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The status of the endemic snails of the genus *Partula* (Gastropoda: Partulidae) on Pohnpei, Federated States of Micronesia.

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Abstract—Approximately 21 terrestrial snail species are endemic to Pohnpei, Federated States of Micronesia (FSM). The only extensive surveys for terrestrial snails on the island were carried out by Y. Kondo in 1936. Subsequently, forests have been destroyed and non-native predators have taken their toll on the gastropod fauna, and its current status is unknown. The present study focused on *Partula guamensis* and *P. emersoni,* two of approximately 120 species in the family Partulidae dispersed across the tropical Pacific Islands. Over 40 different localities on Pohnpei were extensively searched between August 2005 and May 2006 and between May and July 2008 to assess the status of the two *Partula* species. The habitats searched were mixed agro-forest, disturbed forest, rain forest and cloud forest, ranging from sea level to the highest peaks and ridges on the island. No living partulid snails were found, and the only shells collected, those of *Partula guamensis,* were old and eroded. The absence of living partulid snails, once apparently very abundant, is a warning of the possible extinction of the entire terrestrial snail fauna of Pohnpei.

Introduction

The snail family Partulidae includes approximately 120 species scattered across the islands of the tropical Pacific Ocean. The vast majority (~100) fall within the genus *Partula* and are distributed from the Northern Mariana Islands and Palau, in the west, to the Society Islands in the eastern tropical Pacific (Cowie 1992). Morphologically, partulid shells are of moderate size, 11 - 30 mm, and spiraled, and their evolutionary radiations appear extremely conservative when compared to the Achatinellidae, another family of Pacific Island arboreal snails (Kondo 1955; Cowie 1992).

The current study focused on surveys for partulid snails on the Micronesian island of Pohnpei. There are few documented records of the partulid species known to be endemic to Pohnpei, and the taxonomic status of these species has been confusing. *Partula guamensis,* despite its name, has long been recognized as a Pohnpeian endemic (Pilsbry 1909). A second species, *P. emersoni,* was named from a single shell collected by Emerson, reportedly on Pohnpei. However, at

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the time of its description, the species had never been found alive on the island, and even its original describer thought it likely that the single shell on which the species is based came from further to the east, most likely in Melanesian islands (Pilsbry 1913). The only more recent published information on the distribution of Pohnpeian partulids is that of Y. Kondo (1956) who provided a summary of the results of his 1936 surveys on the island and included the name *P. emersoni* in his species list.

The partulid snail best known to be endemic to Pohnpei, *P. guamensis,* would appear from its name to be distributed to the Mariana Islands as well. However, this appears to be another instance of malacological confusion. The species was described from a shell collected by Pfeiffer in 1846 as a species of the genus *Bulimus* and then moved into the genus *Partula* by the same author in 1849 (information in Pilsbry 1909). Later authors discovered the true home of the snail on Pohnpei and affirmed that it did not occur on Guam (e.g., Hartman 1885; information in Pilsbry 1909).

Regarding *P. emersoni,* we sought clarity for Kondo's reference to the name in his brief 1956 paper by examining his field books and collections in the Malacological Division of the Bishop Museum in Honolulu, Hawaii. Kondo did not include the name *Partula emersoni* at any place in his field notes from his 1936 surveys on Pohnpei. However, an examination of the collections revealed that Kondo classified a large number of shells and specimens that he collected on Pohnpei as *P. emersoni,* as well as many more of *P. guamensis*.

Pohnpei is the largest and highest island in the Federated States of Micronesia, lying in the west-central Pacific, and is a roughly circular, five-million-year-old volcanic mountain approximately 23 km in diameter at sea level (355 km^2) (Fig. 1). The island sits roughly 770 km north of the equator in the Eastern Caroline Islands. The maximum elevation in the highlands is about 800 m with 11 peaks greater than 600 m (US Army Corps of Engineers 1986). Pohnpei is thickly forested with ridges and valleys spreading outward and downward to coastal lowlands and surrounding mangrove wetlands. Approximately 31,540 people inhabit Pohnpei (Pohnpei Office of Planning and Statistics 1996). The island is divided into five municipalities, each with its own traditional and cultural leaders. Approximately 61% of Pohnpei is steep mountains, 20% hills and flat terrain, 5% flood valley and coastal plains, and 14% mangrove swamps (Laird 1982). Surrounding the island is an asymmetrical barrier reef enclosing a lagoon with numerous coral reefs and mangrove swamps. The mean annual temperature is 27º C, and the monthly temperature does not vary from the annual average by more than 1º C (Laird, 1982).

