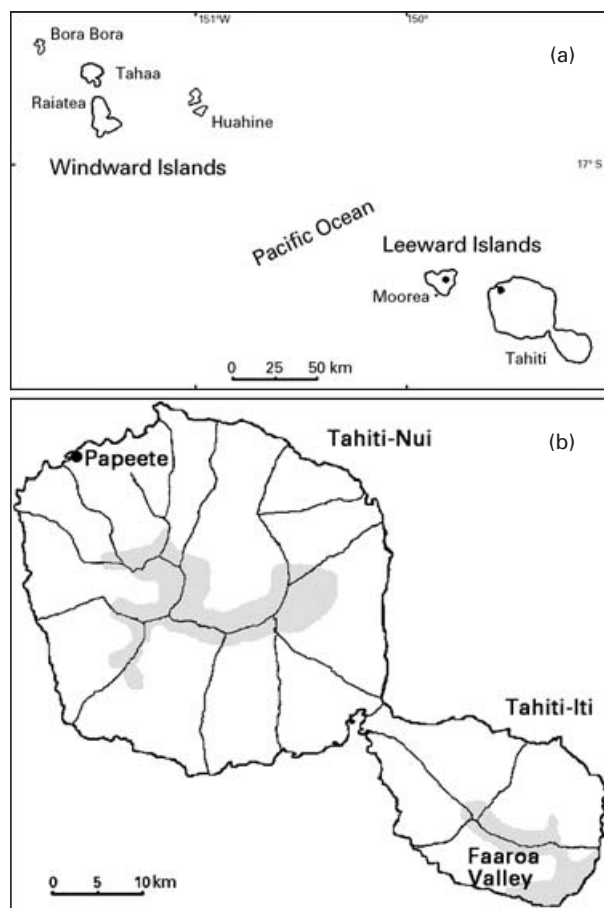


Fig. 1 The Society Islands, French Polynesia (a), and the currently known distribution of the genus *Partula* on Tahiti (b).

The seven species of *Partula* on Moorea declined in the 1980s (Wells, 1985), and by 1987 no living *Partula* could be located and *E. rosea* was found throughout the island, although at declining densities (Murray & Murray, 1987). However, after sightings of individuals of *Samoana* sp. (cf. *attenuata*), a genus closely related to *Partula* and also presumed extinct, in Afareaito Valley in 1996 and 1997, a small population was located in 1998 (Coote, 1999). This species had survived the most intensive era of predation by *E. rosea*.

The larger island of Tahiti was not comprehensively surveyed by single expeditions, but piecemeal over a number of years. A number of populations of partulid have been located, mostly at altitudes above 1,000 m in montane forest, although the largest populations have been found at sea level on the south-east coast. Small populations and a few individuals of species hitherto believed extinct were discovered in the interior of Tahiti (Coote *et al.*, 1999), although their status was unclear.

In 2000 and 2001 we carried out surveys on Huahine, Raiatea and Tahiti to locate any remnant populations of

Partula, and to obtain habitat information for the *ex situ* conservation programme. In this paper we combine the results of these and previous surveys to provide a comprehensive chronicle of the extinction of the species of *Partula* on the Society Islands, and to summarize the present conservation status, both *in situ* and *ex situ*, for all extant species.

Methods

Our surveys focused on those areas where partulids were most likely to have survived: the locations of the 1994 surveys on Huahine (Zoological Society of London, unpublished field report), the locations where *Partula* were found both in the presence and absence of *E. rosea* on Raiatea (Gerlach, 1994), areas on Tahiti previously known to have extant populations (Coote *et al.*, 1999), and marked trees on Moorea containing a relict population of *Samoana* sp. (Coote, 1999).

