

Considering native and exotic terrestrial reptiles in island invasive species eradication programmes in the Tropical Pacific

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Abstract Most island restoration projects with reptiles, either as direct beneficiaries of conservation or as indicators of recovery responses, have been on temperate or xeric islands. There have been decades of research, particularly on temperate islands in New Zealand, on the responses of native reptiles to mammal eradications but very few studies in tropical insular systems. Recent increases in restoration projects involving feral mammal eradications in the tropical Pacific have led to several specific challenges related to native and invasive reptiles. This paper reviews these challenges and discusses some potential solutions to them. The first challenge is that the tropical Pacific herpetofauna is still being discovered, described and understood. There is thus incomplete knowledge of how eradication activities may affect these faunas and the potential risks facing critical populations of these species from these eradication actions. The long term benefit of the removal of invasives is beneficial, but the possible short term impacts to small populations on small islands might be significant. The second challenge is that protocols for monitoring the responses of these species are not well documented but are often different from those used in temperate or xeric habitats. Lizard monitoring techniques used in the tropical Pacific are discussed. The third challenge involves invasive reptiles already in the tropical Pacific, some of which could easily spread accidentally through eradication and monitoring operations. The species posing the greatest threats in this respect are reviewed, and recommendations for biosecurity concerning these taxa are made.

Keywords: Invasive reptiles, glue (sticky) traps, mammal eradications, geckos, skinks, iguanas

INTRODUCTION

Most island restoration projects with reptiles, either as direct beneficiaries of conservation or as indicators of recovery responses, have been on temperate or xeric islands (Townes *et al.* 2006). There have been decades of research on the responses of native reptiles to mammal eradications, particularly on temperate islands in New Zealand, but very few studies in tropical insular systems (e.g., Kessler 2002). Most published papers that identify the effects of invasive mammals on tropical Pacific reptiles focus on ungulates or carnivores (e.g., Gorman 1975; Pernetta and Watling 1978; Kirkpatrick and Rauzon 1986; Case and Bolger 1991; Harlow *et al.* 2007), and there is little information on the effects of rodents (Case *et al.* 1991; Towns *et al.* 2006). Recent increases in restoration projects involving the eradication of introduced mammals in the tropical Pacific have led to several specific challenges related to native and invasive reptiles. I review these challenges and suggest potential solutions to some of them.

The first challenge is that the reptiles of the tropical Pacific are still being discovered, described, and understood. This leads to incomplete knowledge of how eradication programmes may affect these faunas and the nature of potential risks to critical populations. It also impedes our ability to prioritize restoration efforts for reptiles, since the factors impacting species with reduced population numbers are not often known (McCoid *et al.* 1995; Fisher and Ineich *in press*).

The second challenge is that methods for monitoring the responses of these reptile species to specific management actions are not well documented and are often different from those used in temperate or xeric habitats (Gillespie *et al.* 2005; Ribeiro-Junior *et al.* 2008). Reptile survey techniques being used on Palmyra Atoll, Line Islands, and the Aleipata Islands, Samoa (Fig. 1), to measure responses to rat eradication projects are reviewed below but there are many other techniques and protocols that can be used. Documentation and standardisation of procedures and accuracy in species identification are the most important long-term elements in establishing effective management programs.

The last challenge is that there are many invasive species of reptiles already in the tropical Pacific, particularly on Hawai'i and Guam (McKeown 1996; Kraus 2009) and some could easily be spread inadvertently through management

actions, especially if such trips are the only visits to remote island locations. The species most likely to spread in the tropical Pacific are reviewed below and recommendations for biosecurity for these taxa are discussed.

