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The decline of native Pacific island faunas: changes in status of the land snails of Samoa through the 20th century☆

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Abstract

The highly diverse and endemic Pacific island biota is disappearing and being replaced by a relatively small number of widespread alien species. The land snail fauna of Samoa (formerly Western Samoa) contains at least 72 species (58 native, 10 alien, four cryptogenic—of unknown origin). In 1992–1994 we surveyed the fauna in order to evaluate its status and, by comparison with previous surveys, to detect any trends. Twelve species have declined (eight native, two cryptogenic); 17 (15 native, two cryptogenic) show a "probable decline" or "possible decline"; five (four alien, one native) have increased or possibly increased. Some species showed no clear trend; others could not be evaluated, but some of them may be extinct. The fauna faces threats similar to those faced elsewhere, primarily habitat destruction and alien species impacts. Most notable is the introduction of a predatory flatworm, *Platydemus manokwari*, in attempts to control the giant African snail, *Achatina fulica*, which became established in Samoa in the 1990s. The flatworm may or may not be able to control *A. fulica* but poses a serious threat to the native snail fauna. Further introduction and distribution of alien predators should be strongly discouraged.

Keywords: Alien species; Extinction; Gastropoda; Land snails; Pacific; Samoa

1. Introduction

Global biodiversity is declining at an alarming rate. The prime cause of this loss has long been recognized: habitat destruction, for urban and agricultural development and for natural resource exploitation. The impacts of alien species are now commonly regarded as second only to those of habitat destruction (e.g. Alonso et al., 2001; Simberloff, in press). Aliens may have direct impacts via competition, predation or herbivory, or indirect impacts through modification of native habitats and altering of community interactions (D'Antonio and Dudley, 1995; Simberloff, in press).

Endemic island biotas are particularly susceptible to losses caused by these two factors (Simberloff, 2000), which are combining on the islands of the tropical Pacific to cause a catastrophic loss of the islands' highly diverse and endemic plants and animals (Loope, 1998). In order to implement appropriate conservation management programs for this diversity (e.g. Sherley, 2000), the primary scientific requirements are knowledge of species distributions, identification of trends in these distributions, and understanding the causes of these trends. The great majority of Pacific island faunal diversity is composed of invertebrates (e.g. Eldredge, 2000), yet for many of these invertebrate groups little is known of either their past or present distributions. Without this knowledge it is impossible to develop adequate management strategies. With these needs in mind, this paper addresses the status of the highly endemic land snail fauna of Samoa.

Worldwide land snail diversity is second only to that of arthropods, and a large proportion of the world's land snail diversity is found on islands. Many islands, especially in the Pacific, harbor extremely diverse native land snail faunas (e.g. Solem, 1983; Cowie, 1996a, b). Few islands have been adequately surveyed (Cowie and

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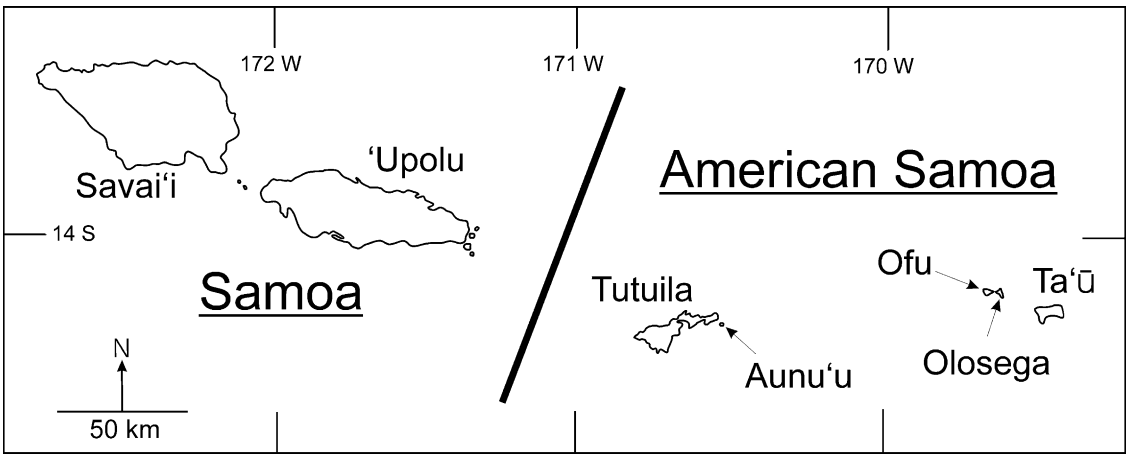

Fig. 1. The Samoan archipelago, excluding Rose Atoll and Swains Island.

Rundell, 2002; Cowie et al., in press). Nonetheless it is clear that many of these native Pacific island snail faunas have declined dramatically in the face primarily of habitat destruction, predation by introduced predators (particularly rats, predatory snails deliberately introduced in misguided attempts to control another introduced snail, the giant African snail, *Achatina fulica*, and possibly ants) and perhaps competition with introduced species (e.g. Hadfield, 1986; Kurozumi, 1988; Solem, 1990; Cowie, 1992, 2001a, b, 2002a; Hopper and Smith, 1992; Hadfield et al., 1993; Bauman, 1996; Bouchet and Abdou, 2001; Cowie and Cook, 2001). On many islands, the endemic snail species are largely confined to upper elevations and/or seem to be restricted to the remaining patches of primary forest. Overall, the native snail fauna of the Pacific islands is disappearing and being replaced by a small suite of widely distributed alien species (Cowie, 2002a).

