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# AN OCEANIC ISLAND REPTILE COMMUNITY UNDER THREAT: THE DECLINE OF REPTILES ON CHRISTMAS ISLAND, INDIAN OCEAN

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***Abstract*.—Christmas Island in the Indian Ocean is home to a terrestrial reptile community that includes five endemic species; *Lepidodactylus listeri*, *Cyrtodactylus sadleiri*, *Emoia nativitatis*, *Cryptoblepharus egeriae*, and *Ramphotyphlops exocoeti*, and one native species *Emoia atrocostata*. Over the last 30 or so years, five of the six species have declined to near extinction with the remaining species, *C. sadleiri*, still reasonably common. A further five species are exotic introductions, the most recent being the Asian Wolf Snake (*Lycodon capucinus*) in the 1980s. Here, we document the declines in the native species and discuss possible causal factors in view of the available knowledge. We conclude that predation by introduced species is likely to be the key factor in the declines of the native reptiles, but other processes, such as inter-specific competition, may also be important. We briefly describe the current management efforts and suggest several additional management actions that could be useful to conservation of the Island's terrestrial reptile community.**

*Key Words*.—Christmas Island; competition; decline; introduced species; island reptile community; predation

## INTRODUCTION

Alarmingly, reptile declines are now recognized as a global phenomenon (Gibbons et al. 2000). Island reptile communities, in particular, appear to be especially vulnerable to decline and there are now several well-documented examples (e.g., Bullock 1986; Fritts and Rodda 1998). This is particularly significant because islands typically have high levels of endemism (Kier et al. 2009), and consequently the loss of species from an island often equates to extinction. Unfortunately, Christmas Island in the Indian Ocean presents another example of a highly endemic, terrestrial reptile community under serious threat. Herein, we provide a description of the terrestrial reptile declines on Christmas Island and discuss the potential causes and the current management/conservation activities. These activities are currently conducted by the island's major natural resource management agency, Christmas Island National Park, because nearly 63% of the island is designated as National Park.

***Christmas Island and its reptiles*.—**Christmas Island (10°25'S, 105°40'E) is approximately 360 km south of the western end of Java, Indonesia (Fig. 1). The island is a seamount with a terrestrial land mass of around 135 km$^2$, consisting of a large central plateau surrounded by a series of steep cliffs, terraces, and slopes. The highest point on the central plateau is 361 m above sea level. The average yearly rainfall is about 2,142 mm and the wettest period usually occurs between November and June (Claussen 2005).

Christmas Island is inhabited by six native terrestrial reptile species, five of which are endemic; Lister's Gecko (*Lepidodactylus listeri* Boulenger 1889), Giant Gecko (*Cyrtodactylus sadleiri*; Wells and Wellington 1985), Forest Skink (*Emoia nativitatis*; Boulenger 1887), Blue-tailed Skink (*Cryptoblepharus egeriae*; Boulenger 1889), and the Christmas Island Blind Snake (*Ramphotyphlops exocoeti*; Boulenger 1887; Cogger et al. 1983, Cogger 2000). Of these, *C. egeriae* is the only species that initially flourished in the disturbed urban habitats of the Island's town (Settlement) in 1979, where it was hyper-abundant in the town area, being extremely common on walls, fences, and buildings. Its subsequent extirpation from this entire area between 1979 and 1998 was thus, dramatic.

The Coastal Skink, *Emoia atrocostata* (Lesson 1830), currently is not thought to be endemic (it was tentatively assigned to the nominate subspecies by Brown 1991). However, the taxonomy of the Christmas Island reptiles is not fully resolved and the taxonomic status of the *Emoia* genus is currently under investigation (Robert Fischer, pers. comm.).

*Emoia nativitatis*, *C. sadleiri* (as *Gymnodactylus marmoratus*), and *R. exocoeti* (reassigned from the genus *Typhlops* by Wallach 2003) were the first reptile species to be collected on the island in 1887 (Gibson-Hill 1947). Later in the same year, J.J. Lister collected specimens of *C. egeriae* and *L. listeri* (Gibson-Hill 1947). *Emoia atrocostata* was first collected by Andrews between 1897 and 1898 (Andrews 1900).

To date, five terrestrial reptile species have been introduced to Christmas Island; Barking or House Gecko

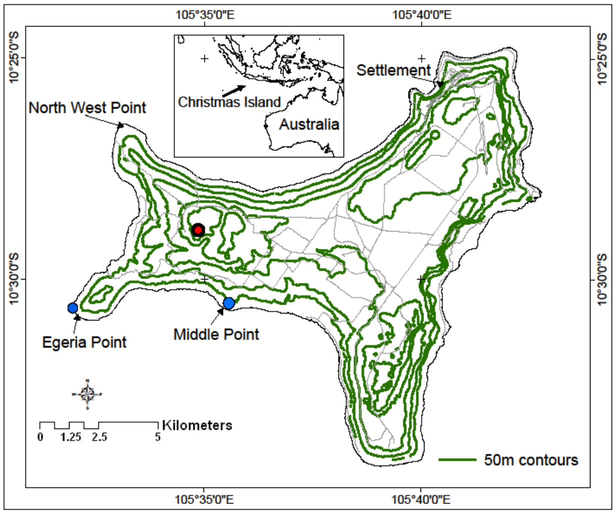


**FIGURE 1**. Christmas Island showing general location of the island, 50 m contours, and important areas with respect to reptiles. The two most recent records of *Emoia atrocostata* (blue circles) and *T. exocoeti* (red circle) are also shown. The *E. atrocostata* record at Egeria Point was made in 2010 and the one at Middle Point in 2004. The *T. exocoeti* record was made in 2009.

