Workshop Report:

Christmas Island National Park Reptile Conservation Planning 2024-2034

Document information

This report records the outputs of a stakeholder planning workshop held at Taronga Zoo, Sydney, from March 27-31, 2023 and the materials prepared to support it. It was prepared for the Christmas Island National Park Threatened Species Program, Director of National Parks. Its contents will inform the development of the 2024-2034 Christmas Island National Park Reptile Conservation Plan.

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CONTENT

ACRONYMS AND ABBREVIATIONS

ARWH	Australian Registry of Wildlife Health
BMP	Biodiversity Monitoring Program
BTS	Blue-tailed skink
CASAP	Crazy Ant Scientific Advisory Panel
CI	Christmas Island
BS	Christmas Island blind snake
CIDHS	Christmas Island District High School
CIRAP	Christmas Island Reptile Advisory Panel
CKI	Cocos (Keeling) Islands
CMR	Capture-Mark-Recapture
DAFF	Department of Agriculture, Fisheries and Forestry
CKIDHS	Cocos (Keeling) Island District High School
DNP	Director of National Parks
eDNA	Environmental DNA
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
GD	Genetic Diversity
GG	Christmas Island giant gecko
IUCN	International Union for Conservation of Nature
LG	Lister's gecko
MAI	Maximum Aviodance of Inbreeding
MHC	Major Histocompatibility Complex
MK	Mean Kinship
DCCEEW NESP	National Environmental Science Program (Federal Dept of Climate Change, Energy, the Environment and Water)
NP	National Park
NZ	New Zealand
PCR	Polymerase Chain Reaction
PKNP	Pulu Keeling National Park
SSC	Species Survival Commission
TBD	To Be Determined
TARONGA	Taronga Conservation Society Australia
TZ	Taronga Zoo
WA	Western Australia
WS	Common Wolf snake
YCA	Yellow Crazy Ants

EXECUTIVE SUMMARY

BACKGROUND

The Christmas Island National Park Reptile Conservation Plan 2014-2024 proposed strategies for halting extinction and restoring populations of native reptile species (especially blue-tailed skink/BTS and Lister's gecko/LG) on Christmas Island. In the intervening years the program has implemented these strategies learning from and adapting to successes and failures.

From 27-31 March 2023, a workshop was held at Taronga Zoo in Sydney to discuss current understanding of the risks to Christmas Island native reptiles, the status of our ability to manage those risks and to recommend priority strategies and actions for the next decade. In addition to BTS and LG, these discussions included Christmas Island giant geckos and blind snakes.

The meeting was attended by 28 stakeholders, including representatives from Parks Australia, Taronga Conservation Society Australia, Christmas Island Shire, Cocos (Keeling) Islands Shire, Christmas Island High School, Cocos Adventure Tours, research ecologists and members of the Christmas Island Reptile Advisory Panel (CIRAP).

SUMMARY OF WORKSHOP DISCUSSIONS AND RECOMMENDATIONS

Currently, the Christmas Island Lizards Conservation Project has three major elements:

- **A program of threat research and abatement** on Christmas Island aimed at restoring conditions suitable for BTS and LG;
- **A program of intensive management** aimed at preventing extinction, maintaining gene diversity and providing a source of animals for release;
- **A program of securing populations under free-living conditions**, as a partial step towards wild release on Christmas Island, to secure the wider meta-population against adaptation to captivity, and to maintain overall numbers at lower cost.

Recommended Year 1 Priorities

Cocos (Keeling) Islands

1. Assessment of an additional, larger Cocos (Keeling) Island for a third BTS release.
2. Risk assessment for introduction of LG to an island inhabited by *L. lugubris* (including hybridisation risk)

Christmas Island

3. Feasibility assessment by leading predator-proof fence supplier, of constructing a Fenced Site on CI that can keep wolf snakes out, and LGs in.
4. Targeted research: wolf snake detection, distribution, & control options.

Health & Biosecurity

5. Improve understanding & management of *Enterococcus* outbreaks including protection of the core CI breeding population.
6. Ensure CI breeding facilities are fit for purpose.

Demographic & Genetic Management

7. Develop & implement a metapopulation-wide plan to serve the program's new targets & priorities.

Based on the challenges identified and discussed, participants developed four goals, 24 objectives and 72 actions for implementation over the coming decade, aimed at preventing extinction and enabling recovery, for all four reptile species considered.

Despite the challenges encountered to date, participants agreed that over the next 10 years the program should proceed on the basis that it will be possible, eventually, to restore self-sustaining populations of blue-tailed skink and Lister's gecko to Christmas Island.

The feasibility of restoring wild conditions to those suitable for self-sustaining lizard populations is highly uncertain at present. The biggest challenge is eradicating or adequately controlling invasive wolf snakes, followed by adequately controlling giant centipedes.

Priorities: researching and testing feasible pathways for eradication or control of wolf snakes and centipedes, and through this, reducing current uncertainty about whether resolution is possible.

For Lister's Geckos

- Captive populations are large and distributed at two locations to reduce risk. Disease poses a significant risk to the Christmas Island sub-population, which is the largest.
- There are no free-living components on Cocos (Keeling) for this species.
- There are Fenced Sites for the species on Christmas Island but they are problematic and their future is uncertain.

Priorities: addressing disease risks at Christmas Island facilities (enclosures and exclosures) and assessing facility needs going forwards, establishing free-living populations on Cocos (Keeling) or alternate site and resolving the uncertainty about the future viability of Fenced Sites on Christmas Island.

For Blue-tailed Skinks

- Captive populations are large and distributed at two locations to reduce risk. Disease poses a significant risk to the Christmas Island sub-population, which is the largest.
- In addition to the intensive component, there is a free-living component on two islets in the Cocos Keeling group. This may be lost over a 20-year time-frame due to climate change related sea-level rise and associated weather events.
- There are Fenced Sites on Christmas Island but they are problematic and their future is uncertain.

Priorities: addressing disease risks at the Christmas Island facility (enclosures and exclosures) and assessing facility needs going forwards, building a population on higher ground on Cocos Keeling (to lower risk from sea-level rise), and resolving the uncertainty about the future viability of Fenced Sites on Christmas Island.

Metapopulation considerations

The Metapopulation for each of these species includes all animals under all management systems. The efficient and effective management of this overall resource is most challenged by disease management issues, which can constrain movement among sub-populations. Further refinements in data sharing and management, genetic and demographic management, sub-population monitoring and reporting, and facility renewals would also add significant value.

Priorities: clarifying 10-year roles, targets, and associated strategies for each management system (captive, Fenced Sites, free-living), and ramping up biosecurity and disease management across the metapopulation, are priorities. Refining population-level management, data management and facility re-design and renewals are also important activities.

Enabling conditions

The following enabling conditions need to be in place to support implementation of the priorities described:

- ongoing community and stakeholder support;
- targeted and appropriate metapopulation-wide monitoring;
- a well-targeted research program;
- regular program evaluation & adaptive management;
- sufficient resources to support implementation of agreed priorities.

Priorities: expanding community and stakeholder support through a range of activities on Christmas and Cocos (Keeling) Islands; updating monitoring programs and protocols; establishing frameworks that clarify key decision points and help ensure that research is targeted towards resolving key areas of uncertainty. Sustaining funding is an ongoing priority. A costing exercise for the plan described here is an essential next step.

Christmas Island Giant Geckos

The giant gecko is one of two endemic Christmas Island reptile species persisting in the wild. Whilst considered abundant in some areas, it is possible the species is being impacted by invasive wolf snakes and other threatening processes. Consequently, it is important the species population trajectory is monitored, current and potential key threats are understood, and relevant conservation actions implemented before any catastrophic decline.

Priorities: develop and implement an appropriate monitoring program to establish the population trajectory for giant geckos; investigate relative impacts of putative threats to giant geckos and how to manage the key threats; establish or confirm husbandry techniques for giant geckos and establish precautionary insurance populations if appropriate.

Christmas Island Blind Snakes

Christmas Island blind snakes are endemic to the island, however there has only been one confirmed sighting (2009) in over forty years and they may already be extinct. Being fossorial they are a highly cryptic and difficult species to detect and monitor. Their threats are also poorly understood compared to other Christmas Island reptile species. Investigation of the status of blind snakes could trigger conservation actions.

Priorities: determine a monitoring methodology for blind snake (e.g., eDNA); establish whether CI blind snakes are extant; determine key threats to blind snakes and identify further priority conservation actions for the species.

DRAFT goals, sub-goals and 10-year performance indicators, are provided below. Further detail is provided in other sections of the document, including program milestones, objectives and actions.

VISION: Populations of native reptile species on Christmas Island are conserved and restored, with all extant species persisting in the wild.

GOAL 1.

The most influential threats are managed effectively.

Sub-GOALs:

- wolf snakes are eradicated in CI Fenced Sites.
- Fenced Sites keep wolf snakes out and BTS & LG in.
- centipede numbers are kept low enough for BTS/LG to persist in Fenced Sites.
- a program is implemented for island-wide wolf snake control if feasible pathway identified.
- general threat abatement continues with priorities & programs aligned with lizard conservation.

10-year performance criteria:

- BTS & LG populations persist in Wolf snake-free Fenced Sites.
- feasibility of island-wide wolf snake control established with control activities underway (if feasible).

GOAL 2.

Metapopulations of BTS and LG are: demographically resilient; genetically diverse; resistant to captive adaptation; secure from disease outbreaks.

- high-performing captive populations are sustained, driving growth, securing gene diversity, providing release animals.
- more large, free-living populations are established on CKI (and elsewhere if feasible), supporting abundance cost-effectively, retaining gene diversity and wild fitness.
- healthy, self-sustaining Fenced Site populations on CI, retaining adaptation to local conditions, improving understanding of threats & preferences.

- viable populations of BTS & LG growing or stable in all 3 management systems
- metapopulation documented, implemented & targets being met.
- metapopulation biosecurity-related protocols & measures in place; informed & risk-based movement of reptiles through the metapopulation; no population-level impacts of disease.

GOAL 3.

Other native reptile species are safe from extinction.

- Christmas Island Blind snakes (BI) are safe from extinction.
- Christmas Island giant geckos (GG) are safe from extinction.

- BI: Extinct/extant status confirmed.
- GG (& BI if extant): viable populations stable or growing in the wild; OR captive populations established & threat mitigation in place in the wild if required.

GOAL 4.

Conditions that enable success are in place.

- communities and other stakeholders are supportive and engaged.
- adequate resources are secured.
- research is well-targeted & used.
- adequate monitoring systems are in place.

Enabling conditions are not limiting progress or success of program activities.

INTRODUCTION

HISTORY OF CHRISTMAS ISLANDS REPTILES - STATUS, THREATS, HABITAT

Editors: Claire Ford, Monique Van Sluys, Lisa Cavanagh.

Historically the reptile fauna of Christmas Island in the Indian Ocean comprised five endemic species: two skinks; the blue-tailed skink (*Cryptoblepharus egeriae,* BTS) and forest skink (*Emoia nativitatis*, FS), two geckos; the giant gecko (*Cyrtodactylus sadleiri, GG*) and Lister's gecko (*Lepidodactylus listeri*, LG), one blind snake; the Christmas Island blind snake (*Ramphotyphlops exocoeti*) and one native, non-endemic skink, the coastal skink (*Emoia atrocostata*).

All endemic Christmas Island reptiles are threatened with the blue-tailed skink and Lister's gecko considered Extinct in the Wild (IUCN Red list) o and Critically Endangered under the *EPBC Act 1999*. A National Recovery Plan was developed for LGs and blind snake (Cogger 2006) and Conservation Advices were drafted for BTS in 2014 and for both species in 2016 and in 2022.

Table 1: Threat listing for Christmas Island endemic reptiles

	IUCN Red list	Australian Environment Protection and Biodiversity Conservation Act 1999
BTS	Extinct in the wild	Critically endangered
LG	Extinct in the wild	Critically endangered
FS	Extinct	Extinct
CI blind snake	Endangered	Vulnerable
CI giant gecko	Endangered	Endangered

In the decade starting 1990, declines in populations' numbers for BTS were reported (Andrew et al 2016, Emery et al 2021) and by 2012, both BTS and LG (and FS) had disappeared from the wild.

