Introduced land snails in the Fiji Islands: are there risks involved?

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Abstract Fiji's land snail fauna is highly diverse. There are over 230 species of which about 90% are native and 78% are endemic to the archipelago. There are 18 introduced species and four that are of uncertain origin within the Pacific. Information to allow easy identification of these species is lacking, as is related information about the risks involved with the introduced species in respect to trade, crop production or human and livestock health. To address this latter information gap, existing and new data on Fiji's introduced land snail fauna were collated. This information is urgently required to identify and manage introduced and potentially invasive species and if possible to prevent their spread to non-infected islands. Other Pacific Island countries and territories have suffered substantial endemic land snail biodiversity loss, particularly because of invasive snail species that are not yet present in Fiji. Except for one of these latter species, the giant African snail (*Achatina* (*Lissachatina*) *fulica*), the Fiji government authorities have no baseline reference material that allows them to quickly and accurately identify and understand the biology of even the most common introduced snails. If not addressed this lack of information may have major long-term implications for agriculture, quarantine, trade and human health. The alien species already introduced to Fiji are spreading unacknowledged despite several of them being known disease vectors and agricultural pests elsewhere. This paper provides collated land snail information to government departments such as agriculture, quarantine, forestry and environment, and in turn provides a platform on which to build a stronger understanding of how introduced snail species may be impacting trade, agricultural production and human and livestock health in Fiji.

Keywords: Mollusc, gastropod, slug, Pacific Islands, *Parmarion martensi*, invasive

INTRODUCTION

The land snail fauna of the south Pacific islands of Fiji is unique and highly diverse. Over 230 species are recorded, of which 22 are non-native. About 90% of the fauna is native and 78% are endemic to the archipelago (Barker *et al*. 2005). Information to allow easy identification of species is lacking, as is collated information about the risks non-native species pose to trade, crop production or human and livestock health (Brodie 2009a). Many of the non-native species are known agricultural pests and parasite vectors elsewhere in the world. Collated information is urgently required to detect and adequately manage non-native species, and if possible to prevent the spread of invasive species to non-infected islands.

Pacific Island countries and territories such as Samoa, New Caledonia, French Polynesia and Hawaii (Fig. 1) have lost much of their endemic land snail biodiversity (Bouchet and Abdou 2003; Brescia *et al*. 2008; Cowie and Robinson 2003; Hadfield 1986), in some cases following the introduction of invasive snail species that are not yet established in Fiji. Two such examples are the "rosy wolf snail" (*Euglandina rosea*) and the giant African snail (*Achatina* (*Lissachatina*) *fulica*). Except for the latter species, Fijian government agencies have very little baseline reference material that allows quick and accurate identification of snails. This even applies to the most common introduced terrestrial snails located close to the well established port area of the capital Suva, on the largest island, Viti Levu (Fig. 2). Fijian government agencies also have relatively little collated biological information which could be used to make management decisions or implement monitoring programmes in relation to any of the currently introduced land snail species. If not addressed this lack of information may have major long-term implications for agriculture, quarantine, international trade, and livestock and human health in Fiji.

This current paper is part of a larger plan by the authors to provide direct land snail identification assistance to sectors of the Fiji government such as agriculture, quarantine, forestry and environment, and to improve understanding of how introduced land snail species may impact biodiversity, economic costs and human health in the Fiji Islands. In turn, collation of this information will also allow estimates of the potential impact of these alien intruders on Fiji's established trading partners. In addition, the current paper addresses a broader acknowledged