(*Hemidactylus frenatus*), Stump-tailed Gecko (*Gehyra mutilata*), Grass Skink (*Lygosoma bowringii*), Flowerpot Blind Snake (*Ramphotyphlops braminus*), and the Wolf Snake (*Lycodon capucinus*; Cogger et al. 1983; Cogger 2000). *Hemidactylus frenatus* and *R. braminus* had been introduced to Christmas Island by 1940 (Gibson-Hill 1947, 1950). *Gehyra mutilata* appears to have been introduced sometime after the mid-1940s (Cogger et al. 1983). *Lygosoma bowringii* (first recorded by Cogger et al. 1983) and *L. capucinus* (Smith 1988) are thought to be introductions that are more recent with first records occurring around 1979 and 1987, respectively.

***Declines in the native reptiles*.—**Four of the six native reptiles have declined significantly (Figs. 1–4), while one species (*R. exocoeti*) has been found so infrequently over the past century that there are insufficient data to assume a decline. Only *C. sadleiri* is still readily found across the island (Fig. 5) and while it appears to be reasonably common, there is some qualitative evidence that its numbers are significantly lower than in 1979. The declines in the lizard species *L. listeri*, *C. egeriae*, *E. nativitatis*, and *E. atrocostata* appear to have occurred over the last 20 to 30 years as Cogger et al. (1983) considered these species to be abundant in 1979. *Ramphotyphlops exocoeti* had not been recorded since 1986 (Hal Cogger, unpubl. report) until one individual was found in 2009 on the central plateau on the western end of the island (Fig. 1). Both *L. listeri* and *R. exocoeti*

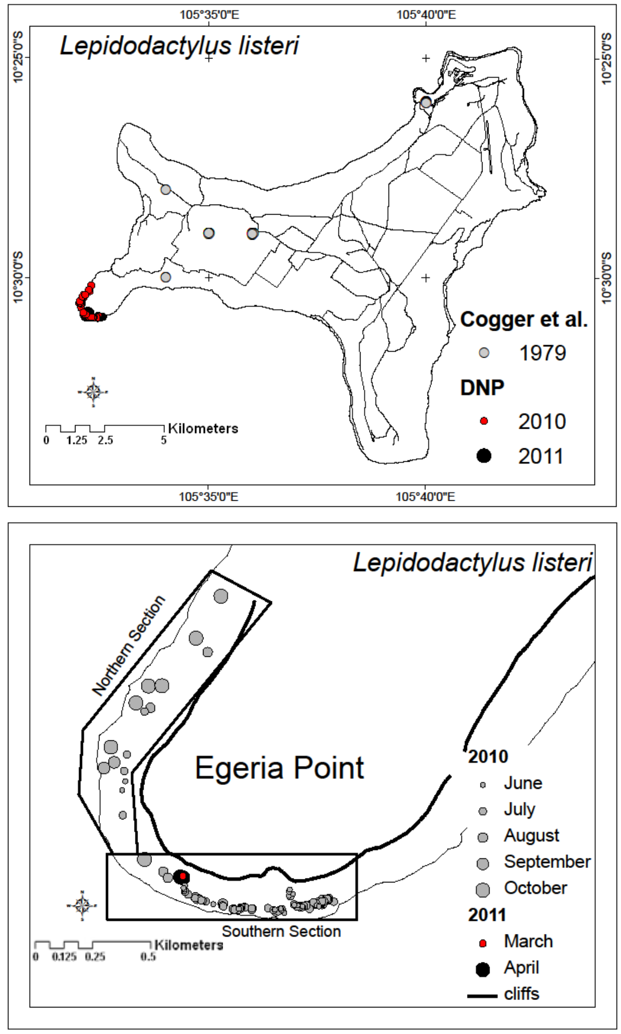


**FIGURE 2.** All *Lepidodactylus listeri* records (top) and a detailed map of the Egeria Point records (bottom) on Christmas Island. Director of National Parks (DNP) records are those collected under the auspices of the Australian Federal Government Director of National Parks. Records made by Hal Cogger and his colleagues are also identified. The Northern and Southern sections of Egeria Point are specified.

(as *Typhlops exocoeti*) are currently listed as Vulnerable under Australia's *Environmental Protection and Biodiversity Act 1999* (EPBC Act) and in the IUCN Red List of Threatened Species (International Union for Conservation of Natural Resources. 2012. The IUCN Red List of Threatened Species. Available from www.iucnredlist.org; [Accessed 26 June 2011]).

Much of the occurrence information presented here comes from surveys conducted by Christmas Island National Park since 2009. The park now uses a range of survey protocols for reptiles that includes diurnal sit-and-wait surveys (Smith et al. 2012), spotlight torch searches, footprint surveys using ink cards (Gotcha Traps Ltd., Warkworth, New Zealand), and acoustic call surveys for *H. frenatus*. Much of the island has been covered using at least one of these techniques (Fig. 6).