A retrospective assessment deemed the Asian wolf snake (*Lycodon capucinus*) to be the primary cause of decline of Christmas Island lizards as its temporal and spatial spread across the island closely matched patterns of lizard disappearances (Emery et al 2021). Other introduced species are also implicated in lizard decline to a lesser extent including the giant centipede (*Scolopendra subspinipes*), yellow crazy ant (*Anoplolepis gracilipes*), as well as cats and rats.

Blue-tailed skink

Blue-tailed skink is a small, insectivorous, and brightly coloured diurnal skink average snout-vent length for adult is 4-5cm. It is moderately arboreal found climbing into the forest canopy, though is far more common within 2m of ground level. Historically, the BTS were abundant and easily found in several different habitats across the island (Parks Australia 2014). It was particularly abundant in the settled area in 1979 (Cogger 1983). The last confirmed sighting in the wild was at Egeria point in 2010.

Lister's Gecko

Lister's gecko with an average snout-vent length for adult is 4-5cm, is an insectivorous gecko with highly variable dorsal markings from marbled to spotted, but always in shades of brown, yellow and off-white.

While more commonly encountered within 2m of ground level, it is mostly arboreal, though in low vegetation and in areas with large limestone boulders the species could be found at ground level. It was thought the last confirmed sighting for LG was 1987 before being rediscovered in 2009. The last confirmed sighting in the wild was in 2012.

Christmas Island Giant Gecko

Christmas Island giant gecko is dark grey, brown or blackish in colour with spotted & flecked lighter patterns. They are a large arboreal gecko. With a snout vent length of 8cm. It has a long tail and thin, birdlike claws for gripping.

They are found in a variety of habitats across the island, from primary rainforest to former mining areas.

They are still present on Christmas Island and reasonably common but numbers are declining.

Christmas Island Blind Snake

Christmas Island blind snake is bright pink or pinkish-brown, they have a rounded snout. Reaching a total length of 35 cm, which includes a tail 8 cm long.

Cryptic in nature, most specimens have been found during clearing of primary rainforest on the plateau. They are also found under fallen logs in the forest.

Last confirmed wild sighting was on 31st July 2009; with few previous records.

Conservation breeding program

The conservation breeding program manages Christmas Island lizards under three different population management structures/intensities which make up the metapopulation:

- Intensive captive breeding program for BTS and LG (Christmas Island and Taronga Zoo)
- Predator-excluded Fenced Sites for BTS and LG (on Christmas Island)
- Free-living, translocated BTS on Cocos (Keeling) Islands

Intensive captive breeding, Christmas Island and Taronga Zoo

Following the steep decline in population numbers for both species, a captive breeding program was initiated in 2009 for BTS and LG. The population size of captive colonies of BTS and LG rapidly expanded, and a subset of the captive populations were transferred to Taronga Zoo in 2011. The captive breeding program has been very successful with populations of BTS growing from 66 wild origin individuals and peaking at approximately 1700 individuals, and LG growing from 43 wild origin individuals and peaking at 1550 individuals.

The 2013 Genetic Management Plan established goals to maintain a population for 10 years: retaining 90% of starting Genetic Diversity [GD]; keeping inter-generational inbreeding coefficient [F] at zero; preventing intra-generational inbreeding coefficients from rising above F=0.125; and maintaining the population in evolutionary stasis with neither selection nor adaptation.

Table 2: Captive Breeding Program Summary

	BTS	**LG**
Founders	66	43
Management Strategy	CI: Maximum Avoidance of Inbreeding (MAI)* TZ: Maximum Avoidance of Inbreeding (MAI)*	CI: Maximum Avoidance of Inbreeding (MAI)* TZ: Mean Kinship (MK)**
Eggs per clutch	2 eggs/clutch (although 1- and 3-egg clutches occur).	2 eggs/clutch (although 1-egg clutches occur). 2-3 clutches per breeding season but up to 5 is possible.
Incubation	60 days (and up to 128 days).	90 days (and up to 139 days).
Sex determination	Not temperature dependent.	Not temperature dependent.
Sperm retention	Yes, females have laid eggs 3mths after being housed separately from males.	Yes, females have laid eggs 3mths after being housed separately from males. Not observed to be parthenogenic; females housed without a male for two years did not lay fertile eggs.
Population size March 2023	CI: 715 skinks (capacity = 450) TZ: 215 (capacity = up to 500, pending resources).	CI: 1123 geckos (capacity of 1000) TZ: 183 LGs (capacity = up to 200, pending resources).

*Maximum Avoidance of Inbreeding (MAI), a low intensity genetic management breeding scheme that involves multi-male and multi-female groups with rotation or exchanges of individuals to minimise or delay inbreeding whilst maximising effective population size.

**Mean Kinship (MK) is a measure of the relatedness of an individual to every living individual in the population. Priority for breeding is given to individuals with low mean kinship values (and therefore fewer relatives) with the intention of equalising founder representation.

Predator–excluded Fenced Sites for BTS and LG, Christmas Island

Two Fenced Sites have been established on Christmas Island for the reintroduction of the Christmas Island blue-tailed skink and Lister's gecko (Circuits [2648m^2 and East-West Baseline [3345m^2). Both are in rehabilitated forest habitat and surrounded by predator-exclusion fencing. Their purpose is to establish self-sustaining populations whilst the threatening processes on island are being addressed. Since the establishment of the first site in 2017, captive bred BTS and LG have been translocated into these sites, which have met varying degrees of short-term success.

BTS released into Fenced Site (CI-origin)

1. 2017 – 137 to Circuits Track
2. 2018 – 170 to Circuits Track
3. 2020 – 200 to W Baseline Site
4. 2023 – 264 to Circuits Track

LG released into SRS (fenced site) - CI-origin LGs

5. -2019 – 160 to Circuits Track
6. 2020 – 200 to W Baseline Site
7. 2023 – 150 to Circuits Track

Translocation of BTS to Cocos (Keeling) Islands (assisted colonisation)

Two self-sustaining populations of BTS have been established on the Cocos (Keeling) Islands representing free-living insurance populations. Captive bred BTS (from Christmas Island and from Taronga Zoo) were translocated to Pulu Blan [2.08 ha] in September 2019 and to Pulu Blan Madar [1.78 ha] in March 2020 (296 successfully released on each), as an assisted colonisation trial which has largely been successful.

Blue-tailed skinks released to Cocos (Keeling) Islands

1. 2019 – CI 150/TZ 150 to Pulu Blan.
2. 2020 - CI 150/TZ 150 to Pulu Blan Madar.
3. 2021 – CI125/TZ125 to Pulu Blan Madar.

BTS and LG management timelines

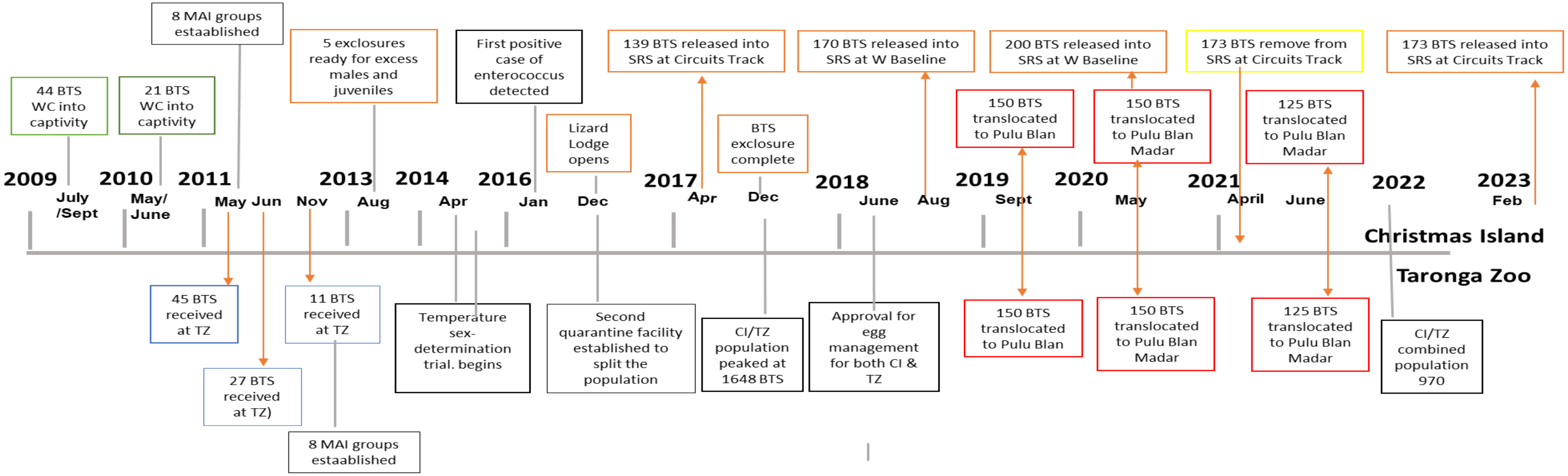


Figure 1.

Christmas Island & Taronga Zoo Blue Tailed Skink Timeline

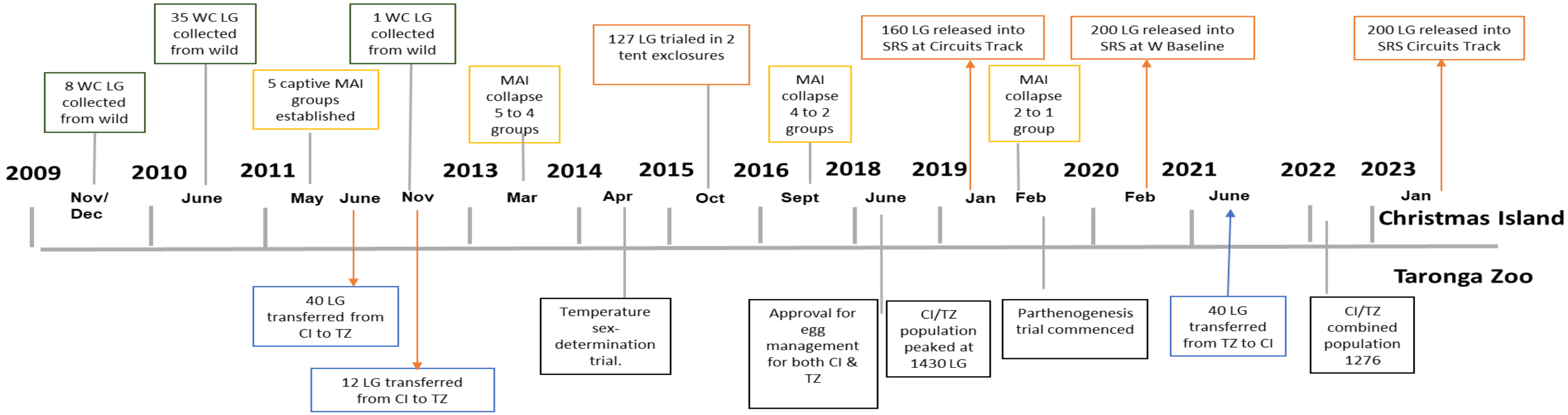


Figure 2.

Christmas Island & Taronga Zoo Listers Gecko Timeline

RISKS TO CHRISTMAS ISLAND REPTILES AND CHALLENGES TO ADDRESSING THEM

INTRODUCTION

Current risks to Christmas Island Lizards and the challenges to addressing or mitigating those risks (referred to collectively here as "issues") were discussed by workshop participants. The issues clustered around four main themes: 1) Management of the physiological, demographic, genetic and behavioural health of blue-tailed skinks and Lister's gecko metapopulations; 2) Developing effective Fenced Sites (large, fenced areas for release) and protocols for hard release; and 3) Managing and expanding free-living populations on Cocos (Keeling) Islands and beyond; 4) Managing key threats and restoring favourable wild conditions on Christmas Island. Working groups were formed around these themes to develop, for each issue, a statement to describe: 1) what the issue is; 2) its impact on Christmas Island lizards or their conservation; 3) the root causes of the issue; 4) any major information gaps relating to this issue that prevent effective action being taken. The results of these discussions are presented below.