Known threats to terrestrial snails of the Pacific islands come primarily from invasive species and habitat destruction (Cowie 1992; Merlin and Raynor 2005). Alien predators, including the New Guinea flatworm *Platydemus manokwari,* the carnivorous snail *Euglandina rosea* and rats can critically impact populations of partulid snails (Fig 2). The predatory flatworm is considered a major cause of extinction of land snails in the Pacific islands, which it tracks by following their mucous trails and attacks them both on the ground and in trees up to 2.0 m above the ground (Sugiura and Yamaura 2008). The carnivorous snail *Euglandina*

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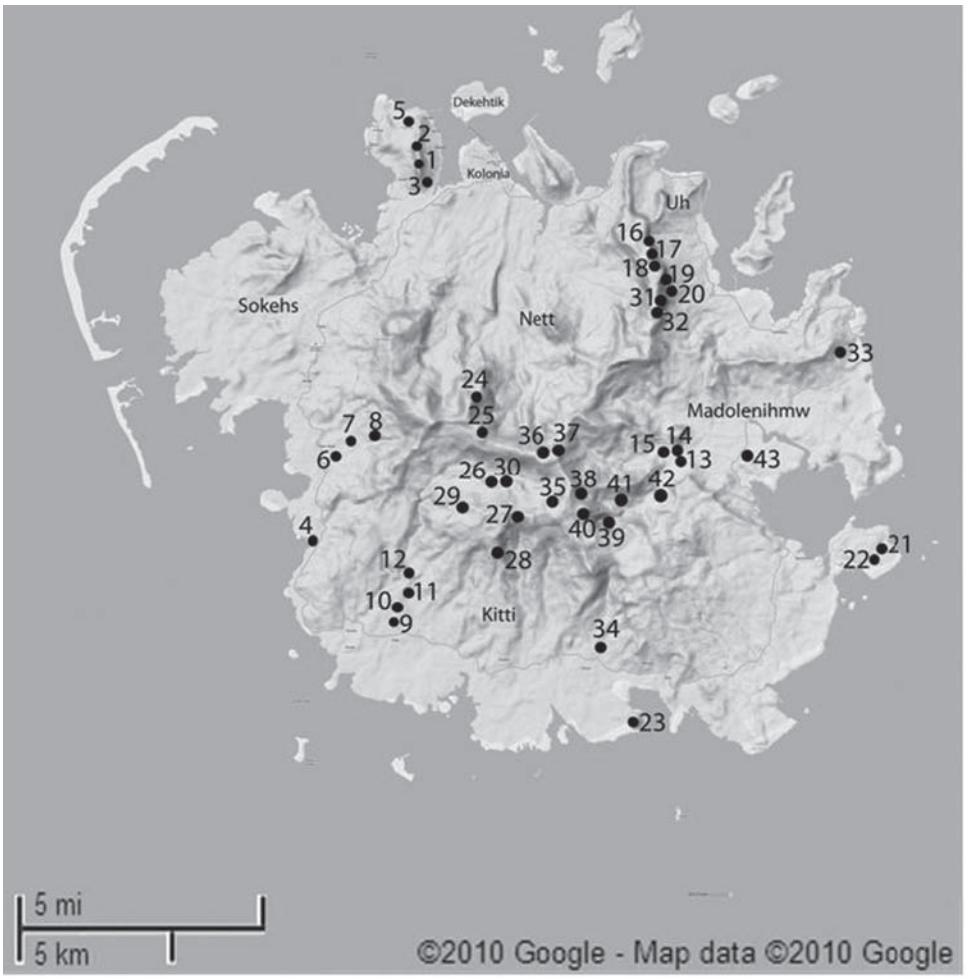

Figure 1. The island of Pohnpei, Federated States of Micronesia. Numbered black circles indicate the 43 sites that were surveyed in this study. Municipalities noted in Table 1 are shown (M, Madolenihmw; K, Kitti; U, Uh; N, Nett; S, Sokehs).

rosea was imported to Pohnpei from Hawaii in 1960, but it is unclear if it became established (Schreiner 1989). The Polynesian rat, *Rattus exulans,* and the black rat, *Rattus rattus,* are predators on many native species, including ground- and tree-dwelling snails, and are well established on Pohnpei (Merlin & Raynor 2005, Schreiner 1989).