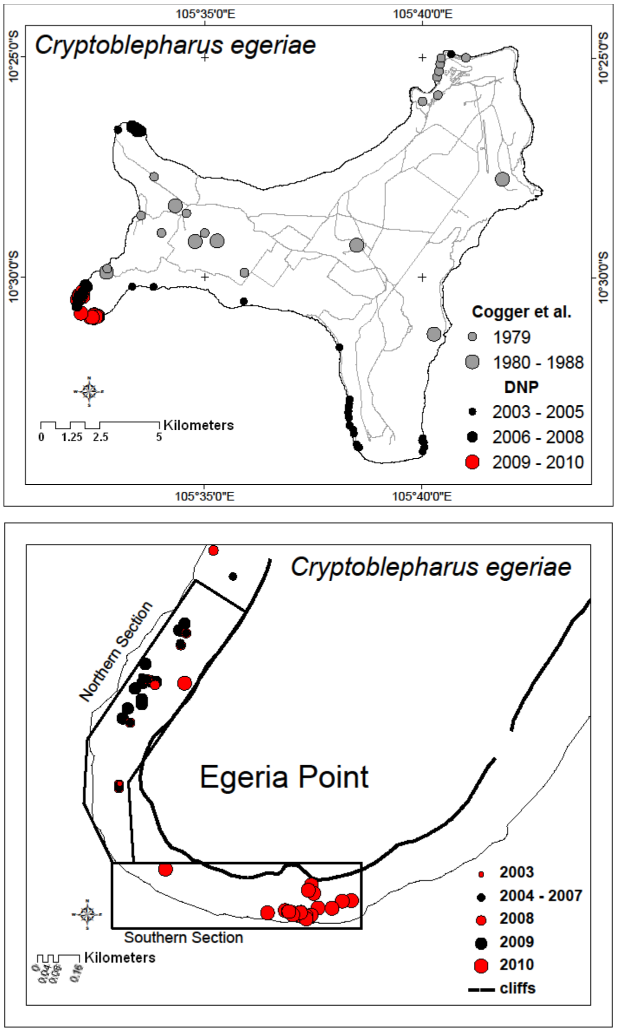


**FIGURE 3.** All *Cryptoblepharus egeriae* records (top) and a detailed map of the Egeria Point records (bottom) on Christmas Island. Symbols follow conventions of Fig. 2.

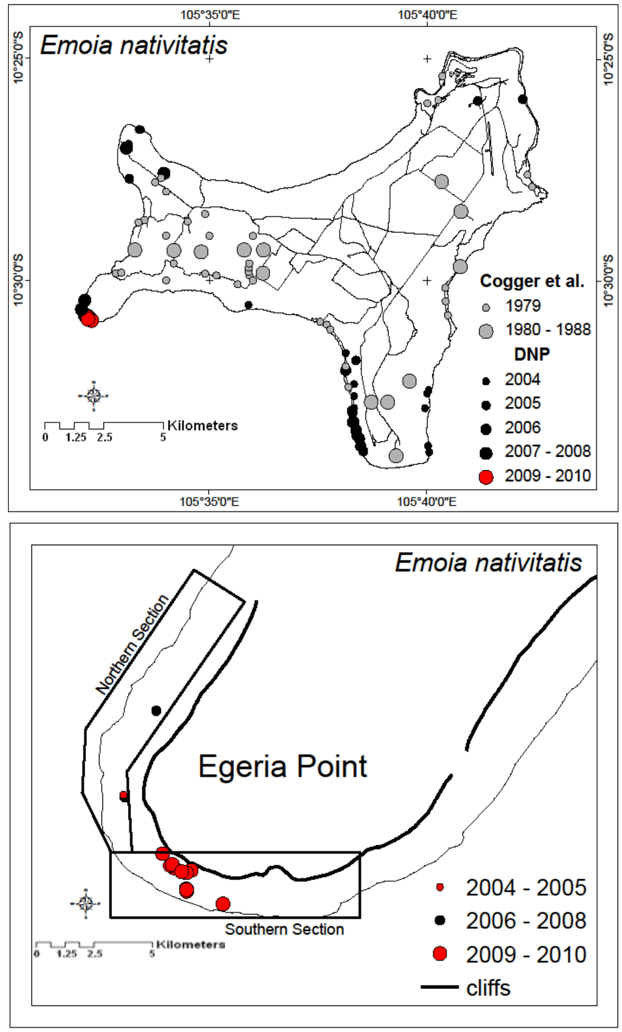


**FIGURE 4.** All *Emoia nativitatis* records (top) and a detailed map of the Egeria Point records (bottom) on Christmas Island. Symbols follow conventions of Fig. 2.

Below we present presence data only with the assumption that, even with imperfect detection, the survey effort has been substantial enough to provide a satisfactory estimate of the distributional status of the lizards and of *L. capucinus*. However, the island is large and has substantial areas of reasonably undisturbed habitat that are difficult to survey. Consequently, with continued survey efforts, new populations of the declining species may be found and our understanding of the distributions of the more common species should improve. We also present some historical data on each reptile species, particularly data collected under the auspices of the Director of National Parks (DNP) and data collected by Cogger et al. (1983) and Cogger and Sadlier (2000). Some of the survey records collected for DNP by Martin Schulz and Clive Heywood Barker (unpubl. report) are also included.

Interestingly, the four lizard species that have declined did so in a westerly direction, such that they are now only known to occur on the southwestern tip of the island (Egeria Point; Fig. 1–4) despite their previously broad distributions (Cogger et al. 1983). This almost certainly reflects the fact that historically most (if not all) introduced species would have first entered the island via the town, port facilities, and airport that have long dominated the north-eastern section of the island. Until 2010 when it was detected at Egeria Point, *L. listeri* had not been reliably recorded since 1979 and was feared extinct (Hal Cogger, unpubl. report). There are very few published records for *E. atrocostata*; however, they were typically thought to be common in all coastal environments until the late 1990s. The most recent record for *E. atrocostata* was in 2004 at Middle Point (Fig. 1) until one record was made at Egeria Point in 2010 (Fig. 1). No one has reported the species since that time. Other than Egeria Point, the most recent area from which *C. egeriae* and *E. nativitatis* disappeared was the North West Point (Figs. 3–4) which occurred between mid to late 2008 and early 2009.

***Declines at Egeria Point*.**—Egeria Point is a peninsula of land that encompasses around 14,000 ha. Four reptile species have declined to the very southwestern coastal terrace of Egeria Point (Figs. 1–4). This area consists of a narrow coastal terrace (ranging between approx. 100 m and 250 m in width) that is bordered by a coastal rock platform and ocean on the western side and steep cliffs up to the central plateau on the eastern side. The vegetation on the terrace grades sharply in a westerly direction from a 50 m to 500 m band of semi-deciduous closed forest (Claussen 2005), to a narrow, but nearly impenetrable, band of *Pandanus* forest (dominated by *Pandanus christmatensis*) that can vary in width from a few meters up to more than 50 m. The *Pandanus* forest in turn typically grades sharply on its western side into a narrow band (usually around 5–15 m wide) of *Scaevola* forest (dominated by *Scaevola taccada*). The band of *Scaevola* forest is bordered on the western side by coastal herbland (Claussen 2005) and rock platform habitats before meeting the ocean.