REPTILE KNOWLEDGE GAPS IN THE PACIFIC

Research on reptile diversity in the Pacific lags behind the more conspicuous groups such as birds. Although the herpetofaunas of most archipelagos have generally been well documented (e.g., Bauer and Henle 1994; Gill 1993, 1998; Gill and Rinke 1990; McCoy 2006; McKeown 1996; Morrison 2003; Zug 1991), faunal lists for many individual islands do not exist. Many newly recognised species remain undescribed including geckos, skinks, and blind snakes (Bruna *et al.* 1996; Radtkey *et al.* 1995; Fisher 1997; Wiles 2004; Watling *et al.* 2010; Buden and Panuel 2010; Wynn *et al.* *in review*), and there are others described during the past 25 years that are still known from single localities and/or few specimens (Zug 1985; Ota *et al.* 1995; Zug and Ineich 1995; Zug *et al.* 2003; Buden 2007; Ineich 2008,

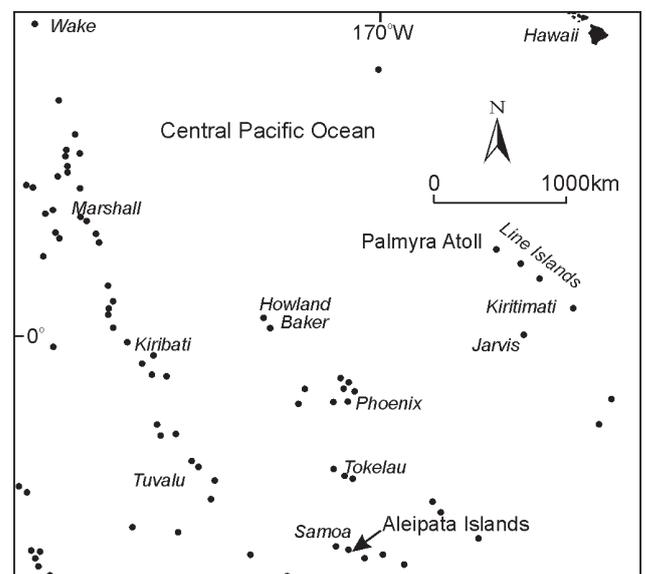


Fig. 1 Location of Palmyra Atoll and Aleipata Islands in the Pacific Ocean.

2009). In addition, some taxa that are known from only one or a few individuals and are presumed extinct could potentially be rediscovered (Ineich and Zug 1997).

Fossil deposits show that reptile faunas were once more diverse on several island groups before the arrival of people and invasive species (Pregill 1993; Crombie and Pregill 1999; Steadman 2006; Pregill and Steadman 2009). Some of these taxa may persist on small refuge islands as this has been shown to be a pattern elsewhere in the Pacific where species are now lacking from the main islands (e.g., Pernetta and Watling 1978; Perry *et al.* 1998; Steadman and Pregill 2004; Towns and Daugherty 1994). We currently know of three new species that appear to have relictual distributions due to the extirpation of insular populations prior to discovery (Pregill and Steadman 2009; Watling *et al.* 2010; Buden and Panuel 2010; Wynn *et al.* In review).

A particular problem in the Pacific is that different reptile species can be superficially similar in appearance. For example, the island groups of the central and south Pacific often have between two and four species of small *Emoia* ground skinks, all of which are striped (Fig. 2), similar-looking species of striped *Lipinia* skinks on the ground or in trees, and a striped *Cryptoblepharus* shore skink. Because supporting museum collections for many areas are often poor or incomplete, any records that are based solely on identification by sight – without capture and study – can lead to errors.

Little is known about the impacts of rodenticides or other toxicants on reptiles (Hoare and Hare 2006). Biomarker studies being carried out on several tropical islands may indicate how the toxicants move through the food webs (Wegmann *et al.* 2008). Fossorial species, such

as blind snakes, might be indirectly affected by rodent bait campaigns that introduce toxicants into the soil, either by direct exposure through the soil or secondarily by consumption of contaminated ant pupae and other foods (Ogilvie *et al.* 1997). On Indian Ocean islands, skinks have been directly observed eating rain-softened bait pellets, although no direct mortality was observed (Merton *et al.* 2002); identifying a potential direct risk of poisoning to similar rare species on Pacific Islands (i.e. *Tachygia*, *Emoia slevini*; Ineich and Zug 1997).