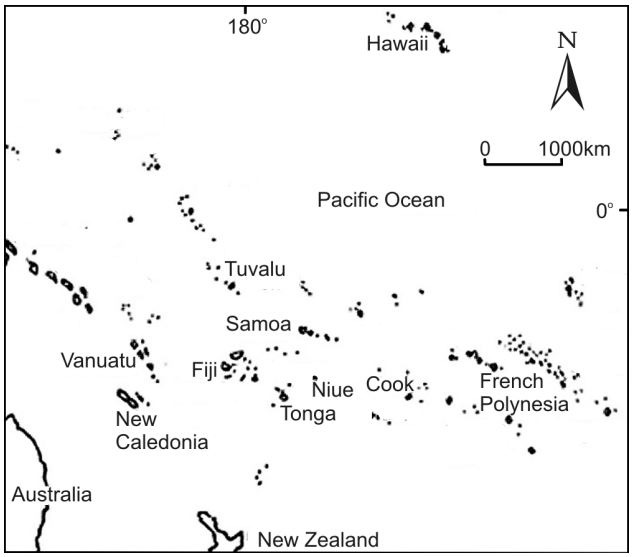

Fig. 1 Fiji's location in the Pacific showing neighbouring islands.

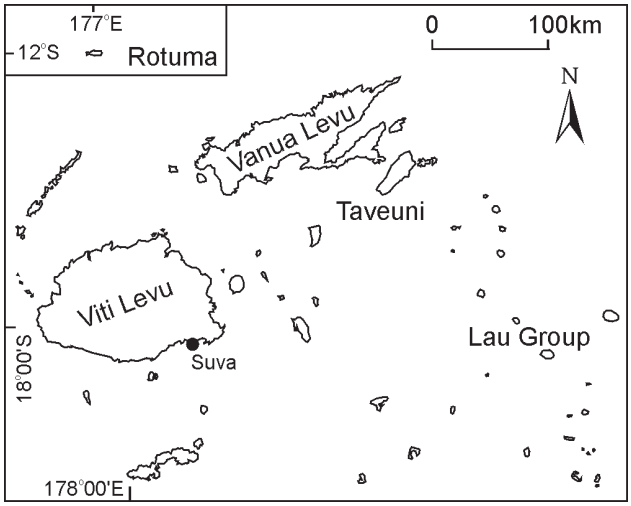

Fig. 2 The Fiji Islands showing the location of the capital city Suva and the islands of Viti Levu, Taveuni and Rotuma. The Lau Group includes all of the small islands in the southeast of the archipelago.

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need to fill major information gaps on the distribution of introduced land snails in the Pacific Islands region (Sherley 2000).

MATERIALS AND METHODS

We compiled a checklist of land snails introduced to Fiji using the results of surveys in many forest areas and villages throughout the archipelago to 2005 (Barker *et al*. 2005; Barker, unpublished data) and in 2008 - 2010 on Viti Levu (Brodie 2009b; Brodie and Copeland in press; Mila *et al*. 2010) and Taveuni (Brodie unpublished data). By combining the above results with our expert knowledge and additional published reports on aspects of distribution, biology, ecology, and "pest" status, we added to our checklist an estimated risk level for each species. Risk level was identified as low, medium or high depending on our estimate of their potential to inflict biodiversity loss, affect agricultural production, and/or impact on human or livestock health in Fiji.

The term 'land snail' as a common name is used in preference to distinguishing 'snails' and 'slugs'.

RESULTS

Eighteen species of introduced land snails from nine families are currently known from the Fiji Islands (Table 1). This total excludes the widespread Pacific Achatinellidae *Elasmias apertum*, *Lamellidea pusilla*, *Lamellidea oblonga* and Helicarionidae *Liardetia samoensis* for which precise origins within the Pacific are uncertain.