Most of the species of native land snails in the Samoan archipelago were described during the latter half of the nineteenth century. During the twentieth century, survey work was undertaken in both American Samoa and Samoa (formerly Western Samoa) (for a brief historical summary see Cowie, 2001a), and some of the material collected was used in major taxonomic revisions of certain components of the Pacific land snail fauna (e.g. Baker, 1938, 1941; Cooke and Kondo, 1960; Solem, 1976, 1983). However, no faunal-wide assessment of the land snails of the Samoan islands had been undertaken until the recent nomenclatural catalog (Cowie, 1998), which lists all species, native and alien, recorded (up to 1998) in the Samoan islands, giving their island by island distributions. The results of recent survey work and an evaluation of the conservation status of the fauna of American Samoa have also recently been published (Cowie, 2001a; Cowie and Cook, 1999, 2001; Cowie and Rundell, 2002; Cowie et al., in press).

This paper reports the results of survey work carried out in 1992–1994 in [Western] Samoa, and, by comparing the results of this survey with those of earlier unpublished surveys, evaluates the conservation status of the native fauna of Samoa and the extent of its replacement by alien species. A similar approach has recently been adopted for assessing the status of Pacific island birds (Blanvillain et al., 2002). In combination with the recent evaluation of the American Samoan land snail fauna (references above), this paper concludes the most thorough, recent, fully published survey of the land snails of a large tropical Pacific archipelago.

2. Study region

The Samoan archipelago is a chain of volcanic islands extending in an approximately east-south-east to west-north-west direction in the central southern Pacific (Fig. 1). It is generally considered a single biogeographic unit. Politically however, it comprises American Samoa (a territory of the United States) and Samoa (an independent state). This paper focuses on Samoa.

Samoa (Fig. 2) is composed of two main islands, Savai'i (1718 km^2) and 'Upolu (1125 km^2), a number of smaller islands, including Apolima (5 km^2), Manono (10 km^2), Nu'utele (1.1 km^2), Nu'ulua (0.3 km^2), and an additional 14 smaller islets. Savai'i (elevation 1858 m) is one of the highest and largest islands in Polynesia. 'Upolu (1143 m) is the second highest island in the group. All the smaller islands are considerably lower.

The Samoan islands are generally thought to have been formed as the Pacific plate moves across a stationary underlying "hot-spot", with magma periodically breaking through the crust to form the islands in chronological sequence, with the oldest (Savai'i) in the west and the youngest (the Manu'a islands, American Samoa) in the east (Keating, 1992). However, their ages are not well understood, in part because of active vulcanism on Savai'i that is probably associated with the proximity of the Tonga trench subduction zone, but

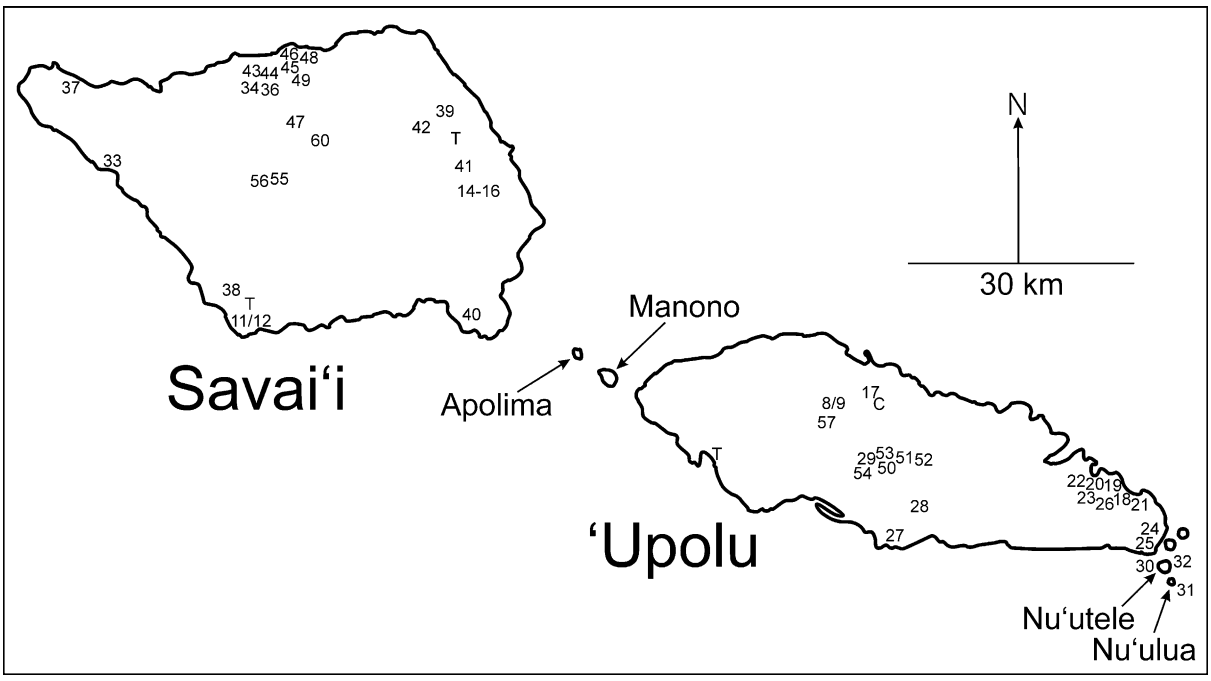

Fig. 2. Samoa, showing locations of 1992–1994 sampling locations. (ACR stations indicated by his field numbers; numbers 1–7, 10, 13, 35, 58, 59 are not part of this survey; numbers 8 and 9 are a single station, as are numbers 11 and 12, and 14–16. RHC station indicated by C; Pepper W. Trail stations indicated by T.)

they appear to range between less than 1 Ma to about 4 Ma (Keating, 1992).

The islands were settled by Polynesians around 3000 years ago and the agricultural and hunting practices of these people undoubtedly had a dramatic effect on the indigenous biota, at least of the lowlands (e.g. Kirch, 1993; Hunt and Kirch, 1997), as they did elsewhere in Polynesia (Athens and Ward, 1993; Loope, 1998). However, modern urban development, extensive logging activity, and other habitat changes, mean that the islands now support much reduced and fragmented areas of natural habitat. Large numbers of alien plants and animals are now present, some resulting from early Polynesian introductions but many more from the ongoing introductions that followed discovery of the islands by Europeans. Further details of the Samoan environment have been provided by Taule'alo (1993), and the remaining relatively natural ecosystems have been described by Park et al. (1992), Pearsall and Whistler (1991a) and Whistler (1992, 1993, and references therein), and mapped by Pearsall and Whistler (1991b).