Often small islands retain bird populations that are identified as key beneficiaries from eradication programmes. However, a thorough evaluation for reptiles on these islands prior to implementation of any feral mammal eradication is warranted and should be required. Small islands often have relict populations of rare or threatened reptiles and/or have high value for reptile conservation. Furthermore, reptiles may be affected directly or indirectly by eradication programmes.

USE OF APPROPRIATE MONITORING PROTOCOLS

Techniques employed for monitoring reptiles in tropical environments include nocturnal and diurnal visual encounter surveys, pit-fall trap, sticky-trap, road search, and removal plots (Rodda *et al.* 2001; Gillespie *et al.* 2005; Ribeiro-Junior *et al.* 2008). Some techniques commonly used on temperate or xeric islands, such as pit-fall traps, do not work well in the tropical Pacific due to differences in habitat and the biology of the target species. For example, the species present on many islands are often predominantly arboreal skinks and geckos. A combination

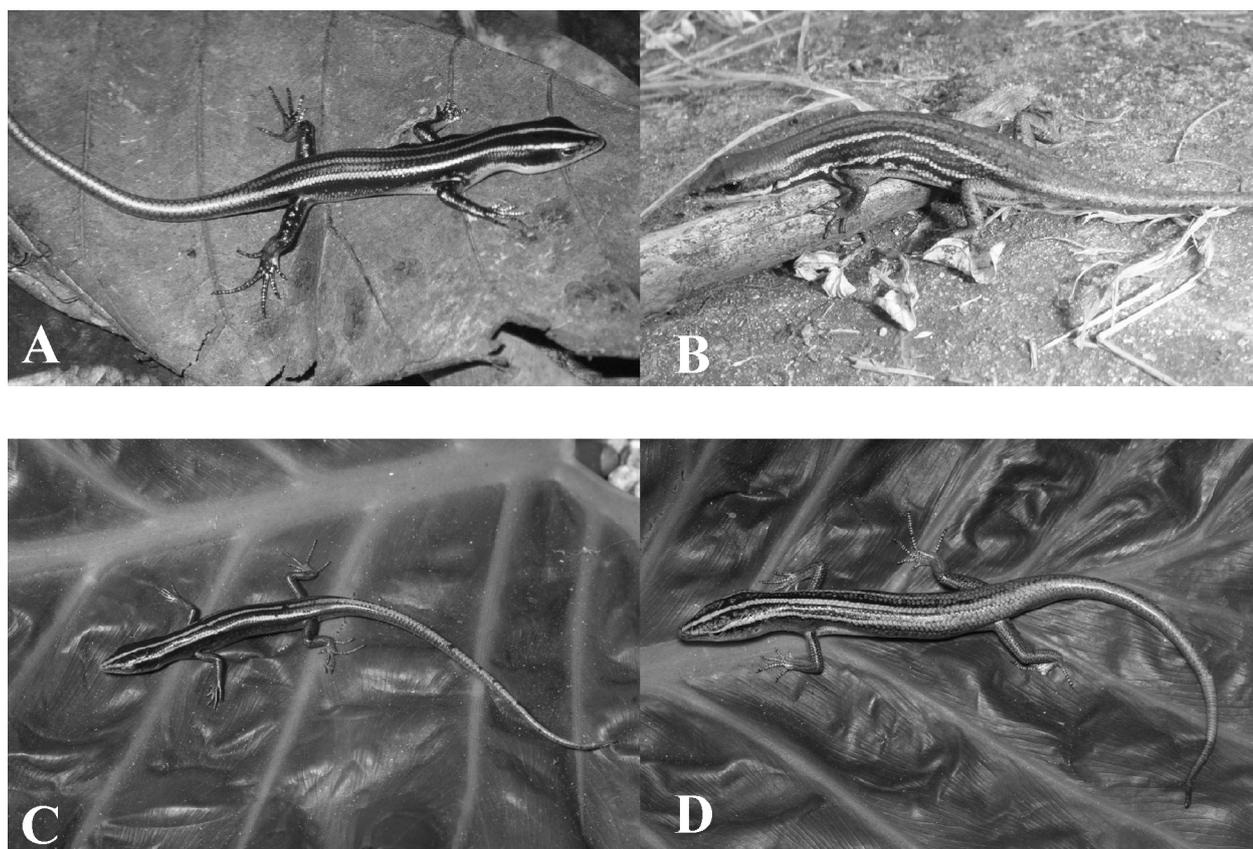


Fig. 2 Superficial similarity in appearance can cause difficulties for visual identification as illustrated by these four widespread striped skinks in the genus *Emoia* from the Pacific Basin. A. *Emoia caeruleocauda* is widespread in Micronesia, Solomon Islands, Vanuatu, and one island in Fiji. It is not endemic to the Pacific Basin but occurs in New Guinea and Indonesia also. B. *Emoia jakati* is introduced into the Solomon Islands and apparently much of Micronesia. It is native to New Guinea (Photo courtesy Don Buden). C. *Emoia impar* is endemic to the Pacific Basin and may represent several different cryptic species. This species has been extirpated from Hawai'i. D. *Emoia cyanura* is endemic to the Pacific Basin and may represent several different cryptic species. This species was accidentally introduced to Hawai'i in the 1970s and later extirpated.

of several techniques should give more information and help identify conservation targets for long-term restoration projects. Such an approach should also reveal targets for monitoring the responses of the eradications. A key factor is to ensure that the people monitoring reptile populations have the appropriate training and equipment. The priority here is to be able to accurately identify the species to be counted and measured. Some species are widespread and easy to identify, whereas others are part of cryptic species complexes, or are similar in appearance to invasive species. The lack of good regional field guides (exceptions are Morrison 2003; McCoy 2006) is part of this problem, as is the dearth of reptile specialists in the field through much of this region.