The feeding types and diets of the introduced species range from herbivores on fresh plant material, detritivores feeding on dead plant material, to carnivorous predators (Table 1). Our data suggest that the introduced *Streptostele musaecola*, *Bradybaena similaris*, and *Deroceras laeve* are restricted to areas of human habitation or disturbance. The remaining species are found in both disturbed and relatively undisturbed habitats and must be considered "invasive". Of these, nine species are considered here as low risk, three low-medium risk and five medium-high risk (Table 2). One species, *Parmarion martensi* (Fig. 3), stands out as very high risk and very invasive because of its hardy nature, active climbing behaviour, close association with local crops and common presence in virtually all sheltered habitats investigated, including the significant forest conservation areas of Nakauvadra, Nakorotubu and Taveuni. While the presence of *P. martensi* is long-known from Fiji's lowland to mid-altitude areas, recent surveys by the first author indicate invasion into relatively undisturbed high altitude areas (i.e., Taveuni, > 800 m) that are vitally important for overall ecosystem function and the conservation of endemic biodiversity.

Fig. 3 *Parmarion martensi* on decaying pumpkin in a suburban Suva garden. Photo: G. Brodie.

DISCUSSION

Although many papers have been published about land snails in Fiji over the last 100 years (see review of Barker *et al*. 2005), this is the first to focus on non-native species in the archipelago. The 18 species listed here include several of the expected widespread tropical "tramp" species that are thought to be replacing Pacific Island native/endemic mollusc fauna (Cowie 2004). There is also considerable overlap with the introduced land snail assemblage reported by Cowie (2001) and Cowie and Robinson (2003) in the neighbouring Samoan Islands, but a much lower number of introduced species than the more than 53 species recorded in Hawaii (Cowie 1998; Cowie *et al.* 2008).

Unlike the neighbouring islands of New Caledonia, Vanuatu and Samoa, but like Tonga, Niue and the Cook Islands, Fiji lacks two of the world's worst invasive land snail species: *Achatina* (*Lissachatina*) *fulica* and *Euglandina rosea*. *Achatina fulica* is a direct economic threat to agricultural production and human and livestock health (Boray 1998; Lowe *et al.* 2004; Raut and Barker 2002), while *E. rosea* poses severe ecological threat by its potential voracious predation on native land snails (Cowie 2001, 2004; Lowe *et al.* 2004).

The risks posed by these two invasive species to Fiji emphasize the need for biosecurity measures to conserve the country's distinctive and diverse endemic land snail fauna. Lydeard *et al*. (2004) highlighted the global and regional importance of Pacific Island land snail fauna, while Sherley (2000) stressed that "prevention of entry, rather than later control, is the most important means of stopping the spread [and therefore effect] of pest snails".

In a Fijian context, discussion of the exceptional need for high-level quarantine vigilance is timely, primarily because of the recent nomination of the island of Rotuma (Fig. 2 inset) as a "Port of Entry" for Fijian shipping and trade, but especially agricultural crops. Like many remote islands in the Fijian archipelago, Rotuma has a distinctive land snail fauna (Barker *et al*. 2005; Brodie *et al*. 2010). To the best of our knowledge, no recent survey of introduced land snails has been undertaken either in Rotuma or its intended primarily agricultural trading partner, Tuvalu. In this context the presence or absence of high-risk *Parmarion martensi* in Rotuma and/or Tuvalu is of great interest, not only because of human health concerns and the invasive nature of *P. martensi* in other parts of Fiji, but because the species is also not yet recorded in several countries with which Fiji currently trades, such as Australia, New Zealand and the mainland USA.

Our reporting of *P. martensi* from at least three of the 13 priority forest conservation areas identified on the Fijian islands of Viti Levu and Taveuni (see Olson *et al*. 2009) makes protection of the smaller, more isolated, priority conservation areas like Rotuma an even higher priority.

At least seven of the introduced land snail species found in Fiji act as vectors for parasitic helminthes (Table 2), such as the rat lung worm *Angiostrongylus cantonensis*, which is associated with eosinophilic meningitis in humans (Boray 1998; Hollyer *et al*. 2010). *Angiostrongylus cantonensis* and eosinophilic meningitis are already established in Fiji (Alicata 1962; Sano *et al*. 1987; Paine *et al*. 1994; Uchikawa *et al*. 1984). A recent study of *Parmarion* cf. *martensi* in Hawaii (Hollingsworth *et al*. 2007) identified its role in spreading *A. cantonensis* through an association with poorly washed home-grown crops, such as lettuce. The parasite has a high infection rate and the vigorous climbing behaviour of *P. martensi* makes it much more likely to come into contact with humans (and their food or water sources) than any of the other known vectors. However, the presence of *A. cantonensis* in Fijian *P. martensi* has not yet been confirmed.