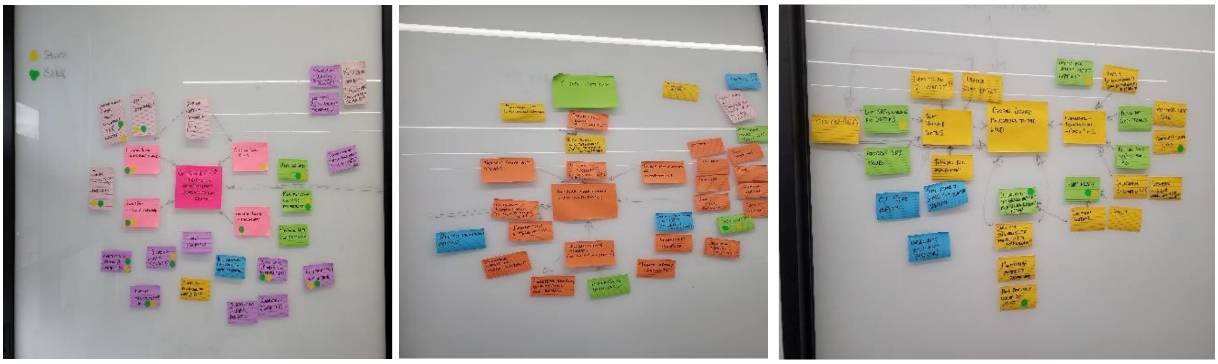
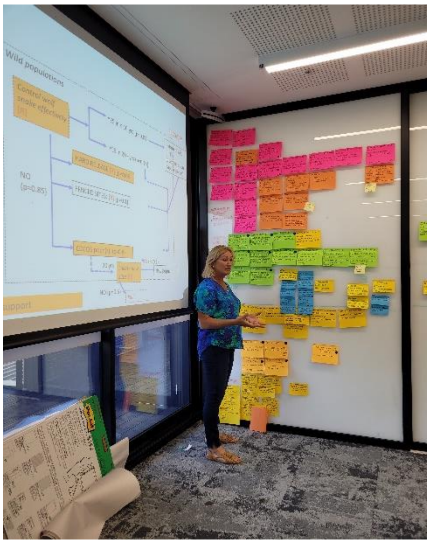


Figure 3. Brainstorm of risks to Christmas Island reptiles and challenges to addressing those risks, by participants of the 2023 workshop during a brainstorming session (see Issues section for details).



Issues related to managing the physiological, demographic, genetic and behavioural health of Blue-tailed Skinks and Lister's Gecko metapopulations

Editor: Claire Ford; **Group members:** Kent Retallick, Matyas Liptovsky, Claire Ford, Karrie Rose and Lisa Cavanagh

Issue 1. Metapopulation management goals and approach

Description: The captive program has been a success, with husbandry protocols and genetic and demographic management now well-established, and baseline molecular genetic profiles assessed. However, the current goals and approach to small population management, including management of health and disease, were designed for the 2014-2024 period. The program has moved on since then and new challenges have emerged. Captive populations currently play a crucial role in securing blue-tailed skinks and Lister's geckos against extinction and providing animals for release. Confirmation of demographic, genetic, health and behavioural goals for the next 10 years, clearly defined roles for each population (captive, wild and fenced), and an understanding of the required interplay between them, will help managers ensure that facilities, protocols and practice keep pace with program needs over the coming decade.

Key information gaps: *Metapopulation and sub-population roles and goals; triggers for winding down or ramping up sub-populations or management systems; optimal biosecurity protocols & logistics for movements; how best to monitor populations in future; how best to align data management and facilitate data sharing across the meta-population; what assumptions to make about effective population size in group-managed sub-populations; how to manage males effectively; how to optimise use of facilities to achieve goals; facility upgrade requirements e.g. for meeting biosecurity needs; whether specific facilities are required for the next 10 years; details of future release programs; agreement on what is an acceptable risk profile for each sub-population (see Appendix VII).*

Issue 2: *Enterococcus* and other diseases

Description: Outbreaks of disease could significantly undermine the management and viability of the metapopulation and welfare of the animals within them. *Enterococcus lacertideformus* was first observed in the Christmas Island captive colony of Lister's geckos in 2014 and later in blue-tailed skinks, its impact is characterised by progressive facial deformity, emaciation and lethargy and can cause significant mortality. It is thought the disease has been contracted from incursions of wild free-ranging feral lizards into captive colony facilities, as well as escaped captive lizards co-mingling with infected wild free-ranging feral lizards and then being returned to captive colonies without quarantine. The prevalence of *E. lacertideformus* in the wild is estimated at 2% (i.e. 2% of individuals are infected with it). *Enterococcus lacertideformus* has not be observed in the Taronga captive populations. It is assumed that the evolution of the *Enterococcus* will be slow (expanding in a clone fashion) and that it may be possible to improve the resilience of hosts. It is also assumed that additional emerging infectious diseases will occur due to the sensitivity and vulnerability of oceanic islands to invasive species.

Key information gaps: *An understanding of the ecology of* Enterococcus *on Christmas Island; mechanisms to protect the captive breeding populations from existing and future disease risk: an* *understanding of transmission routes, incubation periods, effective disinfection protocols; effective treatment; the lack of PCR test; best sample type (e.g. faeces, dead/live tissue, environmental substrates); investigation of susceptibility and resilience; MHC viability; capacity for island level biosecurity.*

ISSUE 3: FACILITIES, CAPITAL AND OTHER RESOURCES

Description: The captive lizard facilities on Christmas Island and at Taronga Zoo are aging and require maintenance and in some cases redesign to ensure they remain fit for purpose. Key consideration for Christmas Island is the capacity to maintain breeding enclosures within Lizard Lodge that can effectively exclude feral wild lizards that could act as disease vectors, and that prevent captive lizard escape. Additionally, building facilities that are resilient to the climate, utilising materials that are available on island. For Taronga Zoo having a functional DAWE approved 7.2 Zoo Animals permanent quarantine that supports required capacity. There are limited resources for capital programs on both Christmas Island and Taronga Zoo. Regarding Fenced Sites, see Issues 5-7.

Key information gaps: *A captive facility design that optimally supports the population management strategy at both sites and addresses biosecurity issues; a Lizard Lodge breeding facility design that adequately contains captive lizards and manages disease risk including the exclusion of feral wild lizards, as well as wolf snakes, and centipedes.*

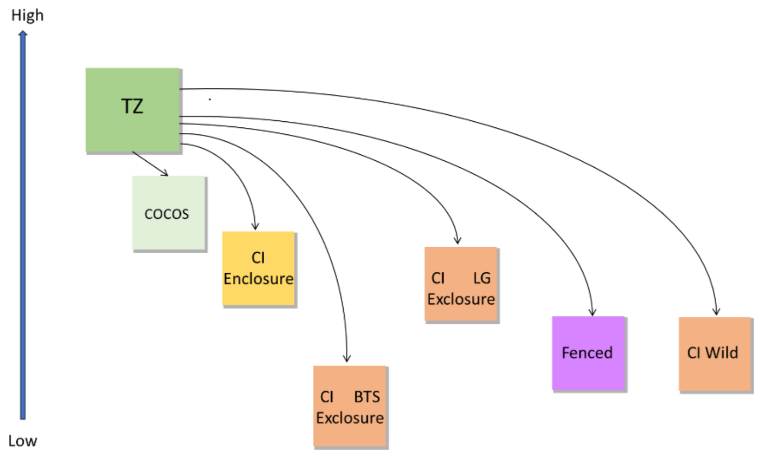


Figure 4. Describes relative health and biosecurity confidence for different BTS & LG sub-populations. The large differences currently impede inter-population movements.

Issues related to developing effective Fenced Sites and conditions for hard release

Editor: Alexia Jankowski; **Group members:** Oliver Lines, Alexia Jankowski, Sam Flakus, Nick MacGregor and Jon-Paul Emery

Issue 4. Purpose and value of Fenced Sites

Description: Fenced Sites on Christmas Island, by design, offer a way to support large populations of lizards under wild conditions, away from the threat of introduced predators. To date, establishing and maintaining them has been challenging and resource intensive. Through numerous trials with BTS and LGs much has been learned, however no fence design has been successful at excluding invasive predators. Meanwhile, BTS populations have been successfully established on two Cocos (Keeling) Islands, addressing some of the original goals of Fenced Sites. Before continuing with fenced site trials, it would be valuable to review the goals of this program component and to weigh the costs and benefits of this approach against alternatives.

Key information gaps: *Future purpose and goals of Fenced Sites.*

Issue 5. Fence design does not exclude predators

Description: Two Fenced Sites have been constructed on Christmas Island with multiple design modifications, however neither has been effective at successfully excluding predators such as wolf snakes and giant centipedes. Christmas Island's climate, temperature and weather conditions make fence construction challenging, and have contributed to fence malfunction and materials not performing as intended. Additionally, wolf snakes, centipedes and invasive gecko species can climb smooth vertical surfaces making adequate fence design a significant challenge. Once wolf snakes enter a site no method currently exists to detect or capture/trap them. Evidence suggests that wolf snakes cause the decline and failure of BTS populations within Fenced Sites, and giant centipedes are also known to prey on reptiles. The only effective method to eradicate both invasive predators from Fenced Sites is via full site destruction and rebuild.

Key information gaps: *Other options for design, materials, shape that may be more suitable for Christmas Island conditions and more effective at predator exclusion. To date design and construction has been undertaken in-house using local trades and builders. Predator-proofing experts who specialise in exclusion fencing have not yet been engaged, and the feasibility of a fully functioning fence on Christmas Island needs assessing.*

Issue 6. Control and eradication of invasive predators from fenced sites

Description: The detection, control and eradication of wolf snakes and giant centipedes from within Fenced Sites has been notoriously challenging to date. Once established within a site these predators can cause catastrophic declines in BTS numbers and an extinction of the population. Wolf snakes are unable to be detected without full site destruction, and no reliable method has been developed for trapping or controlling them. Giant centipedes can be detected through frequent, labour-intensive searches, however no viable control or eradication methods exist without full site destruction and rebuild.

Key information gaps: *Methods to detect the presence of wolf snakes, and methods to lure, trap and ultimately control giant centipedes and wolf snakes within Fenced Sites.*

Issue 7. Habitat within Fenced Sites is not appropriate for both BTS and LG, resulting in LGs leaving the site.

Description: While Fenced Sites have been successful at keeping BTS inside, LGs have been observed leaving the site because fence design is ineffective at preventing their egress. Fences have an internal electrical barrier designed to deliver a low voltage shock to LGs and harmlessly prevent them from leaving. This barrier has not been effective to date. Once outside the fenced site, LGs actively disperse and are likely to be preyed upon by invasive predators. This makes monitoring and measuring the success of LG releases into Fenced Sites unachievable.

BTS and LGs are considered to have different habitat and ecological requirements. BTS are generalists and able to live in many different habitats, whilst LGs were known to inhabit primary, closed-canopy rainforest. Both Fenced Sites have been constructed within rehabilitation fields comprised of regrowth vegetation, therefore it is possible that LGs have chosen to leave Fenced Sites because the habitat is not meeting their needs. It is important to note that LGs continue to live and breed successfully at high densities within captive, tented enclosures filled with bark and stick habitat from which they cannot escape.

Key information gaps: *Other options for specialised fence or barrier design that prevent LGs from exiting the site and perform effectively in Christmas Island's challenging climate and environment. An improved understanding of LG dispersal behaviour and habitat preferences noting that dispersal and habitat usage is highly challenging to monitor.*

Issue 8. Monitoring LGs within Fenced Sites

Description: A method to effectively monitor LGs inside Fenced Sites without significant disruption is yet to be identified. Hide monitoring and nocturnal spotlighting have been used within Fenced Sites as monitoring methods to measure the success of LG releases, however these methods have been found to be ineffective at detecting change in population trend. Capture-mark-recapture (CMR) surveys are known to be statistically effective at monitoring population size however CMR is resource intensive and may cause LGs to disperse from site due to disruption and disturbance.

Ecological and behavioural traits of LGs such as body size, behaviour and movement patterns make them highly challenging to monitor. Without accurate data on semi-wild populations, the success of LG releases cannot be ascertained, and decisions on management actions or future introductions or releases may be uninformed and compromised.