3. Methods

3.1. Survey stations, sampling, identification

Surveys were undertaken in 1992–1994 with the primary purpose of generating species inventories at each station as a means of evaluating overall species distributions. All sites identified as "grade 1" by Park et al. (1992), that is, good quality, relatively undisturbed, lowland rainforest, were sampled formally, as were a number of additional lowland and upland (above 450 m elevation) stations, resulting in 14 lowland and four upland stations on Savai'i, eight lowland and four upland stations on 'Upolu, and one station each on Nu'utele and Nu'ulua; a total of 32 formally sampled stations. In other parts of the islands, snails were collected opportunistically, at an additional five stations on Savai'i, 10 on 'Upolu, and one on Nu'utele. Thus, an overall total of 48 stations was sampled, 23 on Savai'i, 22 on 'Upolu, two on Nu'utele and one on Nu'ulua (Fig. 2).

At each formally sampled station, sampling took place at intervals along a transect line and was by hand collecting of specimens in the field, both from vegetation and from the litter. This method probably undersamples smaller species (Ward-Booth and Dussart, 2001). However, it is the most efficient method for rapid inventory surveying as it yields many more specimens and many more species per unit of person-time than more intensive methods such as collecting litter for sorting in the laboratory (Emberton et al., 1996). It was similar to the approach adopted by Cowie (2001a), Cowie and Rundell (2002) and Cowie et al. (in press) in American Samoa. Almost all Samoan species are <10 mm in size, so any size-related sampling bias may not be great. Each station was searched for a period of at least 30 min by one or two people. Collections of up to five individuals of each species were made (except Partulidae and other rare endemics, which are readily identifiable

in the field and for which only single specimens were usually taken).

All material was deposited in the Bishop Museum (Honolulu) malacological collections (accession number 1996.263, catalogue numbers BPBM 251260, 251261, collected by A.C. Robinson; 1996.278, 263537-263546, P.W. Trail; 2001.101, 263259-263534, 263710, A.C. Robinson and collaborators; 2001.091, 263248-263256, R.H. Cowie). Identification was by reference to previously identified material in the Bishop Museum. The collections have been databased and a basic subset of the data for each lot is available on the Samoan Snail Project website (www2.bishopmuseum.org/PBS/samoasnail/).

3.2. Estimation of trends

There has been no previous assessment of the conservation status of the land snail fauna of [Western] Samoa. However, quantitative estimates of extent of distribution and abundance at the times of earlier surveys (pre-1965 but mostly 1920–1940) were obtained by querying the database of identified specimens in the collections of the Bishop Museum, where almost all the pre-1965 twentieth century survey material is held. The definition of rarity is difficult as it combines the concepts of abundance, which may be very localized, and commonness, which may mean being widespread but sporadically distributed and not necessarily occurring in large numbers locally (Cameron, 1998). Using the same approach as did Cowie (2001a) for American Samoa, we attempted to distinguish between these concepts, as follows. With regard to extent of distribution, if there were collection lots (a "lot" being a collection of one species made at one place at one time) from more than one island (taking into account both Samoa and American Samoa) or if the lots came from a wide range of localities on the island to which a particular species was endemic, that species was considered "widespread". If the collection lots came from only one island and from only a few localities, that species was considered "highly localized". Regarding abundance, if there were 500 or more lots, that species was considered "abundant"; 100 or more but fewer than 500, "common"; 50 or more but fewer than 100, "uncommon"; 10 or more but fewer than 50, "rare"; fewer than 10, "very rare". Necessarily, these assessments reflect the preferences of the original collectors in terms of collection localities, habitats, and species, but they are the best available data. For some species, there were no records in the database, suggesting that they were very rare even in the early twentieth century. The assessments were augmented by information from the primarily taxonomic literature dealing with the Achatinellidae (Cooke and Kondo, 1960), Pupillidae (Pilsbry, 1916–1918; Kirch, 1993), Endodontidae (Solem, 1976), Charopidae (Solem, 1983), and Helicarionidae (Baker, 1938, 1941), and from the very small amount of pre-1965 material in the Field Museum.

In 1965, Laurie Price and Alan Solem collected on Savai'i and 'Upolu. They surveyed 40 stations: 28 on 'Upolu (station numbers 1–26, 39, 40) and 12 on Savai'i (27–38). Their collections are in the Field Museum of Natural History (Chicago). Data for the worldwide pulmonate land snail collections of the Field Museum have been databased and are available on line (www.fmnh.org/research_collections/). Data for the Price/Solem Samoan pulmonate collections were therefore obtained from this on line database. Data for *Ostodes* (Poteriidae), not yet on line, were obtained from the revision of Girardi (1978), which was based on the Price/Solem material. Data for other operculate land snails and for Ellobiidae, also not yet on line, were obtained from the Field Museum collections. For each species, we recorded the number of stations at which it was found on each island. Locations of survey stations 1–38 are in Solem (1983, p. 291), station 39 in Girardi (1978, p. 217) and Solem (1983, p. 201), and station 40 in Girardi (1978, p. 227). Station information for Endodontidae is also in Solem (1976), Charopidae in Solem (1983), and *Ostodes* in Girardi (1978).

In 1967, Yoshio Kondo collected on Savai'i and 'Upolu (Cowie, 2001a). His survey was not a faunal-wide survey but focused almost exclusively on Partulidae. It is therefore not comparable with our 1992–1994 survey or with the historic surveys described above, and has not been used in our analysis.