When used in combination and under similar environmental conditions, the following three techniques will provide repeatable relative measures of the contributions of species in reptile communities. These methods will provide baseline data on reptile communities and later measure the response to eradication actions. The same methods can also be used for biosecurity screening as they will detect most of the invasive reptile species in the Pacific region.

1. Visual Encounter Surveys – Daytime: These use transects traversed on foot across various habitats (Case and Bolger 1991), preferably during fine weather; i.e. not on overcast or rainy days. Each transect should cover a different habitat type or sampling stratum, with any reptiles observed along these transects recorded along with transect length and sampling duration. There are many ways to do these surveys, and they can be quantified either by fixed amount of time, fixed distance, or fixed route, or combinations of these. Whatever is done needs to be well documented so it can be repeated in the future. Validation that the observer can identify the various species present is required before using this or any direct-count technique. This technique works only for day active species, including diurnal skinks, monitor lizards, iguanids (particularly invasive *Anolis* and *Iguana*), and diurnal geckos (e.g., *Phelsuma*). Changes in vegetation cover after an eradication might make repeatability of these surveys difficult, especially if the vegetation becomes too thick to detect reptiles.

2. Visual Encounter Surveys – Night time: These use the same methods as daytime Visual Encounter transects, but can also include village buildings or other structures (Case *et al.* 1994). Bright headlamps or flashlights should be used to detect animals; some observers use a combination of flashlight with binoculars to increase focus on distant observations. As with daylight surveys, appropriate environmental conditions are preferred for comparing across nights and rainfall should be avoided. This technique works best for nocturnal geckos and boids, some invasive taxa (e.g., rats), and also coconut crabs and other species of interest (Harlow *et al.* 2007). It can also be effective for some diurnal species that roost in the canopy such as *Brachylophus* iguanas.