Key information gaps: *Other methods for monitoring LGs that we may be unaware of, would effective LG fence barriers negate the issue of disturbance and allow CMR to be completed.*

Issue 9. Monitoring BTS and LGs after hard release to the wild

Description: A limitation to the experimental hard release of captive bred reptiles is the difficulty in detecting and monitoring animals post-release into the wild. Without being able to monitor released animals we cannot understand population survival, dispersal or predation. Much of Christmas Island's preferred reptile habitat is dense and inaccessible terrain, and monitoring methods used within Fenced Sites are insufficient for wild environments. The key invasive predators of LG and BTS: cats, wolf snakes and giant centipedes remain in the wild and there is a high likelihood of predation.

Key information gaps: *Other methods for monitoring LGs and BTS that we may be unaware of.*

ISSUE 10. MONITORING WOLF SNAKES AND GIANT CENTIPEDES IN AND OUTSIDE FENCED SITES

Description: Wolf snakes and centipedes are key invasive predators of BTS and LG however their life history, physiology and cryptic behavioural traits make them very challenging to detect and monitor in any environment. Without effective monitoring of key predators within Fenced Sites and in the wild environment we cannot ensure longevity of released populations or make informed decisions about potential wild releases. Whilst terrestrial eDNA poses some potential for presence/absence detection of invasive predators, it is yet to be trialled and no other monitoring method has been identified for wolf snakes. Giant centipedes may be counted and destroyed via labour-intensive searching of habitat or pit-fall traps however no other effective tool to measure changes in abundance have been identified.

Key information gaps: *Understanding of wolf snake distribution on Christmas Island, other monitoring methods that may be effective, but we are unaware of.*

ISSUE 11. RESOURCING FOR FENCED SITES NEEDS TO BE SUSTAINABLE TO MAINTAIN SITES

Description: Fenced Sites require significant and ongoing levels of intervention and maintenance both to the fences themselves, and to the habitat within the site, for the best chance of predator exclusion and released population success. From several releases it is now known that ongoing maintenance, monitoring and intervention requirements at release sites are greater than originally expected. Available resources have been inadequate to maintain sites to the standard required to achieve this. Instead of developing a resourced strategy for ongoing maintenance of the site at the pre-construction phase, fenced site maintenance has been undertaken as resources become opportunistically available, and current resources have been used to plan and guide what can be achieved. It is also likely that that the goals and objectives of Fenced Sites have changed over time but resourcing has not been scaled accordingly.

Key information gaps: *Understanding the full cost and resource requirements of Fenced Sites including capital, maintenance and operational costs.*

ISSUE 12. ETHICS OF RELEASES TO THE WILD (HARD RELEASE)

Description: The experimental wild release of captive-bred reptiles has, to date, not received ethics approval due to wolf snakes and centipedes persisting uncontrolled and unmanaged in the wild, and an inability to effectively monitor population trends and the success of a release over time. A perception/view exists that as the root causes of species decline haven't been addressed, a reptile hard release should not be approved because the outcome will be mortality. Whilst this may be the case, trialled hard releases of animals for research purposes would provide opportunities to learn and trial monitoring techniques in preparation for future releases in a predator-controlled environment.

Key information gaps: *Ability to monitor reptiles released into the wild, alignment on ethics position around hard release as a management action vs research action.*

Issues related to managing and expanding free-living populations on Cocos (Keeling) Islands and beyond

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ISSUE 14: Cocos (Keeling) Islands are not a long-term (>20 years) solution

Description: Due to sea-level rise, habitat availability on the CKI is already reduced and it is assumed that within 20 years Pulu Blan and Madar will be underwater. This will significantly reduce habitat available for the long-term establishment of translocated populations. There is sound information and evidence that sea level is already higher than previously anticipated.

Information gap: *It is important to address the timeframe assumption (20 years) and examine what are the real risks to the islands and their timeframe.*

ISSUE 15: Surge of extreme weather events

Description: Extreme weather events such as high tides, higher swells, and stronger cyclones have become more frequent at CKI because of climate change. Meteorological predictions and modelling, coupled with local knowledge acknowledge extreme events are getting worse and unpredictable. The assumption is that the extreme weather events will have a significant detrimental effect on wild BTS as habitat will be lost to erosion, lizards were subject to higher mortality, and nesting success will decrease (loss of egg-laying habitat).

Issue 16. Biosecurity risk from new species invasions into Cocos and new incursions of existing invasive species

Description: There's potential increase in biosecurity risk associated with the upgrade of the CKI airport infrastructure. It is assumed that the increase in works for the infrastructure upgrade pose a high risk of the introduction of new, and the increase of current, invasive species population numbers, both predators and competitors as well as pathogens potentially causing disease outbreaks. The biosecurity risk also applies to potentially moving lizards out of CKI, if required. The introduction of new exotic species is a risk of pathogen introduction in a new environment. Increase in competition and predation via invasive species.

Key information gaps: *What the current biosecurity process in CKI is and how effective it is (e.g. are the biosecurity processes and protocols well-enough resourced to avoid incursions, what protocols and permits need to be adhered to for translocating lizards out of CKI).*

ISSUE 17: Lister's Gecko Translocation

Description: There is no insurance population for LG outside captivity. The suitability of Cocos (Keeling) Islands to sustain free-living insurance populations is unknown due to potential risk of competition with invasive geckos (e.g. *Hemidactylus frenatus*, *Gehyra mutilata*) and impact of (including possible hybridisation with) *Lepidodactylus lugubris*. Another issue is the current lack of an adequate monitoring protocol for LG.

Knowledge gaps: *Habitat suitability of CKI for LG; capacity of LG to hybridise with* L. lugubris*; impact of a potential translocation to Cocos upon* L. lugubris *populations, monitoring methods to detect LG population changes.*

Issue 18. Uncertainty about how and where to establish additional wild populations of LG and BTS outside of Cocos (Keeling) Islands and native range

Description: There are too few secure populations to safeguard both lizard species long-term. Additional LG and BTS insurance populations are needed. We assume that CKI will be submerged in a few decades, therefore the expansion of LG and BTS populations to other sites is required for their long-term viability. However, where and what additional potential release sites (including their carrying capacity, suitability and vulnerability to climate change) for each species are still unknown. There are also biosecurity and genetic implications to address when considering sending lizards to other sites.

Issue 19. Unknown capacity for support from stakeholders and inadequate funding from government

Description: Two translocations of BTS have now occurred on Cocos (Keeling) Islands, with support from community and stakeholders and ongoing population monitoring and maintenance continue. A third translocation of BTS or LG requires community and stakeholder engagement and support, and adequate funding for the planning, implementation and ongoing maintenance and monitoring phases until populations can be deemed secure and self-sustaining. Without appropriate funding for post-release management, program effectiveness may be compromised, information and experience lost, and DNP reputation put at risk. Whilst Cocos Island Adventure Tours provide citizen science monitoring support, community consultation before, during and after translocations needs to be improved.

Key information gaps: *The capacity (untapped) for support; external funding opportunities; long-term commitment to funding.*

Issue 20. Methods for monitoring Lister's geckos have not been developed to incorporate into a monitoring plan

Description: LG are known for their cryptic and camouflaged behaviour, which made it difficult to assess their conservation status and the processes threatening the species leading up to their extinction from the wild. Methods trialled for monitoring LG population density and dynamics, and release success in Fenced Sites have not been effective (see Issue 8). Without monitoring methods which can produce accurate data on the success of LG releases, decisions on management actions or future introductions or releases may be uninformed and compromised, and threatening processes may go unnoticed. Resources may be wasted if monitoring does not directly respond to the aims and questions required to evaluate program success.

Key information gaps: *Accurate methods for detecting LG and monitoring population trends, that can be used to develop a post-translocation monitoring plan for populations in indigenous and non-indigenous areas proposed for assisted colonisation trials; an understanding of the frequency in which potential existing threats (that are unable to be eradicated) need to be monitored and controlled (i.e., YCA, rats, invasive house geckos); an understanding of useful translocation success criteria that reflect the biological and ecological capabilities of LG, and a definition of the success of the program.*

Issues related to managing key threats and restoring favourable wild conditions on Christmas Island

Editor: Brendan Tiernan; **Group members:** Brendan Tiernan, Kerrie Bennison, Freya Hicks, Xianna Te Kotuku Gibson Khaw, Michael McFadden, Jeff Dawson, Lin Gaff and John Woinarski.

Issue 21. Relative impacts and importance of threats on Christmas Island

Description: Christmas Island biodiversity has been affected by many threats (especially invasive species introduced due to inadequate biosecurity), and many of these threats will affect the likelihood of success for any conservation options. Robust evidence (timing, predation records, etc.) strongly implicate wolf snake as the primary threat. Other potential causative factors include: giant centipede, cadmium, YCAs, insecticides applied for YCA control, spiders, cats, rats, disease, competition with introduced reptiles, mining/habitat loss and degradation.

Key knowledge gaps: *More information is needed on the relative impacts of threats, and on capability to control them – in order to prioritise management responses, e.g., cadmium, disease in the wild, introduced lizards, reduction in food resources due to insecticide use.*

Issue 22. Non-target impacts of various threat abatement measures

Description: Some management actions currently being applied, notably baiting for YCAs (Fipronil) and eradication of feral cats, may have indirect collateral detriments to BTS and LG such as reducing food resource availability (e.g., reducing invertebrate abundance) or causing mesopredator release (e.g., increase in rats, introduced reptiles, wolf snakes).

Key knowledge Gaps: *Net benefits or detriments of Fipronil application on invertebrate resources is undetermined. There are also some uncertainties about ecosystem repercussions of cat eradication such as impact to rats and other reptile populations including primary threat wolf snakes.*

Issue 23. Lack of knowledge about the wolf snake

Description: The invasive wolf snake is a small, cryptic species of colubrid snake. It is considered the primary threat to CI reptiles, however substantial knowledge gaps exist regarding wolf snake ecology and status, distribution on the island, as well as monitoring methods, which constrain the development and implementation of potential management options. For example, wolf snake ingress in small, Fenced Sites designed to keep the species out have been difficult to detect despite intensive monitoring using multiple methodologies.

Key knowledge gaps: *wolf snake ecology, distribution, density and suitable monitoring methods; Interplay between wolf snake distribution and density and red crab density.*

Issue 24. How to control wolf snakes on CI effectively

Description: The wolf snake is considered the major cause of CI reptile declines in the wild and impediment to their recovery. There is currently no effective control measure, even in small localised areas (e.g., Fenced Sites) and without effective wolf snake control, re-establishing wild populations of BTS and LG on Christmas Island will not succeed.

Knowledge Gaps: *No established control methods for wolf snakes on CI, and eradication of invasive snakes has proven problematic globally; potential role of biotechnologies (e.g., gene drive) to combat the problem is unknown.*

Issue 25. Inadequate biosecurity on Christmas Island

Description: Many invasive species have been introduced to CI, largely because of ongoing weaknesses in biosecurity. Many of those shortcomings remain, and potential for new invasions continues.

Key knowledge gaps: *Identification of the major potential biosecurity risks to Christmas Island i.e., a prioritised list of pest/weed/disease species that are of high likelihood of entry and could cause significant biodiversity impact. Mechanisms that would support a better coordinated and resourced biosecurity approach.*

Issue 26. Reptile disease and health

Description: Disease (such as *Enterococcus*) can be a major cause of mortality in captive populations of BTS and LG, however little is known of its potential impact on extant wild native reptile populations. Other potential health threats such as impact of cadmium is not fully understood.

Key knowledge Gaps: *A lack of understanding of impact of diseases such as* Enterococcus *on wild lizard populations on Christmas Island. Lack of understanding of impact of cadmium (from mining) on Christmas Island wildlife.*

Issue 27. Community engagement – lack of knowledge, understanding, support for program

Description: Long-term conservation of CI biodiversity is dependent upon the support of the local community and level of knowledge and engagement currently is patchy and suboptimal. Conservation outcomes for CI biodiversity will be enhanced with community awareness and support; or likely to be constrained without such support.

Key knowledge Gaps: *Understanding of the current level of community awareness and support, and identifying how can messaging be more effective. Identified opportunities for more community involvement in reptile conservation efforts.*

Issue 28. Conservation of the Christmas Island blind snake and giant gecko

Description: The loss of LG, BTS, coastal skink and forest skink showed that extinction can happen rapidly, and we should not be complacent about the status of extant CI species. The CI blind snake is very hard to detect and has been reported only once in *ca.* 30 years and it may need urgent conservation attention, while the giant gecko remains abundant in many areas, but its population trend is unclear.