Following the approach of Cowie (2001a), by qualitatively comparing the pre-1965 assessments of distribution and abundance and the data (number of stations at which each species was found) from the 1965 and 1992–1994 surveys, trends were assessed that reflect changes over almost the entire twentieth century. Species listed by Cowie (1998) but not included in these assessments were: those only known from American Samoa; those recorded only from "Samoa" (i.e. Samoa and/or American Samoa) with no island(s) specified; those recorded only questionably from [Western] Samoa; those that could not be identified definitively. Infraspecific names listed by Cowie (1998) were ignored.

4. Results

4.1. Composition of the fauna

Table 1 lists the species recorded during the 1992–1994 survey. It also provides the island distributions of species collected prior to the 1992–1994 survey, including those reported in the literature and hence listed by Cowie (1998), and those not previously reported in the literature but present in the Bishop Museum and/or Field Museum collections prior to 1992. It also lists the

Table 1
Land snail and slug species of Samoa (assessment of trends based on pre-1965 estimates of distribution and abundance, the 1965 survey of Price and Solem, and the 1992–1994 survey reported here)

Family and species[a]	Islands known from prior to the 1992–1994 survey[b]	Status pre-1965[c]	Island(s) and number of stations in 1965[d]	Island(s) and number of stations in 1992–1994[e]	Trend	Origin[f]
Helicinidae						
Orobophana musiva (Gould, 1847)	S U	Widespread/common	S 2, U 8	S 1, U 1	Decline	Indigenous
Pleuropoma sp.[g]	S U	Widespread/common	S 1, U 4	S 3, U 2	–	Endemic/indigenous
Pleuropoma altivaga (Ancey, 1889)	U	Highly localized/very rare	U 2	U 1	Unknown	Endemic
Pleuropoma beryllina (Gould, 1847)[h]	S† U	Widespread/abundant	S† 1, U 2	S 8, U 8, Nt† 2	Possible increase	Indigenous
Pleuropoma jetschini (Wagner, 1905)	U	Not recorded	Not recorded	Not recorded	Unknown	Indigenous
Pleuropoma fulgora (Gould, 1847)	S U	Widespread/abundant	S 9, U 26	S 15, U 11, Nt† 1, Nl† 1	Possible decline	Indigenous
Pleuropoma plicatilis (Mousson, 1865)	S U	Widespread/uncommon	S 11, U 22	S 3, U 9	Possible decline	Endemic
Neocyclotidae[i]						
Ostodes sp.[j]	S U	Widespread/rare	–	S 14, U 6	–	Endemic
Ostodes cookei Clench, 1949	U	Highly localized/very rare	Not recorded	Not recorded	Unknown	Endemic
Ostodes exasperatus Girardi, 1978	S U	Unknown	S 1, U 1	Not recorded	Unknown	Endemic
Ostodes garetti Clench, 1949	S	Highly localized/very rare	S 1	Not recorded	Unknown	Endemic
Ostodes gassiesi (Souverbie, 1859)	S U	Unknown	S 5, U 17	Not recorded	Possible decline	Endemic
Ostodes llanero Girardi, 1978	S	Unknown	S 2	Not recorded	Unknown	Endemic
Ostodes plicatus (Gould, 1847)	S† U	Widespread/uncommon	U 6	U 4	No clear trend	Endemic
Ostodes reticulatus Girardi, 1978	U	Unknown	U 9	Not recorded	Possible decline	Endemic
Ostodes savaii Clench, 1949	S U	Widespread/rare	S 6, U 13	Not recorded	Decline	Endemic
Ostodes tiara (Gould, 1847)	U	Widespread/very rare	U 7	S† 2, U 5	No clear trend	Endemic
Ostodes upolensis (Mousson, 1865)	S U	Widespread/rare	S 1, U 8	U 1	Possible decline	Endemic
Diplommatinidae						
Diplommatina problematica (Mousson, 1865)	S† U	Widespread/very rare	Not recorded	Not recorded	Possible decline	Endemic
Truncatellidae						
Truncatella guerinii Villa & Villa, 1841	S U†	Widespread/rare	U 1	Nl† 1	Unknown	Indigenous
Assimineidae						
Assiminea crosseana (Gassies, 1869)	U	Not recorded	Not recorded	Not recorded	Unknown	Indigenous
Assiminea parvula (Mousson, 1865)[k]	S† U	Widespread/abundant	U 2	Not recorded	Decline	Indigenous
Assiminea similis (Baird, 1873)	U	Not recorded	Not recorded	Not recorded	Unknown	Indigenous
Omphalotropis sp.[l]	S U	Widespread/common	S 8, U 3	S 9, U 2	–	Endemic/indigenous
Omphalotropis bifilaris Mousson, 1865	S† U	Highly localized/very rare	S† 1, U 1	Not recorded	Unknown	Endemic/indigenous
Omphalotropis biliratus Mousson, 1865	S U	Highly localized/very rare	U 1	Not recorded	Unknown	Endemic/indigenous
Omphalotropis conoideus Mousson, 1865	S U	Highly localized/very rare	S 7, U 1	S 9, U 1	No clear trend	Endemic/indigenous
Veronicellidae						
Laevicaulis alte (Férussac, 1822)	U	Not recorded	U 1	Not recorded	Unknown	Alien
Vaginulus plebeius Fischer, 1868	U	Highly localized/very rare	Not recorded	S† 2	Increase	Alien
Unidentified Veronicellidae	–	Not recorded	Not recorded	S 1	–	Alien
Ellobiidae						
Auriculastra subula (Quoy & Gaimard, 1832)	U	Highly localized/very rare	Not recorded	Not recorded	Unknown	Indigenous
Ellobium semisculptum Adams & Adams, 1854	U	Not recorded	Not recorded	Not recorded	Unknown	Indigenous
Melampus spp.[m]	S U	Widespread/common	U 1	U 2, Nt† 1, Nl† 1	Unknown	Indigenous
Allochroa layardi (Adams & Adams, 1855)	U	Highly localized/very rare	Not recorded	Not recorded	Unknown	Indigenous
Cassidula sp.[n]	U	Highly localized/very rare	Not recorded	Not recorded	–	Indigenous
Cassidula crassiuscula Mousson, 1869	U	Not recorded	Not recorded	Not recorded	Unknown	Indigenous
Cassidula paludosa (Garrett, 1872)	U	Not recorded	Not recorded	Not recorded	Unknown	Indigenous
Pythia sp.[o]	Nt†	Highly localized/very rare	Not recorded	–	–	Indigenous
Pythia savaiensis Mousson, 1869[o]	S	Not recorded	Not recorded	Not recorded	Unknown	Indigenous
Pythia scarabaeus (Linnaeus, 1868)	–	Widespread/rare	Not recorded	S† 2, Nt† 1, Nl† 1	Probably no change	Indigenous
Pythia tortuosa Mousson, 1871[o]	U S†	Highly localized/very rare	Not recorded	Not recorded	Unknown	Indigenous