3. Glue (or Sticky) Trap Transects: Although there is often animal welfare concern over the use of this technique, proper application avoids or greatly reduces mortality of the trapped individuals (Ribeiro-Junior *et al.* 2006). Glue traps are generally cheap, easy to deploy, and work well in situations where the vegetation or other features (rocks/trees) are thick and animals are difficult to find. I have used traps set every 10–25 metres in transects that are 100 (or 250 m) long, the distances between sets and the length of the transects depending on the nature of the study. Each trap site consists of three sticky traps: one on the ground, one on a log, and one on a tree. The traps can be set and checked every 15 minutes for about 2 hours. The strength of adhesion varies by trap brand and weather conditions.

Traps may be ineffective within a few hours if hit by direct sun, which should be avoided anyway as it will kill any trapped animals. Other traps last for days, even during rain, although cardboard backed ones will fall apart if they get too wet. Glue traps can also be set in the late afternoon and left overnight to capture geckos and rats, although this often leads to higher mortality due to ant and land crab predation. Trapped animals can be removed using a thin coat of vegetable oil on the operator's fingers and then slowly peeling the animals off of the trap. Lizards can be toe clipped or marked with a temporary mark (felt pen, paint, etc.) to assess future recaptures; these same techniques can also be used for visual transects if animals are captured. Additional data such as invertebrate samples can be collected from the sticky traps if they are wrapped in plastic-film and frozen for later analysis. Each island should have 2–5 transects depending on island size and study questions. This can prove a useful way to confirm day or night time visual identifications along transect lines.

INVASIVE REPTILE SPECIES

Appropriately designed surveys may also reveal the presence of some of the following invasive reptile species. Many of these species have a high risk of spread throughout the tropical Pacific and potentially devastating effects on native and endemic species.

Geckos: The rapid invasion of the Asian house gecko (*Hemidactylus frenatus*) across the Pacific has been well documented (e.g., Case *et al.* 1994; Fisher 1997) and its impacts on endemic geckos in the Indian Ocean were described by Cole *et al.* (2005). More recently the spread of the gold-dust day gecko (*Phelsuma laticauda*) south from Hawai'i has become a concern (Ota and Ineich 2006) after it rapidly invaded the Hawaiian Islands from introductions via the pet trade (McKeown 1996). In Hawai'i, the species uses the night-light niche, which could make it a predator or competitor of native geckos as it spreads across the Pacific (Perry and Fisher 2006; Seifan *et al.* 2010). Currently there are many native and invasive geckos in southeast Asia and Hawai'i that could easily spread into the Pacific and impact the natural gecko communities. Many geckos are extremely successful invaders, which spread as adults through shipping, but also because some species with adhesive hard-shelled eggs deposit them under the lips of buckets, in building materials, and other inconspicuous locations. Such species also spread rapidly once they invade new usable habitat. The potentially invasive gecko species and the sites they have invaded are listed by Kraus (2009). Islands that currently lack certain invasive reptiles, such as the Asian house gecko, should be identified. Maintaining them free of such species will require much vigilance and outreach to local communities.

Skinks: Little is known about the impact of skinks, but the curious skink (*Carlia ailanpalai*) is rapidly spreading through Micronesia, replacing native ground skinks (Buden 2009). Two additional species, *C. mysi* and *C. tutela*, have invaded Bougainville and Palau (respectively), which indicates that the genus contains many highly invasive species (Crombie and Pregill 1999; Zug 2004; McCoy 2006). Other skinks such as *Emoia jakati*, *Lampropholis delicata*, and *Lamprolepis smaragdina* have been present in the Pacific for longer although their impacts are not well studied (Baker 1979; Perry and Buden 1999; McCoy 2006; Kraus 2009; Fisher and Ineich 2011; Fisher and Richmond unpub. data). Continued vigilance is necessary to ensure that these species do not spread further. Recently, *Lampropholis delicata*, which is invasive in New Zealand, was intercepted through biosecurity screening in a shipment of timber to Raoul Island, Kermadec Islands, which lack indigenous terrestrial reptiles (Phil Bell pers. comm.). The

species has apparently become recently established on Lord Howe Island (Kraus 2009).