With increasing human populations throughout Micronesia and resultant land development and agricultural activities, pressure on native upland forests is increasing. Agricultural uses, especially clear-cutting for kava plantation (*Piper methysticum,* locally known as sakau), are among the main causes of deforestation in Pohnpei's upland watersheds (Merlin & Raynor 2005, Buden et al. 2001). The kava plant is a common cash crop throughout the area.

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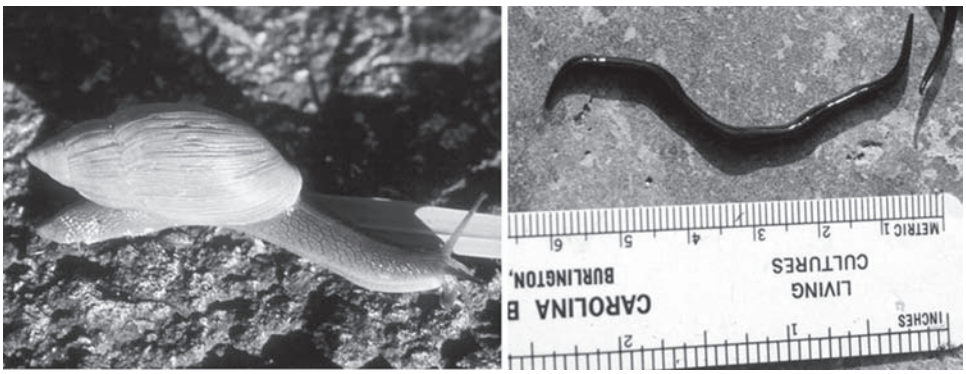

Figure 2. Non-native tree-snail predators known to exist on Pohnpei include the carnivorous snail *Euglandina rosea* (shell ~ 4 cm long) and the New Guinea flaworm *Platydemus manokwari*.

The goal of the current study was to determine the current status of the *Partula* species, the only sizeable arboreal snails, on Pohnpei. To carry out these surveys, we first determined as much as possible from the publications cited above. In addition to Kondo's (1956) brief publication, we extensively utilized the field notes and maps prepared by Kondo and maintained in the Malacology Division of the Bishop Museum. We have also had access to the unpublished survey notes and maps made by Barry Smith of the University of Guam in the 1990s (B. Smith, personal communication). All sites where *Partula* spp. were reported in these two twentieth century surveys were extensively re-surveyed, and the negative findings are presented here.

Study Area and Methods

Field surveys on Pohnpei were conducted from August to May 2005–2006 and May to July 2008, to evaluate the status of *Partula guamensis* and *P. emersoni*. Records from literature cited above and information provided by B. Smith of Guam and local residents were used to search for *Partula* populations on the island. Interviews of local residents in each of the Pohpeian states were extremely valuable in guiding our searches. The field surveys were conducted by slowly walking along the existing trails and searching vegetation and on the ground. At each site where snails had been reported, more extensive searches were made of all trees, bushes and the ground in a 10 m radius around the site. Above ground searches at each site included examining tree trunks, branches, and leaves, followed by a ground survey that included searching under rocks, fallen leaves, broken branches and among dense grasses.

Surveys were conducted in all of the five municipalities of Pohnpei; Sokehs, Kitti, Madolenihmw, Nett and Uh (Fig. 1). All sites where *Partula* had been reported by any of the sources cited above were visited. Additional searches were made in all ideally moist habitats encountered while accessing the historic sites. Within the different localities, most habitats were mixed agro-forest, disturbed forest, rain forest, and cloud forests at the highest elevations. Based on initial visits when

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ground shells were found, the most promising sites were at Temwen and Mesihsou in Madolenihmw municipality (Table 1 and Fig. 1). The habitat at Temwen (Fig. 1, sites 21, 22) is mostly agro-forest with cultivated trees and some native plants and associated understory of shrubs and herbs. However, the Mesihsou site (Fig. 1, site 33) is mostly rainforest with native trees. At both sites kava *(Piper methysticum)* has been planted by residents of the region within the area searched. Altogether, 43 sites were investigated, each searched during the daytime for one to four hours depending on the habitat type. However, two sites at Nahna Laud (Fig. 1, sites 26, 27) were surveyed at night time, as well as during daylight hours, to determine if light is a factor; however, no living snails were found.