In the more northern section of Egeria Point (Figs. 3–4), *C. egeriae* and *E. nativitatis* were noticeably beginning to decline from the semi-deciduous closed forest, early in 2009, so that by mid to late 2009 they were mostly found in the *Pandanus* forest. Both species then contracted in a southerly direction within the *Pandanus* forest (Figs. 3–4). *Cryptoblepharus egeriae* has not been detected since July 2010, despite several survey attempts in appropriate weather (e.g., sunny and warm) that included the last known site of occupancy. *Emoia nativitatis* was last seen in August 2010 in the southern section of Egeria Point. *Lepidodactylus listeri* was rediscovered within the *Pandanus* belt at Egeria Point in 2010 and has also declined in a southerly direction since rediscovery, albeit at a slower rate than the two skink species (Fig. 2). *Lepidodactylus listeri* is still regularly detected within the *Pandanus* forest and in the band of *Scaevola* forest (Fig. 2).

***The spread of the introduced reptiles*.**—Even though the introduced reptiles were initially restricted to disturbed and urbanized areas on the island (Cogger 2000), *L. capucinus*, *L. bowringii*, and *H. frenatus* have now spread across the island (Fig. 7) and are often found in undisturbed forests. The available data suggests that these species broke away from mainly inhabiting disturbed areas and began to move into the more pristine forests over the last 20 to 30 years as Cogger et al. (1983) did not detect *H. frenatus* or *L. bowringii* in the less disturbed forests, and *L. capucinus* was not introduced until the late 1980s. *Lycodon capucinus* have been found in and around the remaining native reptile

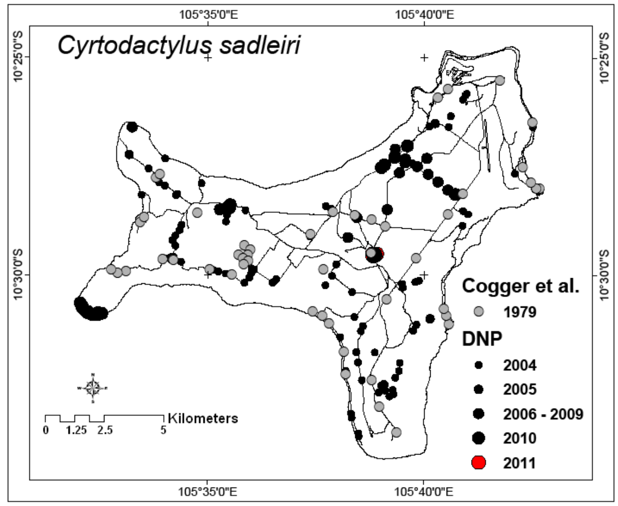


**FIGURE 5.** *Cyrtodactylus sadleiri* records on Christmas Island.

populations at Egeria Point (Fig. 7), including records on the coastal rock platform. *Hemidactylus frenatus* now occurs across most of the island. *Gehyra mutilata* (Fig. 7) and *R. braminus* still appear to be mostly restricted to disturbed areas, but they may be harder to detect in undisturbed habitats than species like *H. frenatus*, which signals acoustically.

## EVIDENCE TO SUPPORT DIFFERENT CAUSAL FACTORS

Globally, several causal factors have been investigated to explain reptile declines that include predation by one or several new predators (Case and Bolger 1991; Fritts and Rodda 1998), changing climatic conditions (Walther et al. 2002; Araújo et al. 2006), the introduction of disease and parasites (Hanley et al. 1995, 1998), inter-specific competition with a newly introduced species (Case et al. 1994), and habitat modification and fragmentation (Driscoll 2004; Brown et al. 2008; Waldron et al. 2008). However, predation and competition are seen as particularly effective forces in shaping reptile community structure and geographic distribution on islands (Case and Bolger 1991).

***Habitat disturbance and fragmentation*.**—Although Christmas Island has undergone significant habitat disturbance in the form of phosphate mining and urbanization (Gray 1981), the native reptiles have declined from vast tracts of land that are reasonably undisturbed (e.g., the decline of *E. atrocostata* from remote coastal habitats). Bearing this in mind, we suggest that even though habitat disturbance is likely to impact negatively upon at least some of the native reptile species (e.g., the clearing of vegetation and removal of soil to bedrock that is associated with phosphate

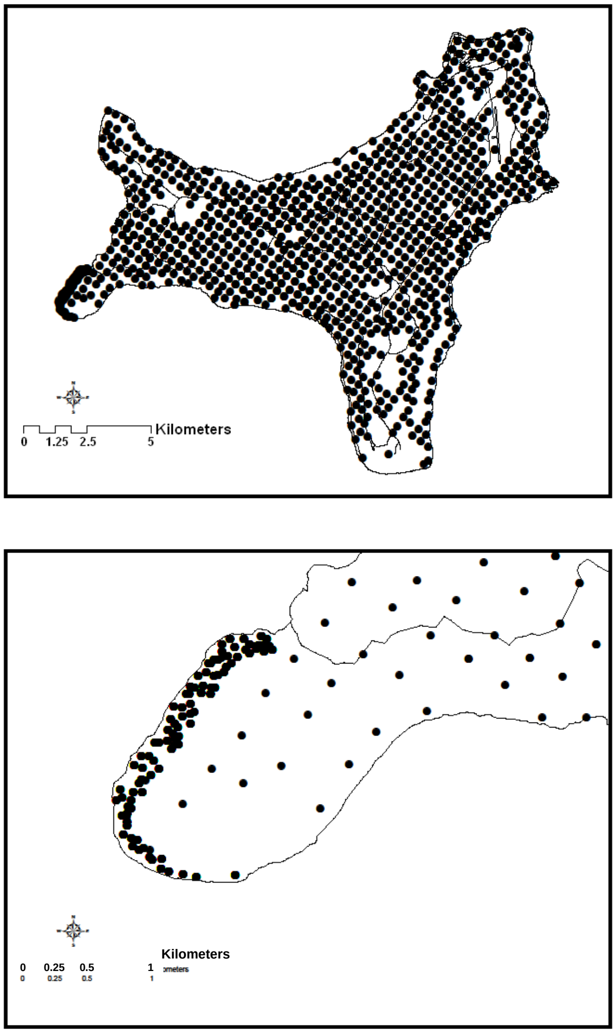


**FIGURE 6.** Sites surveyed for reptiles by Christmas Island Park staff in 2009 and 2010 (top) and survey effort at Egeria Point in 2009 and 2010 (bottom).