(*continued on next page*)

Table 1 (*continued*)

Family and species[a]	Islands known from prior to the 1992–1994 survey[b]	Status pre-1965[c]	Island(s) and number of stations in 1965[d]	Island(s) and number of stations in 1992–1994[e]	Trend	Origin[f]
Achatinellidae						
Lamellidea sp(p).[p]	U	Widespread/uncommon	1	Not recorded	Possible decline	Cryptogenic
Elasmias sp.	U	Widespread/rare	<10	Not recorded	Possible decline	Cryptogenic
Pupillidae						
Gastrocopta pediculus (Shuttleworth, 1852)[q]	U	Widespread/uncommon	Not recorded	Not recorded	Decline	Cryptogenic
Nesopupa godeffroyi (Boettger, 1881)[r]	S† U†	Widespread/uncommon	U 1	Not recorded	Decline	Endemic
Pupisoma orcula (Benson, 1850)[s]	U†	Widespread/rare	Not recorded	Not recorded	Decline	Cryptogenic
Partulidae						
Eua expansa (Pease, 1871)	S U	Widespread/uncommon	S 7, U 10	S 10, U 2	Possible decline	Endemic
Eua montana (Cooke & Crampton, 1930)	U	Highly localized/very rare	U 3	U 4	Unknown	Endemic
Samoana canalis (Mousson, 1865)[t]	S U	Widespread/uncommon	S 9, U 7	S 5, U 2	Possible decline	Endemic
Samoana stevensoniana (Pilsbry, 1909)	S U	Widespread/rare	S 10, U 3	S 2	Decline	Endemic
Subulinidae						
Allopeas gracile (Hutton, 1834)	S† U	Widespread/common	U<3	Nl† 1	Decline	Polynesian introd.
Opeas hannense (Rang, 1831)	U	Widespread/common	U 2	Not recorded	Decline	Alien
Paropeas achatinaceum (Pfeiffer, 1846)	S† U†	Widespread/abundant	S 11, U 20	S 16, U 15, Nt† 1	No clear trend	Alien
Subulina octona (Bruguière, 1789)	S† U†	Widespread/abundant	S 7, U 13	S 12, U 12, Nt† 2, Nl† 1	No clear trend	Alien
Achatinidae						
Achatina fulica Bowdich, 1822	U	Not recorded	Not recorded	Not recorded	Increase	Alien
Rhytididae						
Ouagapia gradata (Gould, 1846)	S U	Widespread/common	S 1, U 11	Not recorded	Decline	Indigenous
Plectopylididae						
Corilla carabinata (Férussac, 1821)	U	Highly localized/very rare	Not recorded	Not recorded	Unknown	Alien
Endodontidae						
Thaumatodon hystricelloides (Mousson, 1865)[u]	U	Widespread/common	U 3	Not recorded	Decline	Endemic
Charopidae[v]						
Graeffedon graeffei (Mousson, 1869)	U	Highly localized/very rare	U 1	Not recorded	Unknown	Endemic
Graeffedon savaiiensis Solem, 1983	S	Highly localized/very rare	Not recorded	Not recorded	Unknown	Endemic
Sinployea allecta (Cox, 1870)	S U	Widespread/very rare	S 2, U 3	Not recorded	Possible decline	Endemic
Sinployea clista Solem, 1983	U	Widespread/very rare	U 2	Not recorded	Possible decline	Endemic
Sinployea complementaria (Mousson, 1865)	U	Unknown/very rare	U 8	Not recorded	Possible decline	Endemic
Succineidae						
Succinea crocata Gould, 1846	U	Widespread/rare	U 1	U 2	Possible decline	Endemic
Succinea modesta Gould, 1846[w]	U	Widespread/uncommon	Not recorded	S† 5, U 1	No clear trend	Endemic
Succinea putamen Gould, 1846	U	Widespread/rare	U 2	S† 4, U 7	No clear trend	Endemic
Helicarionidae[x]						
Diastole sp.	–	–	–	S 2, U 2	–	Endemic/indigenous
Diastole lamellaxis Baker, 1938	S	Highly localized/rare	Not recorded	S 1	Unknown	Endemic
Diastole savaii Baker, 1938	S	Highly localized/rare	S 1	Not recorded	Unknown	Endemic
Diastole schmeltziana (Mousson, 1865)	S U	Widespread/common	S 8, U 20	U 1	Possible decline	Endemic
Lamprocystis perpolita (Mousson, 1869)	S U	Highly localized/very rare	S 1, U 1	Not recorded	Unknown	Endemic
Lamprocystis upolensis (Mousson, 1865)	S U	Widespread/very rare	Not recorded	Not recorded	Possible decline	Indigenous
Liardetia samoensis (Mousson, 1865)	S† U	Widespread/common	S† 1, U 4	Not recorded	Decline	Indigenous
Ariophantidae						
Parmarion martensi Simroth, 1893	U	Not recorded	Not recorded	U 4	Increase	Alien
Zonitidae						
Trochomorpha sp.	–	–	–	U 1, Nt† 1	–	Endemic