To clarify which *Partula* species had lived on Pohnpei and better understand their distributions, the field books, survey notes, maps and collections of former curator Y. Kondo were examined in the Malacological Division of the B.P Bishop Museum in Honolulu, HI. We sought to determine easily recognized differences in shell morphologies of the two partulid species known from Pohnpei and to record the number of preserved specimens collected by Y. Kondo during his survey on Pohnpei in 1936. Photos of shells of *Partula guamensis* and *P. emersoni* were taken to assist in resolving confusion regarding the distributions of Pohnpeian partulids (Fig. 3). Data on Kondo's collection sites for living (now preserved) snails were compared with Kondo's field notes to clarify if both species had arboreal habits or if *P. guamensis* was ground-dwelling, as briefly mentioned in Kondo's Ph.D. dissertation (1955).

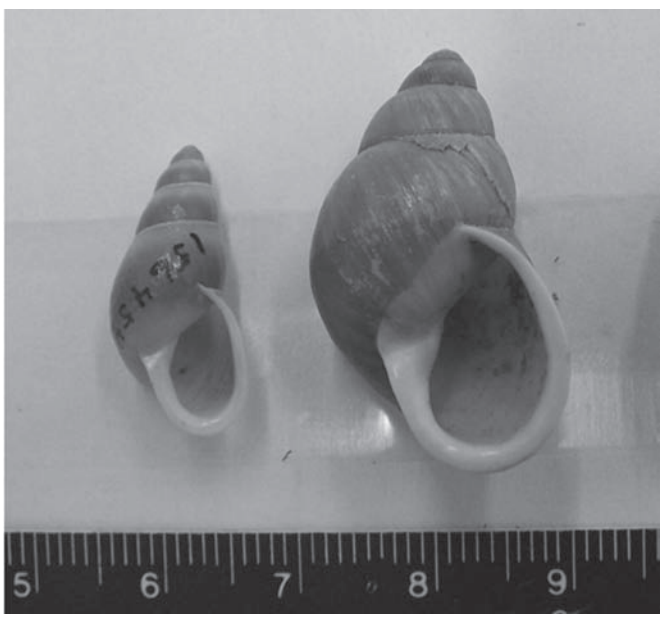

Figure 3. Adult shells of the two partulid species native to Pohnpei, *Partula emersoni* (left) and *Partula guamensis* (right), collected by Y. Kondo during his survey in 1936 (photographed in the Malacological Division of the Bishop Museum in Honolulu, HI). Scale numbered in cm.

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Table 1. Geographic sites searched for *Partula guamensis* and *P. emersoni* on Pohnpei Island.

Site[1]	Location[2]	Habitat[3]	Latitude	Longitude	Elev. (M)
1	(S) Dolap	Agroforest	6°58'4.08"N	158°11'25.65"E	230
2	(S) Dolap	Rainforest	6°58'8.54"N	158°11'24.10"E	245
3	(S) Kamwele	Rainforest	6°57'27.53"N	158°11'40.33"E	54
4	(K) Pwudoi	Disturbed forest	6°50'52.96"N	158° 9'32.07"E	23
5	(S) Paipalap	Agroforest	6°58'45.96"N	158°11'16.18"E	15
6	(K) Pehleng	Agroforest	6°52'37.54"N	158° 9'49.01"E	24
7	(K) Pehleng	Agroforest	6°52'47.13"N	158° 9'56.34"E	27
8	(K) Pehleng	Agroforest	6°52'53.05"N	158°10'11.82"E	44
9	(K) Kipar	Disturbed forest	6°49'27.17"N	158°11'1.69"E	46
10	(K) Kipar	Disturbed forest	6°49'33.25"N	158°11'0.71"E	75
11	(K) Kipar	Disturbed forest	6°49'42.70"N	158°11'4.04"E	77
12	(K) Kipar	Disturbed forest	6°49'57.49"N	158°11'2.84"E	94
13	(M) Senipehn	Disturbed forest	6°52'29.67"N	158°16'13.25"E	60
14	(M) Senipehn	Disturbed forest	6°52'33.54"N	158°16'11.05"E	59
15	(M) Senipehn	Disturbed forest	6°52'34.23"N	158°16'7.88"E	64
16	(U) North of Kupwuriso	Rainforest	6°56'21.45"N	158°15'41.74"E	324
17	(U) North of Kupwuriso	Rainforest	6°56'12.57"N	158°15'41.88"E	376
18	(U) North of Kupwuriso	Rainforest	6°56'2.89"N	158°15'40.25"E	445
19	(U) North of Kupwuriso	Cloudforest	6°55'46.71"N	158°15'48.10"E	552
20	(U) North of Kupwuriso	Cloudforest	6°55'37.69"N	158°15'48.30"E	565
21	(M) Temwen	Agroforest	6°50'42.32"N	158°19'52.12"E	19
22	(M) Temwen	Agroforest	6°50'41.15"N	158°19'51.68"E	18
23	(K) Mwudok	Rainforest	6°47'37.61"N	158°15'25.43"E	99
24	(N) Trail to Nahna Laud	Rainforest	6°53'44.95"N	158°12'32.82"E	601
25	(N) Nahna Laud	Cloudforest	6°53'1.43"N	158°12'30.39"E	654
26	(K) Nahna Laud	Cloudforest	6°52'8.28"N	158°12'57.30"E	337
27	(K) Nahna Laud	Cloudforest	6°51'27.70"N	158°13'19.12"E	628
28	(K) Enpein	Rainforest	6°50'47.00"N	158°12'54.06"E	443
29	(K) Nahna Laud	Cloudforest	6°51'36.26"N	158°12'18.33"E	505
30	(K) Nahna Laud	Cloudforest	6°52'8.28"N	158°12'57.30"E	337