mining), we suspect that habitat clearance is not the primary cause of the declines. There are also large areas of the island that are not fragmented by disturbance from which the reptiles have declined, suggesting that habitat fragmentation associated with disturbance is also unlikely to be a sole cause of the declines. However as a consequence of edge effects, even minor habitat fragmentation, especially that caused by the construction of roads and tracks, can create opportunities for more rapid expansion of invasive species into large blocks of undisturbed native habitat. As described above, declines have continued at Egeria Point, which is a large, unfragmented, and reasonably undisturbed area. Additionally, *C. egeriae* was common in the settled areas and in mine fields for many decades leading up to the declines (Cogger et al. 1983), suggesting that some of the native species may actually have been able to benefit from disturbance prior to the introduction of new competitors or predators.

***Climate change***.—We currently cannot discount any impacts that may be associated with changing climates, due to a lack of reliable data. However, climate change is seen as a significant issue for Indian Ocean islands (Church et al. 2006). The island appears to have gone through a particularly dry period from the late 1980s to the mid-1990s (Max Orchard, pers. comm.) which was about the time that the native reptiles started to decline. One possibility that is currently being investigated is the suitability of tree growth rings to provide more reliable and longer-term climatic information for the island. *Lepidodactylus listeri* and *C. egeriae* have both persisted with low mortality and have bred readily in outdoor enclosures for more than 18 months as part of an on-island captive breeding program (described below), suggesting that the current climatic conditions are still suitable for successful reproduction, at least for these two species.

***Introduction of disease and/or pathogens***.—Christmas Island National Park engaged the Australian Registry of Wildlife Health (Taronga Conservation Society Australia) to examine the possibility that disease is a major cause of the reptile declines (Jane Hall and Karrie Rose, unpubl. report). Introduced reptile species were examined for evidence of parasites, diseases (including viruses), and heavy metals. Three of the native reptile species (*C. sadleiri*, *L. listeri*, and *C. egeriae*) were examined using non-lethal techniques that focused on external examination and hemoparasite identification. Where possible, some hematological and serum biochemistry procedures were also used. The results of the study identified many parasites, but found no evidence of a disease, pathogen, or heavy metal poisoning that could explain the reptile declines; nor was there any significant difference in parasite/pathogen loads and taxonomies between native and introduced reptiles. Additionally, the captive breeding program discussed below, further suggests that disease is not a major issue on the island.

***Competition***.—Inter-specific competition is likely to have occurred between *L. listeri* and *H. frenatus* (Case and Bolger 1991; Case et al. 1994; Hanley et al. 1998) and *L. listeri* is currently known from one spot only, which is also one of the few areas on the island that is free from *H. frenatus* (Figs. 2 and 7). *Hemidactylus frenatus* has been shown to displace *Lepidodactylus lugubris* from disturbed systems (Case et al. 1994). While incrementally expanding its range on Christmas Island, it is likely that *H. frenatus* had preyed upon or competitively excluded *L. listeri*, or otherwise