Focus on the two species in captivity may be detracting from the plight (potential or realised) of the CI blind snake and CI giant gecko. The causal factors of reptile declines on CI still persist. Wolf snakes, cats and giant centipedes are known to prey on giant geckos, and giant geckos may now be more targeted (given loss of other native reptiles).

Key knowledge Gaps: *There is no established monitoring methodology for CI blind snake and it's not even known if it still exists. eDNA monitoring may be difficult as little genetic information exists. Further, its threats are largely unknown and therefore any interventionist actions are also unknown; population status and trajectory are largely unknown for the giant gecko. Relative impacts of putative threats to giant geckos; and how to manage the key threats remains unknown.*

Issue 29. Lack of resources, and lack of systematic information on costs and feasibility of management options

Description: There are many actions needed to conserve CI reptiles; but some uncertainty at present on what are the main priorities, and how much funding is required. Quantification of resources needed to achieve conservation outcomes (including feasibility, costs, priorities, collateral benefits) would be beneficial. The conservation of CI reptiles is a long-term challenge and will require long-term funding targeted to the highest priority concerns.

Key knowledge Gaps: *Work on the feasibility, costs, collateral benefits, priorities for conservation actions are yet to be completed. Ongoing and sufficient funding and support for conservation of CI reptiles is yet to be secured.*

THE DRAFT PLAN

CONTEXT AND OVERVIEW

The Christmas Island Reptile Conservation Program has been running for over a decade. For blue-tailed skinks and Lister's geckos captive populations have been established successfully, providing insurance against extinction and retaining high levels of genetic diversity. In addition, for blue-tailed skinks, successful releases have led to healthy, free-living populations on Cocos (Keeling) Islands that provide additional insurance and guard against captive adaptation. These management systems are supporting the species and buying time while avenues for mitigating remaining risks on Christmas Island are explored and tested. On Christmas Island, though much has been learned about the original causes of decline and significant advances made in their management, wolf snakes and centipedes are proving the biggest and most intractable barrier to wild releases, and disease the biggest challenge to maintaining healthy captive populations. Christmas Island giant geckos and blind snakes need attention to confirm population status and trends and to direct action if needed.

Based on the issue statements developed in the previous section, workshop participants developed four goals, 24 objectives and 72 actions which, if implemented, would be expected to prevent extinction and drive recovery of the four species over the coming decade. A Vision was retained from the previous plan. The Vision, Goals and Sub-goals are described below, with added milestones describing the expected pathways to success. Objectives and Actions associated with each Goal are shown in the section beneath.

VISION

Populations of native reptile species on Christmas Island are conserved and restored, with all extant species persisting in the wild.

GOAL 1. The most influential threats are managed	
10-year sub-goals	**Milestones**
Wolf snakes are eradicated within Fenced Sites.	• Methods of local control for wolf snakes identified through research and trials. • Methods of control implemented in Fenced Sites. • Control methods working at Fenced Sites; wolf snakes absent.
Fenced Sites keep wolf snakes out and BTSs and LGs in.	• New fence designed to meet program needs. • Suitable site(s) identified and new fence/s installed. • New fence working as required.
In Fenced Sites, centipede numbers, are low enough for BTS and LG populations to persist.	• Methods of local control for giant centipedes identified through research and trials. • Control methods implemented in Fenced Sites. • Control methods working at Fenced Sites; centipede numbers adequately controlled.
An ongoing program is directed towards developing island-wide control for wolf snakes.	• Feasibility of island-wide wolf snake control is assessed. • If feasible, a pathway for this is established and control activities commenced.
General threat abatement continues, priorities and progress are regularly re-confirmed with respect to lizards.	• Processes in place to review and if necessary, modify wider threat abatement programs to maximise benefits and minimise costs to lizards.
Overall Performance Criteria (10 years):	
• BTS and LG populations persist within Fenced Sites.	
• Documented feasibility assessment for wolf snake control island wide. If feasible, a pathway to this outcome established and control activities commenced.	

Note: wolf snakes must be eradicated within Fenced Sites. Outside fences wolf snakes must be controlled to densities at which lizards can persist.

GOAL 2. Metapopulations of blue-tailed skinks and Lister's geckos are demographically resilient, retain high levels of genetic diversity, avoid adaptation to captivity, and are insulated against disease outbreaks.	
10-year sub-goals	**Milestones**
High performing captive populations are sustained: as engines for the metapopulations driving growth, securing gene diversity, providing release animals.	• 10-year targets are confirmed with trigger points for winding up/down. • Biosecurity, facilities, management & reporting reviewed and revised to align with new targets. • All release requirements met.
More large, free-living populations are established on Cocos (Keeling) and/or elsewhere: guarding against captive adaptation and increasing metapopulation size cost-effectively.	• 10-year targets are confirmed with trigger points for winding up/down. • Additional populations of BTS & LG established on Cocos (Keeling) Islands. • Biosecurity, facilities, management & reporting reviewed and revised to align with new targets. • Other release sites assessed and progressed if suitable.
Healthy, self-sustaining fenced site populations on Christmas Island: ensuring a population adapted to wild CI conditions and providing for improved understanding of threats and habitat preferences.	See also GOAL 1. • 10-year targets are confirmed with trigger points for winding up/down. • Biosecurity, facilities, management & reporting reviewed and revised to align with new targets.
Overall Performance Criteria (10 years):	
• Viable populations of BTS and LG growing or stable at carrying capacity or growing in all three management systems (captive, fenced and free-living).	
• Comprehensive metapopulation plan documented, implemented and agreed targets being met.	
• Metapopulation biosecurity-related protocols & measures in place; informed & risk-based movement of reptiles through the metapopulation; no population-level impacts of disease.	

GOAL 3. Other native reptile species are safe from extinction.	
10-year sub-goals	Milestones
Christmas Island Giant geckos are safe from extinction	• Monitoring programs in place with capability to detect changes in distribution or abundance, and the cause(s) of decline. • Population trends established. • If needed, demographically & genetically resilient captive insurance population established & threat mitigation in place in wild*.
If extant, Christmas Island Blind Snakes are safe from extinction	• Detection and monitoring methods established. • Monitoring program effectively assesses status. If extant: ○ Ecology and threats understood. ○ Wild animals captured and husbandry requirements understood. ○ Captive population established OR viable populations in the wild maintained (depending on population trends).
Overall Performance Criteria (10 years): Giant gecko	
• Viable populations are stable or growing in the wild (preferred) OR	
• Captive populations established and threat mitigation in place in the wild (if required).	
Overall Performance Criteria: Blind snake	
• Extinct/extant status confirmed.	
• If extant, viable populations are stable or growing in the wild (preferred) OR	
• Captive populations established and threat mitigation in place in the wild (if required).	

*Suggested triggers for intervention include 30% decline over ten years, or trends that predict that decline

GOAL 4. Conditions that enable success are in place	
10-year sub-goals	Milestones
Stakeholders & Communities are supportive and engaged.	• Community feedback sought and received, to assess engagement and support. • Schedule of communications established with communities on CI & CKI. • Long-term engagement programs implemented and funded (e.g. Junior Rangers, Citizen Science initiatives, conservation content embedded in schools' curriculum). • CKI Home Island Elders engaged and supportive of conservation actions.
Adequate resources are secured.	• Draft recommended actions are assessed, costed and priorities reviewed & confirmed.
Research is well-targeted & used	• Appropriate decision tools support research prioritisation. • Research results shared regularly and informing management.
Adequate monitoring systems are in place.	• Adequate detection and monitoring systems in place across the meta-population. • Detection and monitoring information shared regularly & informing management.
Adequate island-wide biosecurity is in place.	• Relationships and regular communication with key influencers & stakeholders established and maintained (CI & CKI). • Risk assessment completed & priority measures identified are in place.
Overall Performance Criteria (10 years):	
• Enabling conditions are not limiting progress or success of program activities.	

GOAL 1. THE MOST INFLUENTIAL THREATS ARE MANAGED.

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
Obj. 1	**Fill key knowledge gaps that impede understanding of wolf snake ecology, abundance, and habitat use.**							
1.1	Engage in post-doc partnership (or equivalent) with research institution or specialist consultant to investigate detection and eradication methods of wolf snakes on Christmas Island a) within Fenced Sites (without site destruction) and b) Island-wide.	1. Detection of 100% of snakes within an enclosed area. 2. Ability to lure/trap/bait snakes successfully, to remove 100% of them from an enclosed area.	X	X			Partnership between Parks Australia and a research institution or specialist consultant.	2
1.2	Trial eDNA as a method of detecting wolf snakes.	Report, with recommendations.	X				Parks Australia, consultants (Cesar).	4
1.3	Research and trial other monitoring methods for wolf snakes.	Reports, with recommendations. Effective monitoring method(s) identified.		X			Consultants, university collaboration.	4
1.4	Undertake further research on wolf snake ecology knowledge gaps.	Report wolf snake ecology better understood.		X			Consultants, university collaboration.	4
Obj. 2	**Identify & assess feasible, effective options for wolf snake control or eradication a) in Fenced Sites (without site destruction) and b) island-wide.**							
2.1	Constantly review and consult with international experts on snake control methods through forum/network e.g., Guam.	CIRAP meeting updates.	X	X	X	X	Parks Australia, CIRAP.	4
2.2	Trial scent lure and trap control methods including captive trials.	Assessment of methods and effective lure and trapping method identified (report).		X			Parks Australia, consultants, university collaboration.	4

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
2.3	Investigate potential of gene drive techniques as a control / eradication method.	Assessment of gene drive technique as an effective control/eradication method (report).			X		University researcher.	4
2.4	Trial additional control methods as identified.	Assessment of additional techniques as effective control/eradication methods (report).			X		Parks Australia, consultants, university collaboration.	4
Obj.3	**Develop a reliable method to control centipedes within Fenced Sites.**							
3.1	Investigate detection and control methods of giant centipedes within Fenced Sites on Christmas Island.	Detection and successful suppression of centipedes and an ability to monitor this.		X			Partnership between Parks Australia and a research institution.	2
Obj. 4	**Design, locate & establish a fence that effectively excludes predators, can withstand Christmas Island conditions and prevents LGs from escaping.**							
4.1	Engage expert consultant on design and feasibility of a fence that will exclude predators (wolf snakes, centipedes and rats) and keep in LGs.	A fence design that can feasibly and cost effectively prevent predator incursion and LG egress. TRIGGER FOR CHANGE: Design or cost is deemed infeasible and Fenced Sites are sunsetted.	X	X			Parks Australia and leading predator-proof fencing expert.	2
4.2	Choose a preferred location on CI for the new Fenced Site.	A suitable location identified that can accommodate the proposed design and meet all requirements.		X			Parks Australia.	2
4.3	Engage contractor to construct preferred fence design in selected location.	Fence constructed to specification meeting contract conditions.		X			Parks Australia.	2
Obj. 5	**Implement wolf snake control at different scales.**							

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
5.1	Apply learning from research trials to implement wolf snake control at small-scale (i.e. at new Fenced Site, which can sustain LG and BTS).	Wolf snakes eradicated, centipedes & other predators under control in Fenced Site. BTS & LGs contained.		X			Parks Australia.	4
5.2	Apply learning from research trials to implement wolf snake control actions island wide.	Wolf snakes eradicated from CI.				X	Parks Australia.	4
Obj. 6	**Evaluate and minimise impacts on BTS and LG (and their resources) of existing threat management programs.**							
6.1	Rank in order of priority the threats to CI lizards and establish the mechanisms to address those threats. Review threats prioritisation periodically.	Revised threat priority list.			X		Parks Australia., CIRAP, external experts.	4
6.2	Assess impact of Fipronil usage on invertebrate and other non-target species populations on CI.	Report with recommendations.	X				Consultants (Cesar).	4
6.3	Implement any recommended actions from Fipronil impact study.	Reports on implemented actions, impacts from Fipronil use mitigated.		X			Parks Australia.	4
6.4	Assess impact of cat eradication on rat abundance and rat reptile predation on CI.	Report, impacts understood.		X			Parks Australia.	4
6.5	Assess impact of cat eradication on invasive gecko species.	Report, impacts understood.		X			Consultant.	4

GOAL 2. METAPOPULATIONS OF BLUE-TAILED SKINKS AND LISTER'S GECKOS ARE DEMOGRAPHICALLY RESILIENT, RETAIN HIGH LEVELS OF GENETIC DIVERSITY, AVOID ADAPTATION TO CAPTIVITY, AND ARE INSULATED AGAINST DISEASE OUTBREAKS.