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31	(U) top of Kupwuriso	Cloudforest	6°55'21.77"N	158°15'50.92"E	560
32	(U) top of Kupwuriso	Cloudforest	6°55'19.20"N	158°15'49.96"E	580
33	(M) Mesihsou	Rainforest	6°54'24.22"N	158°19'8.06"E	83
34	(K) Wone	Rainforest	6°48'57.36"N	158°14'47.12"E	45
35	(K) Ngihneni	Rainforest	6°51'41.85"N	158°13'58.83"E	659
36	(K) Nahna Laud	Cloudforest	6°52'24.67"N	158°13'35.31"E	713
37	(K) Nahna Laud	Cloudforest	6°52'24.45"N	158°13'40.62"E	759
38	(M) Dolente	Cloudforest	6°51'50.54"N	158°14'19.29"E	650
39	(M) Mwhaiau	Cloudforest	6°51'32.25"N	158°14'25.53"E	665
40	(M Mwhaiau	Cloudforest	6°51'27.75"N	158°14'52.58"E	357
41	(M) Senipehn	Cloudforest	6°51'41.83"N	158°15'7.89"E	239
42	(M) Pahn Sile	Rainforest	6°51'48.15"N	158°15'42.19"E	122
43	(M) Nih Pwongin	Agroforest	6°52'23.72"N	158°17'4.06"E	31

[1]Site number: see Fig. 1.
[2]Location: letters indicate municipalities on Pohnpei: K, Kitti; M, Madolenihmw; N, Nett; S, Sokehs; U, Uh.
[3]Habitat: Disturbed forest, below ~200 m where native trees are selectively removed and understory vegetation cleared by human activities or livestock; Agro-forest, native and cultivated plants (mainly kava) merge to form a unified habitat; Rainforest, undisturbed dense forest characterized by high rainfall and most prevalent from the valleys up to ~600 m on mountain slopes; Cloudforest, also called moss or dwarf forest, situated on the highest ridges and peaks above 600 m (categories defined by Merlin and Raynor 2005).

Results

Field surveys of 43 sites on Pohnpei yielded no living partulid snails and surprisingly little in the way of any terrestrial gastropods. However, one shell of *Partula guamensis* was collected by a native farmer at site 33 (Fig. 1), and three *P. guamensis* shells were collected by our search at site 22 on Temwen Island in Madolenihmw (Fig. 1). No shells of P. emersoni were encountered at any location. A very few living *Pythis* sp. were observed in the same area. The most frequently encountered snail was the giant African snail *Achatina fulica*. The introduced predatory flat worm *(Platydemus manokwari)* was abundant at many sites. Although *Euglandina rosea,* a snail that preys on other snails and has been widely introduced in the Pacific Islands in an effort to control the giant African snail, has been reported on Pohnpei, it was not encountered in the present surveys.