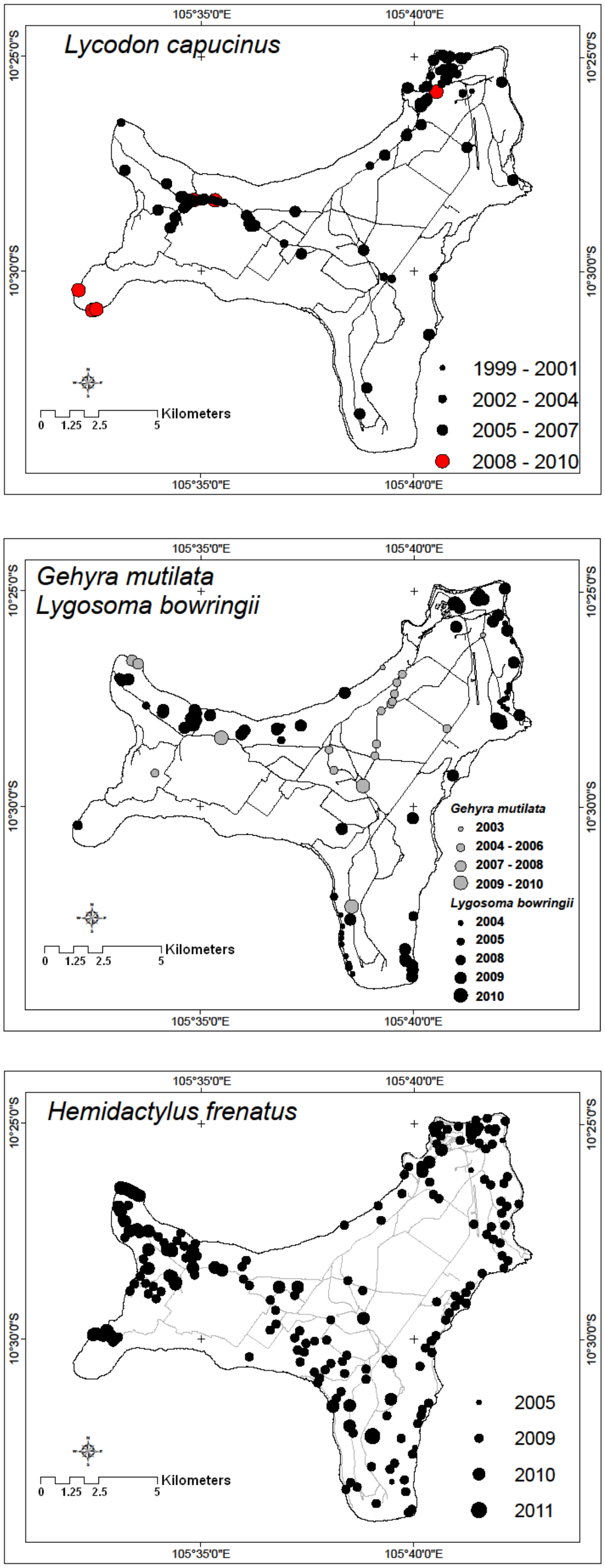


**FIGURE 7.** Records of *Lycodon capucinus* (top), *Lygosoma bowringii* and *Gehyra mutilata* (middle), *and Hemidactylus frenatus* (bottom) locations on Christmas Island.

significantly reduced its numbers. However, in some instances, the declines in *L. listeri* appear to have preceded the spread of *H. frenatus* (e.g., *L. listeri* is declining in Egeria Point in the absence of *H. frenatus*), implying that other significant causal agents have been contributing to its decline.

*Lygosoma bowringii* is likely to have occurred syntopically with *E. nativitatis* and *C. egeriae* (Cogger et al. 1983). As a terrestrial, diurnal litter-skink, it is likely to experience frequent inter-specific interactions with *E. nativitatis*, whereas direct interactions with the semi-terrestrial but primarily arboreal or saxicolous climber *C. egeriae* should be less frequent. However, there is no direct or implied evidence of competitive exclusion between any of these species, and as both *E. nativitatis* and *C. egeriae* have disappeared from areas that *L. bowringii* is unlikely to have ever occupied, an agent other than competition is implicated in their declines.

***Introduced predators*.**—It is hard to believe that predation by introduced species is not a major factor in the native reptile declines on Christmas Island. Four of the native species have contracted to the southwestern tip of the island, which is the most distant area on the island from human settlement (Fig. 1). A large number of known reptile predators have now been introduced to the island, including, the Domestic/Feral Cat (*Felis catus*), House Mouse (*Mus musculus)*, Giant Centipede (*Scolopendra subspinipes*), Red Jungle Fowl (*Gallus domesticus*), Yellow Crazy Ant (*Anoplolepis gracilipes*), Asian Wolf Snake (*L. capucinus)*, Black Rat (*Rattus rattus)*, and Barking or House Gecko (*H. frenatus)*. As far as we know, all of the introduced species have entered the island from the "Settlement" area on the north eastern end of the island (Fig. 1), and it is possible that this suite of introduced predators has acted like a 'super predator,' probably operating in conjunction with other processes like inter-specific competition and disturbance.

*Rattus rattus*, *F. catus*, *A. gracilipes*, and *S. subspinipes* have been on the island since the early 1900s, but *A. gracilipes* (O'Dowd et al. 2003) and *S. subspinipes* (Max Orchard, pers. comm.) in particular, appear to have increased in abundance and range in the 1990s. This coincided with the time of the introduction and subsequent spread of *L. capucinus* and during a period of potentially unusual dry weather (Max Orchard pers. comm.). The considerable ecological consequences of the spread and formation of high-density *A. gracilipes* colonies has been well documented (O'Dowd et al. 2003; Boland et al. 2011). The ecological consequences of changes in the distribution and densities of *S. subspinipes* and *L. capucinus* on Christmas Island are not well understood. Additionally, the rate at which *F. catus*, *M. musculus*, and *R. rattus*

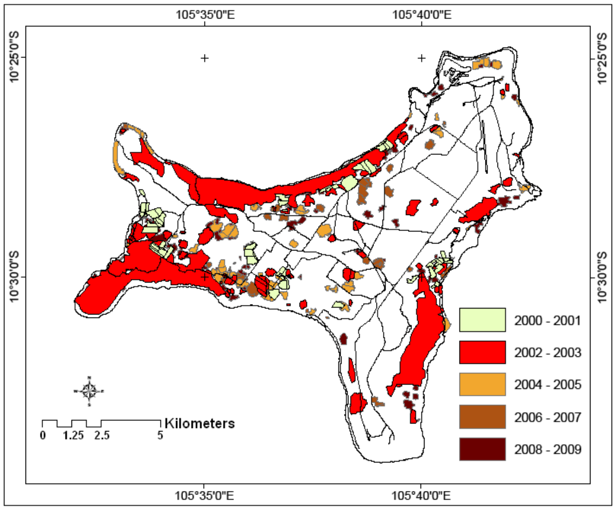


**FIGURE 8.** Historical development of high-density *Anoplolepis gracilipes* colonies on Christmas Island.

spread across the island has not been well documented,but there is no reason to think that these species have not been distributed widely across the island for a long time, given that their introduction was over 100 years ago and they are not restricted to disturbed habitats.

From a predation perspective, the declines at Egeria Point implicate *F. catus*, *R. rattus*, *S. subspinipes*, and *L. capucinus* in particular, as they all occur syntopically with the four reptile species in their last known area of occupancy, within which they continue to decline. *Anoplolepis gracilipes* colonies are very likely to have caused high levels of mortality to the reptiles, but interestingly, some of the most widespread, high-density *A. gracilipes* colonies have developed and then baited on the western end of the island (Fig. 8), which is also the area to which the four native lizard species have contracted.