(*continued on next page*)

Table 1 (*continued*)

Family and species[a]	Islands known from prior to the 1992–1994 survey[b]	Status pre-1965[c]	Island(s) and number of stations in 1965[d]	Island(s) and number of stations in 1992–1994[e]	Trend	Origin[f]
Trochomorpha apia (Hombron & Jacquinot, 1852)	S U	Widespread/common	U 1	S 8, U 2	Probable decline	Endemic
Trochomorpha samoa (Hombron & Jacquinot, 1841)	U	Not recorded	Not recorded	Not recorded	Unknown	Endemic
Trochomorpha troilus (Gould, 1846)	S U	Widespread/rare	U 1	S 2, U 6	No clear trend	Endemic
Trochomorpha tuber Mousson, 1869	U	Highly localized/very rare	Not recorded	Not recorded	Unknown	Endemic
Bradybaenidae						
Bradybaena similaris (Rang, 1831)	S U	Widespread/uncommon	S 3, U 5	S 10, U 9	Possible increase	Alien

[a] Taxonomic arrangement and nomenclature follow Cowie (1998).

[b] S, Savai'i; U, 'Upolu; Nt, Nu'utele; Nl, Nu'ulua. Islands from which the species were previously known, as given by Cowie (1998), and, indicated by a dagger, species not reported by Cowie (1998) but for which there are specimens in the Bishop Museum and/or Field Museum collected prior to the 1992–1994 survey (i.e. new published records for the island).

[c] Based on Bishop Museum collections, augmented by Field Museum collections and literature. For explanation of terms used in these assessments, see the section on trends in the methods section.

[d] The Price/Solem 1965 survey. Islands (abbreviated as above) and number of stations at which the species was found; if no island abbreviation is given, this information is lost. Newly published island records indicated by a dagger (†).

[e] The 1992–1994 survey. Data presented as for the Price/Solem survey.

[f] Biogeographic origin from Cowie (1998). Endemic, occurs only in the Samoan islands (Samoa, American Samoa); indigenous, occurs naturally in the Samoan islands and elsewhere; cryptogenic, unclear whether native or alien in the Samoan islands; Polynesian introd, introduced prior to European discovery of the Samoan islands; alien, introduced subsequent to European discovery of the islands.

[g] The taxonomy of Samoan helicinids is in need of revision; much material in the Bishop Museum and from the present survey is hence only referable to *Pleuropoma* sp.

[h] Tentatively identified. May be *Pleuropoma jetschini* or a mixture of *P. beryllina*, *P. jetschini*, and perhaps an undescribed species. However, may be one variable species and these may be synonyms (see Cowie, 2001a). Perhaps also the reason *P. jetschini* has never been recorded since its original description.

[i] Assessments based on Clench (1949) and Girardi (1978) as well as the Bishop Museum database.

[j] *Ostodes* species are highly variable and difficult to identify, with some species not described until 1949 and 1978. Hence, much early material as well as some of the present material has only been referred to *Ostodes* sp. The record of *Ostodes strigatus* from 'Upolu in the Bishop Museum database (catalog number BPBM 193) is considered in error, following Clench (1949), Girardi (1978) and Cowie (1998).

[k] *Assiminea crosseana* and *A. similis* may be synonyms of *A. parvula* [the commonly used *Assiminea nitida* (Pease, 1865) is also a synonym]; alternatively, some specimens may have been incorrectly referred to *A. parvula*. The record of *A. parvula* from Savai'i is based on a single collection lot (BPBM 108317) referred to *Assiminea* sp. in the Bishop Museum database. The pre-1965 assessments of *A. parvula* are based largely on lots referred to *Assiminea* sp. in the database.

[l] The taxonomy of Samoan *Omphalotropis* is in need of revision and the species are difficult to identify. Very few specimens in the Bishop Museum have been identified to species, which probably explains the "highly localized/very rare" assessment for the three named species. Most of the Price/Solem 1965 material was only tentatively referred to *Omphalotropis conoideus*. The Price/Solem record of *O. bifilaris* fom Savai'i is of the subspecies *teretiformis* Mousson, 1869. Determining these species' status as endemic or indigenous depends on future revision.

[m] Because the various species of *Melampus* are difficult to distinguish and much of the material in the Bishop Museum collections is identified only as *Melampus* sp., all records of species of *Melampus* are combined (cf. Cowie, 2001a). They include: *Melampus castaneus* (Megerle von Mühlfeld, 1816) (reported in [Western] Samoa from 'Upolu; no specimens in the Bishop Museum database), *Melampus fasciatus* (Deshayes, 1830) (Savai'i and 'Upolu; one pre-1965 specimen lot only, from American Samoa), *Melampus luteus* (Quoy & Gaimard, 1832) ('Upolu; five pre-1965 lots, from American Samoa), *Melampus philippii* (Küster, 1845) ('Upolu; one lot, from American Samoa), *Melampus semisulcatus* Mousson, 1869 (Savai'i and 'Upolu; no specimens), *Melampus striatus* Pease, 1861 ('Upolu; no specimens).

[n] Probably referable to either *Cassidula crassiuscula* or *C. paludosa*, which may be synonyms.

[o] Probably *Pythia scarabaeus*.

[p] Records of *Lamellidea oblonga* (Pease, 1865) and *Lamellidea pusilla* (Gould, 1847), both recorded from American Samoa and widespread in the Pacific, have been combined. They may not be distinct species and many records may be misidentifications.

[q] Assessments based on Bishop Museum database records of *Gastrocopta* sp. and *G. pediculus* combined.

[r] Assessments based on Bishop Museum database records of *Nesopupa* sp. and *N. godeffroyi* combined, and of the single Field Museum database record of *Nesopupa* sp.