Table 1 List of Fiji's introduced land snail species with feeding type and habitat. Feeding ecology, secondary/minor trophic relations indicated in parentheses.

Species	Feeding ecology	Habitat	References
Agriolimacidae			
Deroceras laeve	Herbivore, detrit. (carnivore)	Highland interior, in modified areas, including gardens, and forest margins.	Smith and Stanisic 1998; Barker 1999; Barker and Efford 2004
Ariophantidae			
Parmarion martensi	Herbivore, detritivore	Terrestrial, and arboreal on low vegetation. Lowland to high-elevation forests.	pers. obs., Hollingsworth *et al.* 2007
Quantula striata	Herbivore, detritivore	Leaf litter. Lowland to mid-elevation forests; gardens.	pers. obs., Councilman and Ong 1988.
Bradybaenidae			
Bradybaena similaris	Herbivore, detritivore	Terrestrial, arboreal on low veg. Low to highlands, disturbed areas, incl. gardens.	Pers. obs., Smith and Stanisic 1998; Chang 2002
Pupillidae			
Gastrocopta pediculus	Detritivore	Under stones or logs, in leaf litter. Lowland, in forests and modified areas.	Smith and Stanisic 1998
Gastrocopta servilis	Detritivore	Under stones or logs, in leaf litter. Lowland forests.	Smith and Stanisic 1998
Subulinidae			
Allopeas clavulinum	Detritivore (herbivore)	Leaf litter. Forests and disturbed areas, most prevalent in mid-elevation forests.	Smith and Stanisic 1998
Allopeas gracile	Detritivore (herbivore)	Leaf litter. Lowlands to highlands, in forest and modified habitats.	Smith and Stanisic 1998
Opeas hannense	Detritivore (herbivore)	Leaf litter. Lowlands to mid-elevation forest and disturbed habitat.	Barker *et al.* 2005
Opeas mauritianum	Detritivore	Leaf litter. Lowland to high-elevation forests and distributed area.	Barker *et al.* 2005
Paropeas achatinaceum	Detritivore (herb., carn., predator)	Leaf litter. Lowland to mid-elevation forests and disturbed habitat.	Naggs 1994; Barker and Efford 2004
Subulina octona	Detritivore (herbivore)	Under stones, logs and other debris. Leaf litter. Lowland to mid-elevations forests and disturbed habitat	de Almeida Bessa and de Barros Araujo 1996; Smith and Stanisic 1998; d'Avila and de Almeida Bessa 2005; Juřičková 2006; Hollingsworth *et al.* 2007.
Streptaxidae			
Gulella bicolor	Carnivorous predator	Under stones, logs and other debris. Leaf litter. Lowlands, in forests and modified areas, including gardens.	Annandale and Prashad 1920; Dundee and Baerwald 1984; Naggs 1989; Smith and Stanisic 1998, Solem 1988; Barker and Efford 2004
Streptostele musaecola	Carnivorous predator	Leaf litter, under stones and logs. Lowland disturbed forests.	Smith and Stanisic 1998; Hausdorf and Medina Bermúdez 2003
Veronicellidae			
Laevicaulis alte	Herbivore, detritivore	Under stones, grass, decaying wood, leaf litter & ground crevices. Lowland to high-elevation forests, plantations and moist tall grasslands.	pers. obs., Bishop 1977; Raut and Panigrahi 1990; Smith and Stanisic 1998; Gomes and Thomé 2004
Sarasinula plebeia	Herbivore, detritivore	Under stones, grass, decaying wood, leaf litter and ground crevices. Arboreal on low vegetation. Lowland to mid-elevation forests, plantations, grasslands and gardens.	pers. obs., Bishop 1977; Smith and Stanisic 1998; Rueda *et al.* 2002; Gomes and Thomé 2004
Zonitidae			
Hawaiia minuscula	Prob. carnivorous predator	Leaf litter. Lowland, disturbed areas.	Kano 1996; Smith and Stanisic 1998
Valloniidae			
Ptychopatula orcula	Detritivore	Arboreal, on tree trunks and branches. Lowland forests.	Solem 1964, 1988; Smith and Stanisic 1998