Examination of the collections at the Malacological Division of the B.P. Bishop Museum revealed that Y. Kondo did, indeed, collect two partulid species during his surveys on Pohnpei in 1936. The empty shells of the two species (Fig. 3) readily illustrate their differences. Furthermore, shells of *P. emersoni* greatly resemble the drawing of this species included by Pilsbry (1913) in the original

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description of the species. Despite the fact that Pilsbry (1913) thought that the shell he described as *P. emersoni* most likely came from the Melanesian islands, and not Pohnpei as its collector had reported to him, Y. Kondo's collection proves the Pohnpeian home of the species. In a single sentence in his Harvard University Ph.D. dissertation (1955, p.191), Kondo compared *P. martensiana,* a snail endemic to Kosrae (called by an older spelling, Kusaie, by Kondo), with *P. guamensis* and noted that both species were ground-dwelling. This notion is supported by Kondo's collections and his field notes from the 1936 survey. They reveal that all preserved specimens of *P. guamensis,* i.e., not obtained as empty shells, came from leaves on the ground. Kondo collected about 1400 specimens of *P. guamensis* and 500 specimens of *P. emersoni*. Shells of *P. guamensis* were collected from many sites across the island, whereas *P. emersoni* was collected mostly from Kupwuriso, Uh (Fig. 1. site 32, 31), plus a few each from Paipalap, Sokehs (Fig. 1, site 5) and Sapwtakai, Kitti (close to site 4 in Fig. 1).

Discussion

The biological integrity of many Pacific islands is under threat from a number of factors that vary in intensity and effect from island to island. According to both the Nature Conservancy (Merlin & Raynor 2005) and malacologists (Cowie 1992), the two greatest threats to the biota of the Pacific islands are habitat destruction and alien species introductions. These two influences are primarily responsible for hundreds of species extinctions across the Pacific, although it is only in the last 20-30 years that much attention has been drawn to the plight of island snail species. High profile introductions such as the brown tree snake on Guam (Wiles et al. 2003) and the Round Goby (Steingraeber & Thiel 2000) infestations of the U.S. Great Lakes draw much attention and resources, because of the economic damage they inflict to those regions. However, in many parts of the Pacific, it is more difficult to evaluate the economic damage caused by exotic organisms. For example, how does one evaluate the economic impact caused by the predatory snail *Euglandina rosea* (Fig. 2), which was introduced to Pohnpei in the 1960s to control the giant African snail *Achatina fulica,* an alien agricultural pest (Merlin & Raynor 2005). The predatory flatworm *Platydemus manokwari* (Fig. 2) was already established at upper elevations on Pohnpei by 1993 (Eldredge & Smith 1994). Rats, also major predators of many native species including tree snails, are well established on Pohnpei (Merlin & Raynor 2005). The impacts of these predators have been documented on *Partula* species in French Polynesia and on the endemic achatinellid tree snails of the Hawaiian Islands; massive extinctions have occurred in both island groups (Hadfield 1986; Murray et al. 1988; Hadfield et al.1993).

In recent times, the droughts of 1982-1983 and1997-1998 on Pohnpei were especially severe further increasing localized threats to the biodiversity. Groundwater sources were taxed, agricultural systems damaged and problems associated with wildfires and invasive species were exacerbated. High mean water temperatures especially associated with low water spring tides caused coral bleaching and

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damage to inshore marine ecosystems (Falanruw 2001). The impact of these events on the terrestrial biota of Pohnpei has not been measured.

Agricultural clearing, mainly for *sakau* (kava) propagation, has been identified as a serious threat for Pohnpei's forests, especially in recent decades. Resulting deforestation targets all terrestrial habitats except tropical cloud forest, and this threat has been worsened by the rapid population growth and a rapid growth within the cash economy (Trustrum, 1996). Intact forests have been reduced from 42% of the island's land area in 1975 to only 15% in 1995 (Merlin & Raynor 2005); forest loss has continued over the succeeding 15 years. The result of finding no living partulid snails after more than 60 person hours of searching within 43 sites including most of the best remaining forest habitat may well signal the extinction of the two partulid tree snail species on Pohnpei and provide a dire projection for as many as 19 additional endemic terrestrial snail species in Pohnpei (Merlin & Raynor 2005). Only extensive surveys will reveal the actual status of the terrestrial snail fauna of the island.

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