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
Obj. 7	**Manage efficient and effective metapopulations of BTSs and LGs that safeguard against extinction and provide for expansion over time.**							
7.1	**Develop metapopulation-level genetic and demographic targets and high-level management plan: for captive, fenced, free-living, & CI wild sub-populations (including definitions of sub-population roles, evaluation criteria & monitoring & reporting protocols, projected schedule of releases).**	10-20 years metapopulation-wide genetic & demographic targets and 10-year management plan defined & documented.	X	X			Parks Australia, Taronga.	1
7.2	• Establish metapopulation-wide molecular genetics analysis & monitoring to inform genetic management planning & evaluation of success.	Genetic information is incorporated into genetic management planning & evaluation.	X	X			Taronga, University of Sydney.	1
7.3	• Develop protocols and an online platform for data collection and sharing, based on agreed meta-population needs.	Protocols documented, accessible data sharing; online platform supporting adaptive management.	X	X			Parks Australia, Taronga	1
7.4	• Complete a cost-benefit analysis of the 10-year metapopulation management plan and each of its components.	Cost/benefit analysis completed. Benefits & trade-offs of chosen approaches documented and understood.	X	X			Parks Australia.	1

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
Obj. 8	**Ensure high-performing captive populations that safeguard against extinction and provide animals for release.**							
8.1	**Develop sub-plan for captive populations: confirm roles, genetic & demographic targets, 10-year captive breeding strategy, management of relevant biosecurity & behaviour factors, triggers for ramping up or winding down, whether or how best to mix CI & TZ lines. Incorporate any new information from molecular genetic studies and studies of multi-male, multi-female systems (see also actions 8.2-8.5).**	Clear roles, targets, management strategies and plans available for captive populations, for the next 10 years.	X	X			Parks Australia, Taronga.	1
8.2	• Investigate individual contributions to captive breeding in multi-female multi-male tanks & amend management plans if needed.	Refined estimates of effective population size built into management plans.	X	X			Taronga.	1
8.3	• Implement behavioural assessment of the captive populations to ensure lizards are predator aware (especially to snakes) and can hunt for food.	Post-release survival is maximised.	X	X			Taronga.	1
8.4	• Review aging captive facilities (all sites) and renew/add/decommission as needed, to ensure delivery of program objectives, **especially biosecurity and containment** but also size, flexibility, ergonomics, ease of cleaning, watering/misting systems to prevent gout, drainage & lighting. Prioritise Lizard Lodge refurbishment since it is the only breeding facility on CI. (See also biosecurity actions under Objective 15., esp. 15.5).	Facilities adequate for 10-year program goals & objectives.	X	X			Parks Australia, Taronga.	1

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
8.5	• Explore opportunities for expansion of CI and TZ populations, including establishment of additional sites prioritising LG. Implement where useful and achievable.	Expansion opportunities assessed. Where useful and feasible, resources acquired, partnerships formed, and agreements and facilities are in place to fulfil expansion plans. E.g. Perth Zoo.	X	X			Parks Australia, Taronga, new partners (e.g., Perth Zoo)	1
8.6	• Review the purpose, costs, value & design of exclosures with a view to increasing their contribution to the program. If feasible, align biosecurity with that of CI enclosures. Consider potential for a "Gecko Dome" (completely enclosed tent at one of the exclosures).	Documented cost-benefit of biosecurity alignment between Pink House exclosures and Lizard Lodge enclosures. Depending on outcome: biosecurity status aligned, animals in exclosures have a functional role in the metapopulation.	X	X			Parks Australia, Taronga	1
Obj. 9	**Secure and expand the contribution of Cocos (Keeling) populations of BTS and LG and develop populations that are robust enough to survive extreme events.**							
9.1	**Develop high-level plan for Cocos (Keeling) free-living populations: confirm roles, genetic & demographic targets, success thresholds for translocation programs, triggers and protocols for ramping up or winding down and for intervening in the event of extreme events and ongoing sea-level rise (see also action 10.2 and actions 22.1-22.3).**	Clear roles, targets, management strategies and plans available for Cocos (Keeling) free-living sub-populations, for the next 10-20 years.	X	X			Parks Australia, Taronga.	1

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
9.2	• Ensure management and monitoring plan for Cocos (Keeling) populations includes monitoring (and prediction of) impacts from extreme events, and protocol for management/trigger point intervention if required **(see also action 10.2 and actions 22.1-22.3)**.	Monitoring program includes assessment of extreme events and impacts to populations. Intervention protocols in place.		X			Parks Australia, (desktop and ground staff).	3
Obj. 10	**Establish more than one self-sustaining population of LGs on Cocos (Keeling) Islands within the next 3 years.**							
10.1	Evaluate risk of LG translocation to CKI (i.e. likelihood, consequence of hybridisation with *L. lugubris*, native status of *L. lugubris*) and potential impacts of other threats such as YCAs.	Having the knowledge and tools to decide whether or how to translocate.	X					3
10.2	Develop breeding and translocation plan (including permits, animal ethics, biosecurity approvals), then monitoring and management plan (see also actions **9.1-9.2**, **22.1-22.3**), Shire approvals, community engagement plan.	Plans developed and permit granted for translocation.		X			Parks Australia and CIRAP with external input.	3
10.3	Implement a trial translocation to monitor LG (island TBD).	Established population, according to success criteria outlined in translocation plan.		X			Parks Australia.	3
10.4	Translocate an additional population to CKI, island TBD (following successful trial).	New population on CKI		X			Monitoring: Parks Australia, University collaboration.	3
Obj. 11	**Find alternative locations on Cocos (Keeling) for both species.**							
11.1	Evaluate the feasibility of other islands in CKI that are larger, more complex, with higher elevation for a translocation for both species.	Feasibility report outlining islands suitable for translocation.	X				Parks Australia, Cocos Shire.	3

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
Obj. 12	**Establish additional self-sustaining, free-living populations outside Cocos (Keeling) Islands (BTS & LG).**							
12.1	In consultation with other agencies and Traditional Owners, research new potential islands for translocations, including potential risks of any such translocation to the biota of those islands.	Report/plan.					Parks Australia, CIRAP.	3
12.2	Conduct a feasibility assessment (ground truthing) collaborating with landholders and agency.	Feasibility of assessed sites identified.		X			Parks Australia.	3
12.3	Carry out actions 10.1-10.4 for new site (if identified). Incorporate new site(s) into the metapopulation plan.	Population(s) outside CKI and CI established and managed as part of the metapopulation.			X		Parks Australia.	3
Obj. 13	**Manage secure, healthy populations within Fenced Sites as integral components of the metapopulations.**							
13.1	Develop plan for CI populations within Fenced **Sites:** confirm roles, genetic & demographic targets, biosecurity management, triggers and protocols for ramping up or winding down.	Clear roles, targets, management strategies and plans available for populations in Fenced Sites for next 10-20 years.	X	X			Parks Australia.	
13.2	Implement plan for populations within Fenced Sites once this becomes possible, following Objectives 2-5.	Secure, healthy populations within Fenced Sites operating as part of BTS & LG metapopulations.		X	X	X	Parks Australia.	
Obj. 14	**Establish a program and plan for CI wild releases.**							
14.1	Develop a plan for experimental wild releases that define research questions and success criteria.	A plan is created and implemented.		X	X		Parks Australia.	2
Obj. 15	**Manage metapopulations of BTSs and LGs that are free from and resilient to deleterious impacts of infectious, parasitic and toxicological disease processes.**							

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
15.1	Access to PCR testing to determine who is infected and what they are infected with.	Accessible PCR test for *Enterococcus* for live lizards.		X			ARWH.	1
15.2	Attempt growing organisms, determine effective disinfections.	Effective disinfectant identified (for *Enterococcus* and other disease) and utilised in captive management protocols.	X	X			ARWH.	1
15.3	Investigate transmission routes for *Enterococcus* e.g. mesh-to-mesh contact, faeces, substrate, water, exhibit furniture.	Thresholds for translocation success confirmed (or amended as needed).		X			ARWH.	1
15.4	Implement biosecurity and translocation protocols to mitigate *Enterococcus* transmission risk.	Biosecurity and translocation protocols adequate for mitigating *Enterococcus* transmission risk.	X	X			ARWH.	1
15.5	Carry out biosecurity review of Christmas Island captive facilities (including quarantine facility) and develop protocol for animal exhibit moves, escapes & translocations. Prioritise Lizard Lodge.	Biosecurity information is available for the development of next 10-year management plan.	X				Parks Australia, Taronga, ARWH.	1
15.6	Identify new emerging bacteria to understand life-cycle and transmission routes.	New bacteria identified and transmission routes understood and mitigated.	X	X			ARWH.	1
15.7	Explore cadmium distribution and ecology across the island, i.e. how it moves between water, plants, soil, air, dust, and monitor animal food sources for cadmium.	Cadmium impact information for CI lizards documented and available for development of next 10y management plan and animal food sources monitored for cadmium.	X				ARWH.	1
15.8	Review nutritional analysis and supplement sources.	Nutritional analysis conducted and diet sheets updated.	X				Taronga.	1

GOAL 3. OTHER NATIVE REPTILE SPECIES ARE SAFE FROM EXTINCTION.

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
Obj. 16	**Achieve effective conservation of CI giant geckos through enhanced knowledge and management.**							
16.1	Review monitoring methods and identify method(s) to be used for giant gecko.	Report, with recommendations.	X				DCCEEW NESP, Parks Australia.	4
16.2	Undertake regular monitoring of giant gecko on CI (note: start time contingent on identification of suitable methods - action 16.1).	Monitoring reports including population metrics e.g. relative abundance.	X	X	X	X	DCCEEW NESP, Parks Australia.	4
16.3	Review threats, assess impacts and identify further priority conservation actions for giant gecko.	Report, with recommendations.		X			Parks Australia.	4
Obj. 17	**Achieve effective conservation of CI blind snakes through enhanced knowledge and management.**							
17.1	Lit. review and consultations into blind snake ecology, behaviour and survey/monitoring methods.	Report with list of recommendations.	X				Parks Australia.	4
17.2	Develop primers for CI blind snake from museum specimens (for eDNA surveys).	CI blind snake primers developed to be used in eDNA survey.	X				Cesar.	4
17.3	Implement eDNA monitoring to detect and survey the CI blind snake.	CI blind snake status established. Report, with recommendations.	X				Parks Australia with collaborators.	4
17.4	Trial other monitoring methods for blind snake (monitoring & detection).	Documented assessment of methods and their utility.			X		Parks Australia.	4
17.5	Review threats, assess impacts and identify further priority conservation actions for CI blind snake.	Report, with recommendations.		X			Parks Australia.	4

GOAL 4. CONDITIONS THAT ENABLE SUCCESS ARE IN PLACE.