Table 2 Currently known status of introduced land snail species considered to be present in the Fiji Islands archipelago.

Species	Place of origin	Recorded pest/risk type	Where risk recorded	Estimate of risk in Fiji	References
Allopeas clavulinum	Probably tropical East Africa	No known threats	n/a	low	
Allopeas gracile	Probably neotropics	No known threats	n/a	low	
Bradybaena similaris	Asia	Crop pest; vector of human and livestock parasites	Fiji, Australia	medium to high	Alicata 1965; Godan 1983
Deroceras laeve	Holarcic and possibly Andean South America	Crop pest; vector of human and livestock parasites	Australia	low to medium	Mackerras and Sandars 1955; Alicata 1965; Smith and Stanisic 1998
Gastrocopta pediculis	Indonesia. Probably western Pacific-Australian area.	Status unknown could compete with native species	n/a	low	
Gastrocopta servilis	West Indies	Status unknown, could compete with native species	n/a	low	
Gullella bicolor	Indian subcontinent	Predator of native fauna (micro predator on snails)	Australia	medium to high	Smith and Stanisic 1998
Hawaiia minuscula	Canada to northern Mexico	Status unknown, could prey on native fauna	n/a	low	
Laevicaulis alte	Africa	Crop pest; vector of human and livestock parasites	Australia, Hawaii, Samoa	medium to high	Alicata 1965; Malek and Cheng 1974; Liat *et al*. 1965
Opeas hannense	Tropical Central America	Status unknown	n/a	low	
Opeas mauritianum	Unknown, probably India	Status unknown	n/a	low	
Parmarion martensi	South-east Asia	Vector of human and livestock parasites, crop pest	Hawaii, Japan	very high	Hollingsworth *et al*. 2007; Hollyer *et al*. 2010.
Paropeas achatinaceum	South-east Asia, Indonesia	Vector of human and livestock parasites, competes with native species	Hawaii, Pacific Islands	low to medium	Alicata 1965, Cowie 2000.
Ptychopatula orcula	India	Status unknown	n/a	low	
Quantula striata	Southern Malay Peninsula	Status unknown, may compete with native species	n/a	low	
Sarasinula plebeia	Central America	Crop pest; vector of human and livestock parasites	Honduras	medium to high	www.invasive.org; Alicata 1965; Rueda *et al*. 2002
Streptostele musaecola	West Africa	Predator of native fauna (micro predator on snails)	Australia	medium to high	Smith and Stanisic 1998
Subulina octona	Caribbean and tropical America	Crop pest; vector of human and livestock parasites	Brazil, Hawaii	low to medium	de Almeida Bessa and de Barros Araujo 1996; Hollingsworth *et al*. 2007

CONCLUSION

Increased collaborative effort is required to collate and disseminate available land snail information in a user friendly format. Improved access to such information will assist with baseline surveys of isolated priority conservation areas. Although eradication of pest snail species may not be technically possible (Sherley 2000), preventing entry or halting the spread of high-risk pest snails into some countries and islands is more likely to be achieved when local awareness strategies are in place. For the high risk species such as *Parmarion martensi,* these awareness strategies should include provision or reinforcement of the need for preventative public health measures for both local communities and tourist facilities.

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