Legislation passed in 1998 for the protection of the family Partulidae precluded any collecting for the captive breeding programme, although permission was obtained to collect a maximum of two individuals of any species for identification purposes. The surveys on Huahine and Raiatea took place during December 2000, at the beginning of the hotter, rainy season in French Polynesia, and those on Moorea and Tahiti (on the main island, Tahiti-Nui, and on the Peninsula, Tahiti-Iti) in January 2001. Each survey, except for the 2-day survey on Tahiti-Iti, was restricted to a single day. At the head of Faaroo Valley on Tahiti-Iti counts of snails were made along 14 30 m transects to estimate the population of each species. All locations were recorded to an accuracy of 15 m using a Global Positioning System.

Results

Although we found shells of partulids, *E. rosea*, and *A. fulica* on Huahine, no living individuals were located. *Lei* sold in Papeete Market, Tahiti, made from shells of *P. rosea* and *P. varia* from Huahine, were widely available up to 1997, presumably from old stock, and in May 2001 we purchased a crown and two rings that were sold as the last ones available. We conclude that the three species of *Partula* on Huahine are now extinct in the wild.

In our survey of Hamoa Valley on Raiatea we found live *E. rosea* and shells of *Partula* that, based on the colour in the periostracum of the shell, probably died during 1998–1999. These shells were in the area behind what is now Kaoha Ranch, 300–400 m from the coast. Apart from the four species of extant *Partula* in captivity, it appears that the other 29 species are now extinct.

Of the 13 marked trees on Moorea two had fallen and were dead, and the foliage on a further two was too

high to be surveyed. On the remaining trees we found no evidence of living *Samoana*, although we found three empty shells and one shell fragment. Two of these were at the base of marked trees and one was 2 m from a marked tree. We found three shells of *E. rosea* that had died within the last few months. Two of these were lying at the base of marked trees, and one next to a *Samoana* shell. In a further search of the area we found no live *Samoana*.

In Faaroa Valley, Tahiti-Iti, the population of live partulids was estimated to be 2,100 (approximately 0.16 snails m⁻²) based on counts along 30 m transects. Although the population seemed relatively healthy, but not in large numbers, at 500 m into the valley a number of dead *Partula* shells and a few *E. rosea* shells, together with three live predators, were found. The *Partula* mortality rate, as indicated by the number of freshly dead shells, was more than would be expected in the absence of *E. rosea*. On Tahiti-Nui, in a very steep area at c. 1,400 m just below the crest of Mount Tahiti, above Orofero Valley, populations of *P. otaheitana*, polymorphic for both colour and coiling, were found, although in low numbers. There were an unusually high number of dead shells in this area, far from the nearest predator population. In a low elevation area long since considered devoid of *Partula*, we discovered a juvenile and an adult *P. hyalina*.

Discussion

The ill-judged attempts at biological control in the 1970s and 1980s, carried out in defiance of expert advice (Bryan Clarke, pers. comm.), precipitated the decline of the endemic land snail fauna of the Society Islands to a small number of species living in threatened and fragmented populations (Table 1, Appendix). This extinction in the wild of 56 out of 61 endemic partulid species is perhaps one of the best-chronicled extinctions. These extinctions had unknown consequences for the micro-ecology of the native forests, caused a loss of income for the local Polynesian community, and were a loss to the scientific community. On Huahine the loss of *P. varia* and *P. rosea*, the two species used for making *lei*, caused many of the women of the villages to lose their livelihoods, and the artisan's association closed down. The shells of dead partulids could not sustain this craft as the shells quickly lose their colour in the Polynesian climate. In view of the highly threatened status of many species of Partulidae, the remaining species and isolated populations are of particularly important conservation value.

Our surveys have confirmed the loss of all species of *Partula* and *Samoana* from the Leeward Islands, and a reduction in the fragmented populations of the surviving

Table 1 Chronicle of the extinction of the genus *Partula* on the Society Islands (see Appendix for a list of all species of the family Partulidae originally known from the islands).