Iguanids (and Polychrotids): Several species of anoles or American chameleons (Polychrotidae: *Anolis*) are now in Hawai'i, Commonwealth of the Northern Mariana Islands and Guam (McKeown 1996; Kraus 2009). Studies of *Anolis carolinensis* in the Ogasawara Islands (Suzuki and Nagoshi, 1999) indicate that anoles could compete with the endemic skinks of the Pacific Basin. Additionally, *Anolis sagrei* in Hawai'i apparently uses the same habitat as the native *Cryptoblepharus poecilopleurus* (Fisher pers. obs.) although the effects of this need further study. Additionally, green iguanas (Iguanidae: *Iguana iguana*), which have been in Hawai'i at least since the 1950s (McKeown 1996), were introduced to Fiji early this century and now threaten endangered Fijian iguanas (*Brachylophus* spp.; Naikatini *et al.* 2009; Thomas *et al.* 2011). Restricting the spread of green iguanas in Fiji is a major concern. The potential impact of the species on the vegetation community is unknown since the invasion is just now erupting.

Chameleons: Jackson's chameleon (*Chamaeleo jacksonii*) was introduced into the Hawaiian islands in the early 1970s and is now widespread (McKeown 1996). The species had not spread beyond Hawai'i until recently, when the chameleons were reported from the Marshall Islands (Vander Velde 2003). In Hawai'i, the species preys on endemic and endangered invertebrates, which adds to the pressure on these species (Holland *et al.* 2010).

Snakes: There is an extensive literature on the brown tree snake (*Boiga irregularis*) and the threats posed by the species are well known (Rodda and Savidge 2007). Other snakes such as the wolf snake (*Lycodon aulicus*) also appear to be capable invaders and could threaten the endemic Pacific fauna if it spreads from southeast Asia (Buden *et al.* 2001; Cheke and Hume 2008; Kraus 2009). The flower pot snake (*Ramphotyphlops braminus*) continues to spread throughout the Pacific Basin although its impacts are not well known (Kraus 2009). With the recent discovery of new endemic species of blind snakes (*Ramphotyphlops* spp.) within the oceanic Pacific, concern over confusion between indigenous and invasive species increases and other endemic species might go unnoticed and unprotected (Buden and Panuel 2010; Watling *et al.* 2010; Wynn *et al.* in review). Competition between native blind snakes and the invasive flower pot snake might become a concern as the latter species continues to spread.

These invasive reptile species raise biosecurity issues that must be taken very seriously, especially since conservation actions, including eradication efforts, could be a mechanism for their spread. Training tools and protocols for cleansing of equipment and supplies between islands should be developed and rigorously implemented to ensure that restoration projects do not spread unwanted aliens. Geckos pose the greatest threat through their accidental spread with the movement of materials used for remote island restoration activities. Boats are a particular risk pathway for some of these species and require careful planning to minimise this threat when visiting and working on remote islands.

CONCLUSION

Reptiles should be considered an important component of adaptive management projects in the Pacific because there are often endemic or relict populations on remote islands. Because knowledge of these species is often poor, experts should be consulted to ensure that these management actions have positive rather than negative impacts on native species. This is vital, especially in light of the number of highly-localised, poorly-understood endemic species distributed intermittently across the Pacific

Basin. Capacity building through species identification courses and the development of better, more exhaustive field guides should be conducted with those who plan to monitor reptile responses to these management activities.

Understanding and managing the biosecurity risks associated with conducting fieldwork at remote sites is vital to ensure that restoration activities do not further the spread of invasive species, such as the Asian house gecko or gold-dust day gecko (Hathaway and Fisher 2010).

Lastly, if priority reptile areas for conservation in the Pacific were mapped, management activities that would benefit multiple taxa could be identified, thereby adding the recovery of reptiles to birds and invertebrates as restoration targets.

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