There are several cases of island lizard declines and extinctions following the introduction of rats (especially *R. rattus* and *R. exulans*) in Australia's island territories. A gecko (*Christinus guentheri*) and a skink (*Oligosoma lichenigera*) are endemic to the oceanic islands of the Lord Howe and Norfolk Island complexes. The populations of both of these lizards underwent major declines on the inhabited main Lord Howe Island following the introduction of *R. rattus* from a shipwreck in 1927 (Cogger et al. 1983; Donald Colgan et al., unpubl. report), although both species remain abundant on a number of offshore islets that remain rat-free. On Norfolk Island, the introduction of the Polynesian Rat (*R. exulans*) by Polynesian visitors *ca*. 850 BP led to the extinction of *Christinus guentheri*, and possibly *Oligosoma lichenigera*, on Norfolk's main island (sub-recent beach fossils of *C. guentheri* confirm its earlier presence; Donald Colgan et al., unpubl. report). The gecko remains abundant on all of the rat-free offshore islands and rocks, while the skink is abundant and secure on the largest of these (Phillip Island).

Yet a number of field studies of *R. rattus* have clearly demonstrated that its diet is primarily vegetarian, though it may occasionally take carrion. These studies include subantarctic islands (Copson 1986), the Australian mainland (Watts and Braithwaite 1978), and the Galapagos Islands (Clark 1982). In the absence of any data indicating that the diet of *R. rattus* on Christmas Island is different from that of its populations elsewhere, one possibility is that the impact of rats on the island is through predation on lizard eggs. All native lizards on Christmas Island are oviparous. However, this does not explain why several of the introduced species (e.g., *H. frenatus*), which are also oviparous, are increasing in distribution and presumably population size. Additionally, the reptile fauna has evolved with two endemic rat species, *R. macleari* and *R. nativitatis*, which went extinct shortly after the island was settled and *R. rattus* was introduced (Andrews 1900; Wyatt et al. 2008).

Of the other potential predators, three out of five *L. capucinus* captured in the direct vicinity of the last known *C. egeriae* population at Egeria Point (within a few weeks of the last *C. egeriae* record at that site) had *C. egeriae* in their stomachs (unpubl. data). More recently, one *L. listeri* and one *C. sadleiri* were found in the stomachs of *L. capucinus* captured at Egeria Point. Personnel at Christmas Island National Park have also collaborated with the South Australian Museum to conduct a stomach-genetic study confirming that *S. subspinipes* on Christmas Island consume introduced reptiles (Steve Donnellan and Kyle Armstrong, unpubl. data). *Hemidactylus frenatus* and *G. mutilata* DNA was detected in the stomachs of *S. subspinipes* (Steve Donnellan and Kyle Armstrong, unpubl. data). It is likely that *S. subspinipes* also preys upon the native reptiles, but this is not yet confirmed. *Scolopendra subspinipes* are detected commonly throughout Egeria Point (Fig. 9). Additionally, a juvenile *L. bowringii* has been found in the stomach of an adult *H. frenatus* (unpubl. data).

A motion sensing camera survey has confirmed the presence of *F. catus* and *R. rattus* at Egeria Point (Fig. 10). Over a 12 mo period, *F. catus* was recorded at 12 of 18 sites, and it was estimated that there were at least six different individuals in the area. *Felis catus* have been recorded as major predators on small reptiles in a wide variety of ecosystems (Case and Bolger 1991), including Christmas Island (Tidemann et al. 1994). The predation rates by cats are unknown. Similarly, no data are available on the relative impacts of *G. domesticus* on native lizard populations, though they might well be significant predators of adults, juveniles, and eggs.

With the motion sensor cameras, *R. rattus* was

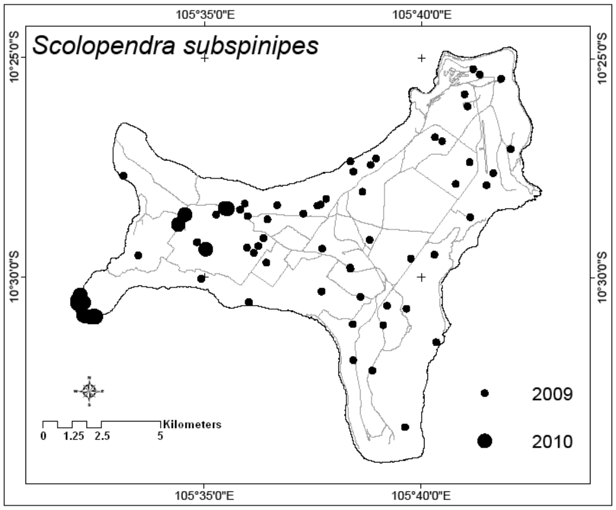


**FIGURE 9.** *Scolopendra subspinipes* records on Christmas Island.

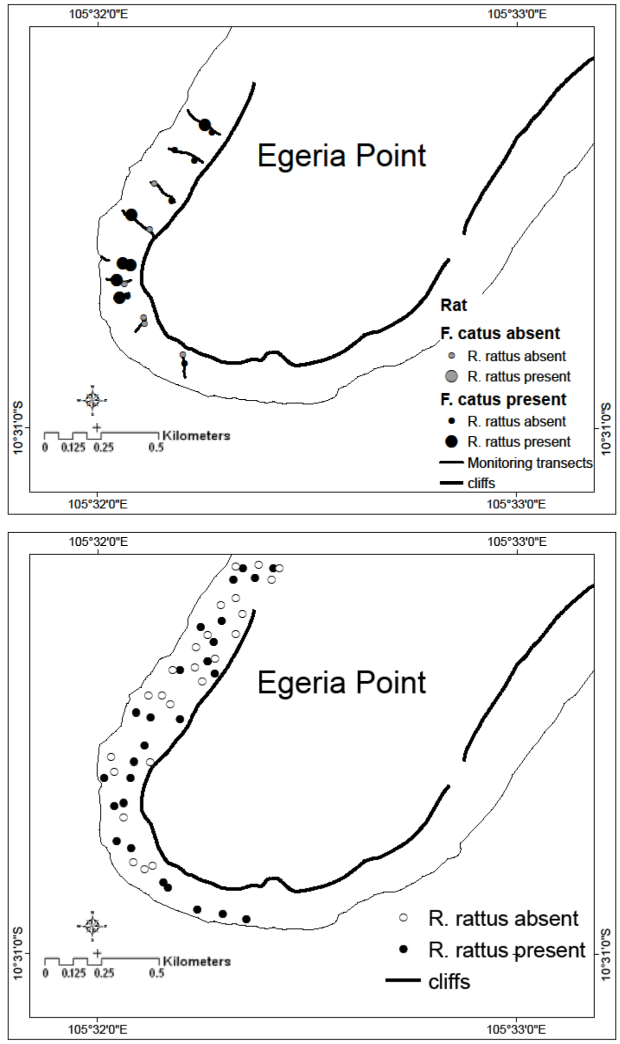


**FIGURE 10.** *Felis catus* and *Rattus rattus* records on Christmas Island at Egeria Point collected with motion sensor cameras (top) and ink cards (bottom).