[s] Assessments based on Bishop Museum database records of *Pupisoma* sp. and *P. orcula* combined.

[t] The few records of *Samoana conica* (Gould, 1847) from 'Upolu, which is otherwise known only from American Samoa, may be misidentifications of *S. canalis*, or the two may be synonyms (see Cowie, 1998). *S. conica* is omitted from this treatment.

[u] Assessment based on Solem (1983, p. 455), referring to the 1860s and 1870s. An assessment based only on Bishop Museum collections would be "highly localized/very rare".

[v] Assessments based on Solem (1983) as well as the Bishop Museum database.

[w] Many specimens are listed as *Succinea* sp. in the Bishop Museum database. Those from the main islands (i.e. excluding the Manu'a islands) are considered mostly to be referable to *S. modesta*.

[x] The single Bishop Museum database record of *Lamprocystis unisulcata* (Mousson, 1865) (catalog number BPBM 115365) is ignored, pending further study. This species was only tentatively considered Samoan by Baker (1938) and this may be a misidentification.

species collected by Price and Solem in 1965. From these combined sources, the total number of land snail (and slug) species recorded from Samoa is 72 (a slight under-counting because all *Melampus* spp. were counted as one species). Of these, 58 are native (35–38 endemic to the Samoan islands); one is a Polynesian, pre-European introduction; nine are more recent introductions; and four are cryptogenic (of unknown native or alien origin—Carlton, 1996).

Review of pre-1992 collections in the Bishop Museum (and the very small amount of pre-Price/Solem 1965 material in the Field Museum) resulted in 14 new island records for 11 species (including those listed as "sp." only if they represented a new island record for the genus); these new island records included new records for [Western] Samoa for four species:*Pupisoma orcula* (cryptogenic; also in American Samoa and recorded by Cowie, 2001a), *Nesopupa godeffroyi* (endemic to the archipelago; also in American Samoa), *Paropeas achatinaceum* (alien), *Subulina octona* (alien) (both these latter two species also in American Samoa, in great abundance, and recorded by Cowie, 2001a).

Records of much of the Price/Solem 1965 material have never been published. Their records of *Pleuropoma beryllina*, *Omphalotropis bifilaris* (as subspecies *teretiformis*) and *Liardetia samoensis* are the first records of these species for Savai'i.

The 1992–1994 survey recorded at least 29 species (all *Melampus* spp. combined as one). Of these, 23 were native and six were alien (including the single Polynesian introduction). A single species (*Pythia scarabaeus*) was recorded from [Western] Samoa for the first time, although previous records of other *Pythia* species are probably referable to this species. The known distributions of 13 species were increased (18 new island records).

4.2. Trends

Differences in locations and methods between our 1992–1994 survey and previous surveys preclude truly rigorous comparison. However, these data are the best available and some probably reliable overall trends can indeed be detected.

Our qualitative evaluations of the changes in distribution and/or abundance of the species during the twentieth century are presented in Table 1. Overall, 12 species appear to have declined. Of these, the majority (eight) are native species, and two are cryptogenic. An additional 17 species (15 native, two cryptogenic) show a "probable decline" or "possible decline". Five species (four alien, one native) appear to have increased or possibly increased. For species that appeared extremely rare even in the early twentieth century and that were collected in low numbers or not at all in the 1965 and 1992–1994 surveys a clear assessment is not possible and any change in distribution/abundance is stated as "unknown". Some species that were widespread and in some cases abundant early in the twentieth century, and remain so, show "no clear trend"; for some we can make a tentative assessment of "probably no decline" or "probably no change".

Some species remain relatively common on Savai'i but appear to have declined on 'Upolu (e.g. *Omphalotropis conoideus*, *Trochomoprha apia*). Some native species (e.g. *Ostodes tiara*, *Succinea crocata*, *S. putamen*, *Trochomorpha troilus*) also appear to remain more common at higher elevations, while some of the aliens are more common at lower elevations (e.g. *Subulina octona*, *Laevicaulis alte*).

5. Discussion

5.1. The fauna

The native land snail fauna of the Samoan islands as listed by Cowie (1998) with additional records by Cowie (2001a) and Cowie et al. (in press) included 99 native species. Of these, 64 are known from Samoa and 47 from American Samoa (some are common to both). Table 1 lists only 58 native species in Samoa because a number of nomenclaturally valid but unidentifiable species (two helicinids and an assimineid) and a possible misidentification (*Samoana conica*) have been omitted, the six nominal species of *Melampus* have been combined as "*Melampus* spp.", but three native species are recorded for the first time (*Pleuropoma beryllina*, *Pythia scarabaeus*, *Nesopupa godeffroyi*). The native fauna of Samoa is thus approximately 30% more speciose than that of American Samoa, possibly because the total land area of Samoa is much greater and because the two large islands ('Upolu, Savai'i) are much larger than the single large island of American Samoa (Tutuila).

The non-native faunas also differ. The combined records of Cowie (1998, 2001a), Cowie and Rundell (2002), Cowie et al. (in press), and the present report, give totals of 20 alien species (plus seven cryptogenic species) in American Samoa but only 10 (plus four cryptogenic) in Samoa. Thus, not only do the numbers of species in Samoa and American Samoa differ but the proportions of native to alien (including cryptogenic) species are radically different. Of the total fauna of Samoa, 21% (14 of 72) of the species are alien/cryptogenic, whereas in American Samoa this figure is 36% (27 of 74). This difference is statistically significant (log-likelihood G-test, $G = 5.288$, 1 d.f., $P = 0.021$). It may be a reflection of the much larger areas in Samoa that remain relatively unspoiled compared with American Samoa, which in turn reflects the human population pressure: the most recent figures available (Dahl, 1991) are 54 people per km^2 in Samoa (1986 data), 172 per km^2 in American Samoa (1982 data).