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
Obj. 18	**Promote island-level biosecurity (CI & CKI).**							
18.1	Establish close working relationships with port authorities, biosecurity teams on islands and communities.	Regular communication in place. Community inputs to risk assessments. Stakeholders working together to assess & address changing conditions and threats.	X				Parks Australia, Biosecurity – DAFF, CI & CKI Shires	1
18.2	Establish monitoring at strategic locations on CI and CKI for small reptiles and other biosecurity threats to prevent incursion.	No new biosecurity threat incursions.		X			PKNP Biosecurity – DAFF.	1
18.3	Promote community education and awareness of biosecurity risks (including protocol on how to respond, who to alert, what information to report).	Communities aware of how to help prevent/respond to an incursion. Regular reports/notifications about concerns from the community.	X	X	X		Parks Australia, Biosecurity – DAFF, CI & CKI Shires.	1
18.4	Establish an action plan for DAFF/stakeholders to respond in the event of an incursion.	Plan established outlining clear responsibilities for all stakeholders.	X				DAFF	3
Obj. 19	**Build & sustain community engagement & support.**							
19.1	Pursue a range of opportunities, with partners, to engage stakeholders and communities in the program (see WG report in Appendix I).	Regular activities that successfully engage stakeholders and communities.	X	X	X	X	Parks Australia with collaborators	3
Obj. 20	**Develop an ethics framework for management of all animals in the metapopulation that accommodates all stakeholder voices.**							
20.1	Develop an ethics framework for metapopulation management decisions (including issues related to "surplus" individuals).	Position statement released for the decision made using the ethics framework.	X				Taronga, Parks Australia.	1
20.2	Develop and implement a communications plan for community and stakeholder engagement prior to wild releases.	Communications plan developed, implemented and community support for the wild release program is secured.		X	X		Parks Australia.	2
Obj. 21	**Increase community awareness of and engagement in CI giant gecko & blind snake conservation.**							

Action	What	Success Indicators	1 yr	2-5 yrs	5-10 yrs	10+ yrs	Who	WG
21.1	Produce community education material on CI giant gecko.	Giant gecko fact sheet produced, distributed and readily available.	X				Junior rangers and CI Visitors Service Officer.	4
21.20	Produce community education material on CI blind snake.	Blind snake fact sheet produced, distributed and readily available.	X				Junior rangers and CI Visitors Service Officer.	4
Obj. 22	**Develop effective monitoring plans for BTS and LG for ALL release programs, including reintroduction trials on CI, hard release trials on CI, and translocations to Cocos (Keeling) and other islands.**							
22.1	Review and revise success criteria for all release programs (as part of metapopulation and population planning - see action 7.1).	Meaningful and measurable success criteria.	X				Parks Australia to develop, CIRAP to review.	3
22.2	Test various methods for monitoring LG in wild releases to identify most effective and efficient monitoring method for assessing success criteria.	Repeatable and effective method identified that can be used to monitor LG in wild habitats, and detect population changes.	X	X			Parks Australia.	2
22.3	Develop monitoring plans, ensuring success criteria can be addressed effectively by the monitoring protocols selected.	Meaningful and measurable success criteria. Monitoring protocols aligned with success criteria.		X			Parks Australia to develop, CIRAP to review.	3
Obj. 23	**Ensure research is well-targeted and used.**							
23.1	Develop decision tools to support research prioritisation.	Research is well-targeted and supporting plan implementation.	X	X	X	X	CIRAP Members (& collaborators).	3
Obj. 24	**Secure adequate resources.**							
24.1	Assess actions to quantify and prioritise resources needed to achieve conservation outcomes.	Recommended actions are assessed, costed and resource priorities confirmed.	X				Parks Australia	3

DRAFT Framework for Decision-making and Research Prioritisation (BTS & LG)

The following section gathers together contributions from the following working groups: Research prioritisation; Goals, Roles, Targets; Trade-offs. Additional text from Nick McGregor & additional work on Bayesian Belief Network and research prioritisation by John Woinarski.

Background

The metapopulations of BTS and LG (current and potential) are (or may be) made up of several elements:

- Captive populations at Taronga Zoo and on Christmas Island and (potentially) at other zoos.
- Translocated free-living populations on Cocos (Keeling) Islands.
- Translocated free-living populations on other suitable islands (potential).
- Managed populations in Fenced Sites on Christmas Island.

A wider element of the program is research and management of threats on Christmas Island more generally (especially the wolf snake). The program aims not only to prevent extinction but also to achieve recovery. The different elements of the program complement each other towards these ends, but also potentially compete for resources:

- **Captive populations** are a well-tested and relatively certain path to preventing extinction. They will not on their own deliver recovery, though they can support and accelerate it by providing animals for release to the wild. They are relatively expensive and labour intensive. They can lose damaging amounts of gene diversity over time and become adapted to captive conditions depending on size, management, and generations in captivity.
- **Free-living translocated populations** on Cocos (Keeling) or other suitable islands offer a lower cost option for maintaining large numbers of lizards away from major threats and at no risk of captive adaptation. Again, this does not on its own deliver species recovery. Also, free-living lizards are expected to retain less gene diversity than an equivalent number of captive ones although this risk can be offset by free-living populations being an order of magnitude larger than captive populations. Cocos (Keeling) Islands populations have greater uncertainty about the long-term success and longevity of the sites involved than captive populations. Sites outside CKI are not yet identified so are even more uncertain at present. Furthermore, there are currently no LGs at these sites, and translocation of LGs may be challenging.
- **Fenced Sites** offer another option for maintaining larger numbers of lizards safe (ideally or potentially) from major threats. These offer the advantage of being on Christmas Island, ensuring animals remain adapted to local conditions and providing opportunities for *in situ* research into behaviour and preferences. For this system there is considerable uncertainty about long-term success and about cost (though operational costs may be low, capital costs may be prohibitively high). Furthermore, there are currently no LGs at these sites, and translocation of LGs may be challenging.
- **Wild releases** on Christmas Island are contingent on successful control of wolf snakes, which is currently unfeasible, and the likelihood of development of feasible options is highly uncertain.

At present, finding an efficient pathway to both preventing extinction and driving recovery requires balancing investment three areas:

- actions or management delivering certain but lower impact outcomes;
- actions or management delivering uncertain but potentially higher impact outcomes;

- research programs aimed at reducing the uncertainty of actions or management but which carry their own uncertainty of successful delivery.

This is complicated to navigate. During the workshop several elements were developed that together can form a framework to support decision-making:

1) A DRAFT General Approach: a recommended general approach to future investment in the various management systems. The metapopulation plan document the final agreed approach.
2) A DRAFT Bayesian Belief Network (decision tree): showing a step-wise flow of decision points and alternative pathways for the program, informed by estimates of the likelihood of success, enabling the evaluation of research.
3) DRAFT trigger points for ramping up/winding down each program element
4) A table of research programs generated during the workshop
5) Research programs ranked according to potential impact and likelihood of success.

1) A DRAFT GENERAL APPROACH

For both species, the recommended target is an effective population size of at least 1000 (based on Frankham's 100/1000 rule, whereby a genetically effective population size of N=1000 is expected to achieve mutation drift balance – that is, loss of GD through drift (chance) should be balanced by that generated through mutation) and a total population size of at least 10,000 across the metapopulation (with the majority of individuals in free-living populations) (this is the number required to achieve Ne=1000 assuming an Ne/N ratio of 0.1, the mean found from a large study of vertebrate taxa (Frankham, 1995). This 10,000 also comfortably meets generic Minimum Viable Population thresholds proposed by Traill *et al* (2006). Note that the Ne will determine the <u>rate of loss</u>. Starting GD and the number of generations over which the program runs, will determine the amount of original GD that is lost. Targets for retention of wild-sourced GD are typically 90-95%, depending on circumstance.

- If the status quo level and allocation of effort is maintained:
    - BS population spread across six locations and across all management levels now number more than 5000 individuals and is increasing. This provides reasonable confidence that the BTS metapopulation will experience minimal genetic diversity loss and be resilient to chance demographic events in the short to medium term.)
- LG population is now spread across four locations, number in excess of 1400 individuals, with the majority of animals in captive management. Through careful intensive management genetic diversity loss can be minimised, however overall population is insufficient and concentration of efforts in captive breeding facilities risks adaptation to captivity and a catastrophic disease event unless core breeding populations can be protected.Any scenario for the gecko that does not include maintenance of current levels of captive breeding would incur major risks, given that it is not yet established in any location beyond captivity. For the skink, reduction of captive breeding would also be risky. Cocos (Keeling) populations (especially if expanded) provide an important short to medium-term backup, but climate change risks mean coral-atoll populations have a limited timeframe (~70 years), with uncertainty over when climate-change-driven storms could obliterate them.
- For both species, captive breeding plus large wild populations outside Christmas Island is a plausible scenario that would meet conservation goals from the perspective of population size and genetic diversity; however <u>this would raise a question about whether it would be acceptable to abandon efforts to return the species to wild or even semi-wild conditions in their natural range</u>.

Therefore, a balanced approached that, informed by consideration of risks, cost effectiveness and likelihood of success, includes captive breeding, wild populations on CKI or other islands, and continued attempts to establish fenced/enclosed populations on Christmas Island, is recommended for both species. Maintenance of captive breeding and establishment of free-living populations away from Christmas Island are the highest priorities. At the same time, it is

critical to continue research into controlling wolf snakes, including methods for lethal control or reducing reproduction, and methods for excluding them from small areas with fences, as well as developing effective monitoring methods.

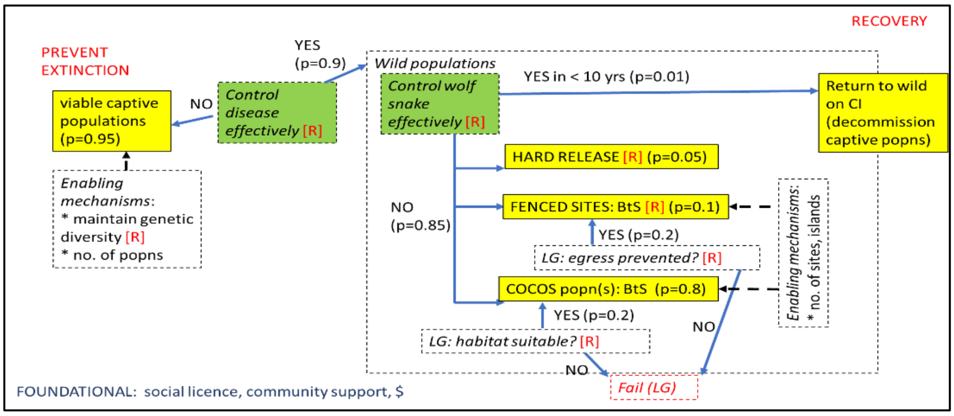
Two possible approaches were discussed:

1. <u>A base level mid-term security against extinction:</u>
    a. Blue-tailed skink: maintained captive breeding at two or more sites; established free-living populations on at least three islands outside CI
    b. Lister's gecko: maintain captive breeding at two or more sites; develop an effective fenced area design (perhaps a fully enclosed structure – 'super tent' or 'gecko dome') to support at least a small population (recognising that establishment on islands outside CI is still speculative at this stage), until free-living populations established on at least three islands;
2. <u>An enhanced (ideal) approach:</u>
    a. As for 1 above but also with: both species also established in several fenced areas on Christmas Island that can each support up to 1000 individuals.
    b. Wolf snake monitoring methods established, lethal control/reproductive control options understood and methods deployed, physical exclusion methods developed and deployed (a above), multi-species meta-population simulation modelling available to predict outcomes and prioritise control/exclusion effort.
3. <u>Next steps.</u>
4. <u>Prioritise and cost operational plan</u>

The above management (2) represents an expansion of the current program, with consequent resource requirements, and that there could be tension/trade-offs between investment in managing the metapopulation versus investment in research and experimental management to reduce the pressures (particularly wolf snakes) that are currently blocking reintroduction to the wild on Christmas Island.

2) A DRAFT BAYESIAN BELIEF NETWORK/DECISION TREE FRAMEWORK

The following diagram provides a draft example of an approach that could help program decision-makers navigate the options and uncertainty in the system under management, to help evaluate alternatives and to weigh the relative value and urgency of different lines of research. Note that the probability levels (p) are indicative only, and should be informed by elicitations from experts. This decision tree is designed to indicate pivotal and/or weak points in the program, and to allow predictions of flow-on consequences of research or other actions that can increase the likelihood of management success at key points in the program.



3) Draft trigger points for ramping up/winding down each program element

The following table is incomplete and under development as part of the metapopulation plan.

	TRIGGERS	
Program element	**Ramping up**	**Winding down**
Captive populations	Other systems fail, burden of gene diversity retention lies with captive population.	Wild populations of sufficient size in place; or enough animals persisting in alternative management systems to replace insurance and release role.
Fenced Sites	Shown to be feasible & affordable; other options (population components) provide limited benefits.	Shown to be unfeasible/unaffordable; other options (e.g., return to wild outside exclosures) are adequate.
Free-living populations	Ongoing failures or unacceptable risks to captive populations. Broader search for potential destination sites beyond CI and CKI demonstrates acceptable risks and likelihood of successful establishment.	Monitoring indicating lack of success of current BTS CKI populations, despite management responses; ongoing risks of factors that may prevent successful translocation of LGs to CKI. Broader search for potential destination sites beyond CI and CKI demonstrates unacceptable risks (e.g., to biota present at potential release sites) or lack of suitable sites.
Wild Populations (CI)	Effective control of wolf snake demonstrated.	No effective control of wolf snake.