Island	Area (km ²)	Max. altitude (m)	Original number of species	Estimated introduction date of <i>E. rosea</i>	Estimated date of extinction of <i>Partula</i>	Last surveys (reference)*	No. of species alive in the wild	Percentage of species extinct in the wild	Number of species remaining in captivity	Percentage of species extinct
(Windward)										
Bora Bora	30	727	1	1986	1987	1991 (Unpublished field report, ZSL)	0	100	0	100
Huahine	75	669	3	1992	1997	2000 (this study)	0	100	2	33
Raiatea	171	1,035	33	1986	1998	2000 (this study)	0	100	4	89
Tahaa (Leeward)	90	590	6	1986	1992	1994 (Pearce-Kelly <i>et al.</i> , 1995)	0	100	0	100
Moorea	142	1,207	7	1977	1987	1991 (Unpublished field report, ZSL)	0	100	5	39
Tahiti	1,045	2,240	8	1975	–	2001 (this study)	4	50	5	38
Total			58				4	93	16	72

* ZSL Zoological Society of London, London, UK.

four species on Tahiti (Fig. 1). On Moorea the extinctions ended over a decade ago, and all efforts have concentrated on the captive populations, in which five of the seven species are maintained, and on the trial reintroduction of three species into an area of protected habitat (Coote, 1999; Coote *et al.*, 2002). In addition, although we failed to locate *Samoana* sp. on the 13 marked trees on Moorea, they have since been 'rediscovered' there (C. Hickman, pers. comm.).

While the extinctions throughout the Society Islands were being documented in detail, the situation on Tahiti remained more complex, probably because of the greater area and altitude of the island. It seems that remaining populations of partulids on the larger part of the island, Tahiti-Nui, are confined largely to the interior, much of which is very difficult to access. Populations of four of the original eight species of partulid have persisted, even where *E. rosea* is present. In 1995 it was believed that the south-eastern corner of Tahiti-Iti was devoid of *E. rosea*. However, by the end of 1998 only Faaroa Valley contained no evidence of incursion of the predator. Although the presence of *E. rosea* has created an emergency situation in the valley, it is unclear how long the predator has been there, whether it is spreading towards the coast, or if there is an environmental impediment to its spread.

The predator *E. rosea* has colonised all of the Society Islands except for a few locations in the interior of Tahiti. Efforts are under way to try and identify possible impediments to the spread of this species. From previous surveys, there is little doubt that throughout the islands *E. rosea* now exists at much lower densities than formerly. On Moorea, no live individual has been seen in the forest for almost 3 years and none were seen on Huahine in 2000. Similarly, the giant African snail *Achatina fulica* has become rare in the forests, though there is anecdotal evidence of a population revival in some garden districts of Tahiti. The main threat from *A. fulica* now lies in its introduction to islands where it does not exist. This event is invariably followed by introduction of the predator *E. rosea*. This is the major fear for the islands of the Marquesas where there are an estimated seven species of partulid; in 1995 *A. fulica* was on Fatu Hiva but neither *A. fulica* or *E. rosea* were on the other three islands. Surveys are an acute priority for the Marquesas.

Our surveys have highlighted the necessity of regular field surveys to monitor the status of both the endemic and introduced snail species, and to continually update information for the captive breeding programme. The challenge now is to protect the extant but diminishing populations currently under the greatest threat. Action is currently being undertaken to construct a predator-proof reserve to protect the mixed species populations in Faaroa Valley on Tahiti-Iti. It is hoped that the con-

siderable effort and resources currently being expended on diverse aspects of *ex situ Partula* protection will lay the grounds for a fully funded conservation programme that will include regular monitoring of extant *in situ* populations. The conservation of the endemic snail species is intimately associated with the protection of some of the finest montane forest habitat remaining on any oceanic Pacific island. The French Polynesian government is taking an increasing interest in the protection of the endemic species of the islands, and ultimately this will be the government's responsibility. The scientific expertise and local willingness and experience are already in place.