5.2. Status of the species and threats to them

Fewer alien species have been recorded in Samoa than in American Samoa, but the trends are similar in both. Alien species appear to be increasing; native species are declining. In Samoa, as in American Samoa (Cowie, 2001a), these apparent trends seem convincing despite the limitations of the various surveys and the impossibility of drawing quantitative conclusions based on carefully replicated data.

For a number of species we could make no evaluation or could identify no clear trend. In many cases these were native species that had probably declined long ago (even before the early twentieth century surveys) and that may be extinct (e.g. Endodontidae, Charopidae) (see also Solem, 1976, 1983), or alien species that were introduced long ago and were already widespread and abundant by the early twentieth century (e.g. some of the Subulinidae).

Partulid tree snails in particular have achieved renown among Pacific island non-marine snails as being especially vulnerable (e.g. Gould, 1991); they have received more attention than any other group (e.g. Cowie, 1992; Johnson et al., 1993; Coote, et al., 1999; Goodacre and Wade, 2001); and have been termed the flagships of terrestrial invertebrate conservation in the Pacific (Cowie and Cook, 2001). Partulids are endemic to the islands of the Pacific, and most species occurr on only one island or within a single archipelago (Cowie, 1992). The four partulid species of Samoa could still be found in 1992–1994, as could the partulids of American Samoa in 1998 (Cowie and Cook, 2001). At least on Savai'i, *Eua expansa* remains fairly widespread, although it may have declined on 'Upolu. *E. montana* is an upper elevation species that has never been considered common. *Samoana canalis* remained in a number of localities, though it was not abundant and may be declining. *S. stevensoniana* has probably declined since 1965. Overall, the Samoan partulids are probably declining and are certainly threatened, as are partulids elsewhere (including in American Samoa).

Two other species deserve mention. The native helicinid *Pleuropoma beryllina* remains widespread and abundant, as it does in American Samoa, where it was the most numerous species collected in the recent survey (Cowie, 2001a). However, whereas in American Samoa the native helicarionid *Diastole schmeltziana* was considered stable or even increasing (Cowie, 2001a), it seems to have declined dramatically in Samoa, based on the 1965 to 1992–1994 comparisons (Table 1). Even if unidentified *Diastole* sp. records are assumed to represent *D. schmeltziana*, the trend remains. This contrast is unexplained.

The apparent scarcity of Ellobiidae and Truncatellidae in 1965 and 1992–1994 probably reflects undersampling of their supralittoral habitat, rather than real declines, although some of these species, while widespread, are naturally sparsely distributed.

No doubt the reasons underlying these changes in the fauna are similar in both American Samoa and Samoa (as well as elsewhere throughout the Pacific) and include: habitat modification, as a result of both invasion of alien plants and more direct destruction resulting from human development (agriculture, logging, urban expansion); possible competitive interactions between native and alien species, although this remains speculative; and predation by alien species. Cowie (2001a) discussed these threats more fully.

One of these threats, however, is of particular significance. Introduction of the giant African snail (*Achatina fulica*) to 'Upolu during the 1990s (not recorded in the 1992–1994 survey) poses perhaps the greatest immediate threat to the native Samoan fauna. Its introduction in 1977 to American Samoa (at present only on Tutuila and Ta'ū) led to the introduction of the predatory snail *Euglandina rosea* (and perhaps other predatory snail species) as an ill-considered putative biological control agent. The efficacy of *E. rosea* as a biocontrol agent has not been demonstrated (Cowie, 2001b), but it is now a serious threat to the native snail fauna. Elsewhere in the Pacific it has caused or been seriously implicated in the extinction of many native snail species (e.g. Murray et al., 1989; Hadfield, 1986; Cowie, 1992; Hopper and Smith, 1992; Hadfield et al., 1993; Civeyrel and Simberloff, 1996; Coote et al., 1999). As yet, it has not been introduced to Samoa. However, a perhaps even more serious snail predator, the flatworm *Platydemus manokwari*, has recently been introduced and is being reared in Samoa with the prospect of dispersing it widely as a control agent against *A. fulica* (Cowie, 2002b). *P. manokwari* has been seriously implicated in the decline of native snails elsewhere in the Pacific (Hopper and Smith, 1992).

5.3. Conclusion

The overall trend in Samoa is of decline of the native land snail fauna and its replacement by alien snail species, as is the case throughout the Pacific (Cowie, 2002a). However, this trend may be less dramatic in Samoa than in American Samoa. Furthermore, within Samoa, the fauna seems to be faring better on Savai'i than on 'Upolu, which probably reflects 'Upolu's smaller size, lower maximum elevation, and greater human population pressure. Nonetheless, there is no cause for complacency. The giant African snail (*Achatina fulica*) is now established on 'Upolu and efforts underway to control it could have serious consequences for the native snail fauna (see above). As yet, *A. fulica* is not on Savai'i, but should it get there, the temptation to introduce *P. manokwari* will be strong.

The native land snail faunas of Pacific islands exhibit high levels of endemism and diversity. However, they are

perhaps the most vulnerable members of these island biotas (Paulay, 1994). Extinction rates are dramatic. For instance, of Hawaii's over 750 species (Cowie, 1996a), 75% (Solem, 1990) or as many as 90% (R.H. Cowie, unpublished) are extinct. In the Ogasawara Islands 40% of the 114 species have become extinct since the 1860s (Tomiyama and Kurozumi, 1992). On Rota (Northern Marianas) 68% of the 43 species are extinct or declining (Bauman, 1996). All the Partulidae of Moorea (French Polynesia) are extinct in the wild (Murray et al., 1989).

The native snail fauna of Samoa, although declining, does not seem to be quite so imminently endangered. These species therefore deserve special attention because we now have an opportunity to preserve an important component of the Pacific island biota and perhaps prevent these species from going the way of many of the other unique Pacific island land snails. In particular, efforts must be made to discourage the further introduction and spread of alien predators.

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