also found at six of 18 sites. Footprint detection devices were used to survey for *R. rattus*, and with this technique, *Rattus rattus* was detected at 44 of 81 sites (Fig. 10). Consequently, several known reptile predators are common in and around the last known area of occupancy by *L. listeri*, *E. nativitatis*, *E. atrocostata*, and *C. egeriae*, which continue to decline within this area.

## DISCUSSION

We suggest that predation is likely to be the key factor in the decline of Christmas Island's reptile fauna, bearing in mind that any decline hypothesis based primarily on a predation model has some logical implications that have yet to be fully explored. For example, the absence of any evidence that the non-native lizard species are less susceptible to predation than native species (through predator-avoidance behavior, size, toxicity, different habitat preferences, etc.) means that the analogous species in both groups should be equally vulnerable to predation. Also, unless native taxa have lower reproductive rates than analogous non-native species, each should be subject to approximately equal rates of decline from predation. From a management perspective, it would be valuable to determine the relative contribution of each of the known or suspected predators to mortality in each of the declining native species, with a particular emphasis on *L. capucinus*, a species known to be an important reptile predator (Fritts 1993). With such knowledge, funds and other key resources could be expended more effectively on control programs for pest species.

***Current invasive species management.***—Christmas Island National Park now has a range of natural resource programs that, to different degrees, monitor *A. gracilipes*, *R. rattus*, *F. catus*, *L. capucinus*, *H. frenatus*, *L. bowringii*, and *S. subspinipes* across the island. Since 2001, personnel at Christmas Island National Park have managed *A. gracilipes* by poisoning high-density colonies with Fipronil (housed in a fish meal pellet) when the colonies reach densities high enough to cause red crab mortality (Boland et al. 2011). There is no published evidence that Fipronil is negatively impacting Christmas Island's reptile fauna. Biologists from two Australian Universities, LaTrobe and Monash, in collaboration with personnel at Christmas Island National Park, are currently working on a biocontrol program to introduce a wasp that parasitizes the scale insects, which are believed to be an important link in the process of high density *A. gracilipes* colony formation (O'Dowd et al. 2003). This research is making significant progress, but as with most biocontrol programs, it may be several years before implementation occurs.

An eradication program for *F. catus* is in development (David Algar and Michael Johnston, unpubl. report) and may be extended to include *R. rattus*. If the cat eradication and biocontrol programs are successful, several potentially major threatening processes with respect to the reptiles should decrease in severity. There is currently no control or eradication methodologies available for species like *L. capucinus* (Rodda et al. 2002), *H. frenatus*, or *S. subspinipes*.

***Native reptile management*.—**Personnel at Christmas Island National Park have now developed survey and monitoring programs that include estimates of occupancy for all of the lizard species except *E. atrocostata* and *L. capucinus*, and have embarked on a captive breeding program for the *C. egeriae* and *L. listeri*. The captive breeding program has developed into a collaboration with Taronga Zoo (www.taronga.org.au/taronga-zoo). Sixty-four *C. egeriae* and 43 *L. listeri* were taken into captivity in 2009–10. Both species have been breeding readily in captivity. The ultimate management goal for *C. egeriae* and *L. listeri* is to identify, and where possible, ameliorate, threatening processes with a view to developing a program that will allow the successful reintroduction of these two species back into the wild.

## CONCLUSIONS AND FUTURE DIRECTIONS

The causes of the reptile declines on Christmas Island are not yet fully resolved, but it is likely that predation by introduced species is the major factor. Unfortunately, there is a reasonable possibility that the two *Emoia* species and *T. exocoeti* will become extinct. However, *L. listeri* and *C. egeriae* may avoid extinction if the captive breeding program continues to be successful and if some form of reintroduction (possibly into exclusion areas) can be achieved. Reintroduction efforts may be a good approach and the associated lessons learned may lead to quantitatively resolving the causes of the declines.

Better understanding the interactions between *L. listeri* and the two introduced gecko species will be critical if *L. listeri* is to be reintroduced. In particular, *H. frenatus* appears to be gradually moving into Egeria Point. There is considerable scope to continue to study *L. listeri* at Egeria Point with a view to better understanding the processes that underlie the decline. A stomach-genetic study in the Egeria Point area would help to determine whether the centipedes are preying on *L. listeri*. Similarly, examining the stomach contents of *R. rattus* and *F. catus* in and around the *L. listeri* population at Egeria Point could prove to be informative, possibly even guiding future conservation efforts.

Probably one key part of the reptile declines on Christmas Island that has not been examined adequately yet is the continued persistence of *C. sadleiri* across the island when all other native reptile species have declined significantly. Research aimed at determining why this species has persisted may prove to be particularly valuable. Initial results from research that is currently being conducted by some of the authors has shown that *C. sadleiri* and *S. subspinipes* rarely co-occur in closely located microhabitats that both species readily utilize, suggesting that some form of habitat exclusion or avoidance process is operating between these two species. Finally, the potential impacts of climate change on both the native and introduced species on the island needs to be better understood as changing climatic conditions may impact greatly on fitness, distributions, and interactions with other species (Araújo et al. 2006).

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