Acknowledgements

Funding was provided primarily by Flora & Fauna International, the British Ecological Society, the Bristol, Clifton and West of England Zoological Society, and the Zoological Society of London. We thank H el ene D esmeraux, Eric Lenoble, and Clement Rochette. We also thank Jean-Yves Meyer for his invaluable advice, information and knowledge, and for translation. We thank Noa for accommodation and hospitality on Huahine, and Jean-Louis Kerek of RFO News.

References

- Clarke, B., Murray, J. & Johnson, M.S. (1984) The extinction of endemic species by a program of biological control. *Pacific Science*, **38**, 97–104.
- Coote, T. (1999) *The Genetics and Conservation of Polynesian Tree Snails (Family Partulidae)*. PhD Thesis, University of London, London, UK.
- Coote, T., Clarke, D., Hickman, C., Murray, J. & Pearce-Kelly, P. (2002) Experimental release of endemic *Partula*, extinct in the wild, into a protected area of natural habitat on Moorea. *Pacific Science*, in press.
- Coote, T., Loeve, E., Meyer, J.-Y. & Clarke, D. (1999) Extant populations of endemic partulids on Tahiti, French Polynesia. *Oryx*, **33**, 215–222.
- Cowie, R.H. (1992) Evolution and extinction of Partulidae, endemic Pacific island land snails. *Philosophical Transactions of the Royal Society of London B*, **335**, 167–191.
- Crampton, H.E. (1916) *Studies on the variation, distribution and evolution of the genus Partula. The species inhabiting Tahiti*. Carnegie Institute of Washington Publication, **228**, 1–311.
- Crampton, H.E. (1925) *Studies on the variation, distribution, and evolution of the genus Partula. The species of the Mariana Islands, Guam and Saipan*. Carnegie Institute of Washington Publication, **228A**, 1–116.
- Crampton, H.E. (1932) *Studies on the variation, distribution, and evolution of the genus Partula. The species inhabiting Moorea*. Carnegie Institute of Washington Publication, **410**, 1–335.
- Gerlach, J. (1994) *The ecology and behaviour of Euglandina rosea*. PhD thesis, Oxford University, Oxford, UK.

- Johnson, M.S., Murray, J. & Clarke, B. (1993) The ecological genetics and adaptive radiation of *Partula* on Moorea. In *Oxford Surveys in Evolutionary Biology*, **9**, 167–236.
- Murray, J. & Clarke, B. (1980) The genus *Partula* on Moorea: speciation in progress. *Proceedings of the Royal Society of London B*, **211**, 83–117.
- Murray, J. & Murray, E. (1987) *Partula Rescue Expedition: 1987*. Report to the Captive breeding Specialist Group, IUCN Gland, Switzerland.
- Murray, J., Clarke, B. & Johnson, M.S. (1992) Adaptive radiation and community structure of *Partula* on Moorea. *Proceedings of the Royal Society of London B*, **254**, 205–211.
- Murray, J., Murray, E., Johnson, M.S. & Clarke, B. (1988) The Extinction of *Partula* on Moorea. *Pacific Science*, **42**, 150–153.
- Pearce-Kelly, P., Clarke, D. & Mace, G. (1995) *Proceedings of the Annual Meeting of the Pacific Island Land Snail Group*. Unpublished Report, Zoological Society of London, London, UK.

- Wells, S.M. (1985) *Collection of endangered Partula snails, Moorea, Society Islands, June 1985*. Unpublished Final Report to the Flora and Fauna Preservation Society.

Biographical sketches

Trevor Coote is a population geneticist, and since 1995 he has been the principal field biologist involved in the protection of the endemic snails of French Polynesia. He works in collaboration with local Polynesians, biologists and with those in the Territorial government concerned with nature conservation.

Éric Loève's main interest is in the protection of the natural heritage of French Polynesia. He is the President of Fenua Animalia, the principal organisation on the Territory involved in the welfare of domestic animals.

Appendix

Status of the family Partulidae on the Society Islands, French Polynesia.

Species	Island						Extinct in the wild	In captivity*
	Bora Bora	Huahine	Raiatea	Tahaa	Moorea	Tahiti		
Partula								
<i>P. affinis</i>						X		BIH
<i>P. arguta</i>		X					X	
<i>P. atilis</i>			X				X	
<i>P. aurantia</i>					X		X	
<i>P. auriculata</i>			X				X	
<i>P. bilineata</i>				X			X	
<i>P. candida</i>			X				X	
<i>P. citrini</i>			X				X	
<i>P. clara</i>						X		BIH, ZSL
<i>P. crassilibris</i>			X				X	
<i>P. cytherea</i>						X	X	
<i>P. dentifera</i>			X				X	BIH, ZSL
<i>P. dolorosa</i>			X				X	
<i>P. eremita</i>				X			X	
<i>P. exigua</i>					X		X	
<i>P. faba</i>			X				X	JER, ZSL
<i>P. filosa</i>						X	X	
<i>P. formosa</i>			X				X	
<i>P. fusca</i>			X				X	
<i>P. garretti</i>			X				X	
<i>P. hebe</i>			X				X	EDI, POZ, ZSL
<i>P. hyalina</i>						X		SHD, STZ, ZSL
<i>P. imperforata</i>			X				X	
<i>P. labrusca</i>			X				X	
<i>P. leptochila</i>			X				X	
<i>P. levilineata</i>			X				X	
<i>P. lugubris</i>			X				X	
<i>P. lutea</i>	X						X	
<i>P. mirabilis</i>					X			BIH, CHE, EDI, NOT, POZ, ZSL
<i>P. mooreana</i>					X		X	JER, NOT, ZSL
<i>P. navigatoria</i>			X				X	
<i>P. nodosa</i>						X	X	DET, SHD, STZ, MEM, ZSL
<i>P. otahaitana</i>						X		BIH, ZSL

Appendix (Continued)

Species	Island						Extinct in the wild	In captivity*
	Bora Bora	Huahine	Raiatea	Tahaa	Moorea	Tahiti		
<i>P. ovalis</i>			X				X	
<i>P. planilabrum</i>				X			X	
<i>P. producta</i>						X	X	
<i>P. radiata</i>			X				X	
<i>P. remota</i>			X				X	
<i>P. robusta</i>			X				X	
<i>P. rosea</i>		X					X	BIH, EDI, ZSL
<i>P. rustica</i>			X				X	
<i>P. sagitta</i>				X			X	
<i>P. subangulata</i>				X			X	
<i>P. suturalis</i>					X		X	BIH, EDI, NOT, POZ, ZSL
<i>P. taeniata</i>					X		X	BIH, CHE, NOT, JER, WIS
<i>P. thalia</i>			X				X	
<i>P. tohiveana</i>					X		X	BIH, EDI, ZSL
<i>P. tristris</i>			X				X	ZSL
<i>P. turgida</i>			X				X	
<i>P. umbilicata</i>				X			X	
<i>P. varia</i>		X					X	BIH, CHE, WIS, ZSL
<i>P. vittata</i>			X				X	
<i>P. X callifera</i>			X				X	
<i>P. X cedista</i>			X				X	
<i>P. X cuneata</i>			X				X	
<i>P. X dolichostoma</i>			X				X	
<i>P. X levistriata</i>			X				X	
<i>P. X protracta</i>			X				X	
Samoana								
<i>S. annectens</i>		X					X	
<i>S. attenuata</i>	X		X	X	X	X	X	
<i>S. diaphana</i>					X		X	

*BIH Bristol Zoo, UK; CHE Chester Zoo, UK; EDI Edinburgh Zoo, UK; MEM Memphis Zoo, USA; NOT Nottingham University, UK; POZ Poznan Zoo, Poland; SHD Shedd Aquarium, USA; STZ St Louis Zoo, USA; WIS Martin Mere Wildfowl Trust, UK; ZSL London Zoo, UK.