Figure 5. Recommended actions for the first 0-2 years of the new program, for further synthesis and prioritisation post workshop.

4) Details of research programs generated during the workshop

Table 3. Research programs relevant to the draft plan.

Research theme	**Number**	**Research topic**	**Practical conservation application?**	**Impact on program goals?**	**Likelihood of success/a definitive answer?**	**Time-frame to result?**	**Cost?**	**Who does it?**
Giant gecko Research	1	Assess population abundance and distribution over time.	Establish and implement effective monitoring program to determine GG status and its changes over time.	High	High	2-3 years	Med	Consultant then Parks Australia.
	2	Identify threats and control options.	Foundational information to manage GG.	Medium*	Medium	2-3 years	Med	University collaboration.
	3	Investigate husbandry methods.	Establishment of husbandry techniques for GG in advance of any urgent need.	Low	High	1-2 years	Low	Parks Australia.
	4	Investigate life history/biology/ecology.	Identification of factors that may explain lack of decline to date of GG; and to help acquire basic knowledge that can inform management.	Medium	Medium	2-3 years	Medium	University collaboration.
	5	Assess whether fenced areas are useful for GG conservation, and how many would be required.	Establishment of conservation management techniques for GG in advance of any urgent need.	Low	Unknown	2-3 years	High	University Collaboration.
Blind snake	6	Design effective survey methods & establish existence/distribution.	Establish and implement effective detection monitoring program to determine status and its changes over time.	High	Unknown	3-5 years	Medium	Consultant then Parks Australia.

Research theme	Number	Research topic	Practical conservation application?	Impact on program goals?	Likelihood of success/a definitive answer?	Time-frame to result?	Cost?	Who does it?
	7	Husbandry - lit review of any husbandry information on blind snakes generally; and establish trials for other blind snake spp.	Proactive establishment of husbandry techniques for blind snake, should any be found and captive breeding considered potentially beneficial.	Unknown	Unknown	3-5 years	Low	University collaboration.
Health and disease of reptiles	8	Assess Cadmium impacts on CI reptile spp.	To help rank threats and their need for management response.	Low	High	1-2 years	Low	Taronga.
	9	Resurrect *Enterococcus* PCR to explore ecology of the organism on CI.	to deliver a test/tool for rapidly determining disease status in individuals.	High	High	1-2 years	Low	Taronga; PhD student /University collaboration
	10	Conduct cost-benefit analysis of additional (*Enterococcus*) transmission trials.	provide more evidence for disease transmission and risks in captive colony, and how this can be most effectively managed.	Medium	High	1 years	Low	Taronga.
	11	Continue with additional attempts to grow organism (*Enterococcus*) in culture.	to allow further investigations of possible treatments of enterococcus.	High	Low	3-5 years	Medium	Taronga.
	12	Further assess drug susceptibility and disinfectant protocols (for *Enterococcus*).	to support hygiene and biosecurity operations and options for treatment for captive populations.	High	Medium	3-5 years	Medium	Taronga.
	13	Origin of organism (*Enterococcus*) – how did it get to CI?	to help enhance biosecurity settings for CI and other islands and mainland Oz more generally	Low	Low	3-5 years	Low	Taronga.

Research theme	Number	Research topic	Practical conservation application?	Impact on program goals?	Likelihood of success/a definitive answer?	Time-frame to result?	Cost?	Who does it?
	14	Investigate new/emergent bacterium ID, antibiotic sensitivity & ecology.	Improved biosecurity for lizard movements among components of metapopulation.	High	Medium	3-5 years	Medium	Taronga.
	15	Investigate host susceptibility and resilience with respect to infectious disease: species; management style; MHC variability; mounting an immune response.	to help enhance management of disease.	High	Medium	3-5 years	Medium	Taronga.
	16	Evaluate options for best biosecurity practices.	to help enhance biosecurity settings for CI and other islands and mainland Oz more generally	Medium	Medium	3-5 years	Medium	Taronga.
	17	Assess options for community communication and behaviour change in relation to biosecurity.	to help enable better biosecurity and community acceptance.	Medium	High	1-2 years	Low	Taronga.
	18	Assess and refine options for biodiversity protocols for wild-captive flow.	improved protection for captive populations.	High	Medium	1-2 years	Medium	Taronga.

Research theme	Number	Research topic	Practical conservation application?	Impact on program goals?	Likelihood of success/a definitive answer?	Time-frame to result?	Cost?	Who does it?
Island scanning	19	Undertake assessment of options for other islands that may provide suitable destinations for assisted colonisation of LG/BTS?	(beyond CKI) desktop and feasibility assessment of suitability, risks, and other constraints, costs and benefits of islands that could support LG & BTS.	Medium (in short term - may be higher in 20-30 years)	High (to do assessment), but maybe low to actually find a suitable island	1-2 years	Low	Parks Australia (CIRAP)
	20	What permitting approvals are required for other island options?	for potential islands beyond Cocos (Keeling), what community approval, permissions, biosecurity etc is needed.	Medium (in short term - may be higher in 20-30 years)	Medium	1-2 years	Medium	Parks Australia
Wolf snake Research	21	E-DNA monitoring/detection biosecurity.	detection and monitoring tool for WS; biosecurity for fenced areas and Cocos (Keeling).	High	High	1-2 years	Low	Consultant
	22	Gene-drive.	genetic technology to eradicate wolf snake.	Very High	Low	20-30 years	High	research agencies/ University collaboration
	23	Wolf snake biology, ecology.	to help build evidence base for enhancing management of major threat.	Medium	High	3 years	Low	University collaboration
	24	Bait development.	to assess possibility for more effective control of wolf snake threat (n.b., some application on Guam).	High	Medium	3 years	Medium	Consultant
	25	Trapping/luring development.	to assess possibility for more effective control of wolf snake threat.	High	Low	3 years	Low	Consultant

Research theme	Number	Research topic	Practical conservation application?	Impact on program goals?	Likelihood of success/a definitive answer?	Time-frame to result?	Cost?	Who does it?
	26	Biocontrol.	to assess possibility for more effective control of wolf snake threat (e.g., pathogens, disease, bacteria [n.b. social licence and collateral detriment risks]).	Medium	Low	3-5 years	High	Taronga.
	27	Community driven control e.g. bounty.	to assess possibility for more effective control of wolf snake threat.	Low	Low	3-5 years	Medium	Christmas Island Shire
	27a	Investigate whether detector dogs can usefully detect WS.	to assess possibility for more effective control of wolf snake threat (including within exclosures).	High	Medium	2-3 years	Medium	Consultant.
Captive populations	28	In multi-male, multi-female breeding tanks, are a few individuals dominating breeding?	genetic management; improved husbandry.	Medium	High	1-2 years	Low	Taronga.
Cocos research	29	Is habitat on Cocos (Keeling) adequate to support Lister's gecko?	feasibility of establishing 1 or more 'wild' populations beyond CI.	High	High	3-5 years	Low	Parks Australia.
	30a	is *L. lugubris* native on Cocos (Keeling)? (and is it on all islands?).	feasibility of establishing 1 or more 'wild' populations of LG beyond CI.	Medium	Medium	1-2 years	Low	Consultant.
	30	Do LGs hybridise or compete with *L. lugubris*?	feasibility of establishing 1 or more 'wild' populations of LG beyond CI.	High	High	1-2 years	Low	Taronga.
	30b	if *L. lugubris* is problematic, can it be eradicated?	feasibility of establishing 1 or more 'wild' populations of LG beyond CI.	Medium	Low	1-2 years	Medium	University collaboration.

Research theme	Number	Research topic	Practical conservation application?	Impact on program goals?	Likelihood of success/a definitive answer?	Time-frame to result?	Cost?	Who does it?
	31	Are Macau wasps a risk to BTS/LG populations. (e.g., through competition and/or predation by wasps on lizards).	feasibility of establishing 1 or more 'wild' populations of LG beyond CI.	Low	Medium (but maybe hurtful)	2-3 years	Low	Parks Australia.
	31a	what other (larger, higher) islands in Cocos (Keeling) are most suitable destination sites?	feasibility of establishing 1 or more 'wild' popns of LG beyond CI.	High	High	1 year	Low	Parks Australia.
Threats	32	Off target impacts of fipronil on BTS and LG.	to help assess relative impacts of threats, and hence to refine management	Low	Medium	2-3 years	Medium	Consultant or university collaboration.
	33	Detection and control methods for centipedes.	To reduce risks to lizards in Fenced Sites.	Medium	Medium (effective control may be challenging).	2-3 years	Medium	Consultant or university collaboration.
	34	Meso-predator interactions of rats following cat eradication.	to help assess relative impacts of threats, and hence to refine management.	Low	Low.	2-3 years	Medium	University collaboration (partly done through Rosie).
Lister's gecko	35	Detection and monitoring methods for LG.	Monitoring success of management actions, esp. for potential Cocos (Keeling) translocations.	High	Medium	2-3 years	Medium	Consultant or university collaboration.

Research theme	Number	Research topic	Practical conservation application?	Impact on program goals?	Likelihood of success/a definitive answer?	Time-frame to result?	Cost?	Who does it?
	36	Investigate habitat preference of LG.	Will inform selection of suitable mainland islands or CKI translocations.	High	High	2-3 years	Medium	Consultant or university collaboration.
Facility design	37	Investigate best facility design that meet program objectives and address biosecurity concerns.	improved conditions for captive colony.	High	High	1 year	Medium	Contractor.
Community engagement	38	Investigate best approach to community engagement.	Establish social licence.	Medium	High	1 year	Low	

5) Research programs ranked according to potential impact and likelihood of success

Shading describes the following research categories:	
(pink)	Threats & their management
(green)	Survey & monitoring
(yellow)	Basic ecology
(blue)	Community engagement, regulation

	LIKELIHOOD OF SUCCESS			
IMPACT	**High**	**Medium**	**Low**	**Unknown**
Very High			22 (WS) Gene-drive	
High	1 (GG) Assess population abundance and distribution over time.	12 Further assess drug susceptibility and disinfectant protocols (for Enterococcus).	11 Continue with additional attempts to grow organism (Enterococcus) in culture.	6 (blind snake) Design effective survey methods & establish existence/distribution.
	9 Resurrect Enterococcus PCR to explore ecology of the organism on CI	14 Investigate new/emergent bacterium ID, antibiotic sensitivity & ecology.	25 (WS) Trapping/luring development.	
	21 (WS) eDNA monitoring/detection biosecurity.	15 Investigate host susceptibility and resilience with respect to infectious disease.		
	29 Is habitat on CKI adequate to support Lister's gecko?	18 Assess and refine options for biodiversity protocols for wild-captive flow.		
	30 Do LGs hybridise or compete with *L. lugubris*?	24 (WS) Bait development.		

	LIKELIHOOD OF SUCCESS			
IMPACT	**High**	**Medium**	**Low**	**Unknown**
	31a what other (larger, higher) islands in CKI are most suitable destination sites?	27a (WS) Investigate whether detector dogs can usefully detect WS.		
	36 Investigate habitat preference of LG.	35 Detection and monitoring methods for LG.		
	37 Investigate best facility designs that meet program objectives and address biosecurity concerns.			
Medium	10 Conduct cost-benefit analysis of additional (*Enterococcus*) transmission trials.	2 (GG) Identify threats and control options.	26 (WS) Biocontrol.	
	17 Assess options for community communication and behaviour change in relation to biosecurity.	4 (GG) Investigate life history/biology/ecology.	30b if *L. lugubris* is problematic, can it be eradicated?	
	19 Undertake assessment of options for other islands.	16 Evaluate options for best biosecurity practices.		
	23 Wolf snake biology, ecology.	20 What permitting approvals are required for other island options?		
	28 In multi-male, multi-female breeding tanks, are a few individuals dominating breeding?	30a is *L. lugubris* native on CKI? (and is it on all islands?).		
	38 Investigate best approach to community engagement.	33 Detection and control methods for centipedes.		

	LIKELIHOOD OF SUCCESS			
IMPACT	**High**	**Medium**	**Low**	**Unknown**
Low	3 (GG) Investigate husbandry methods.	31 Are Macau wasps a risk to BTS/LG populations. (e.g., through competition and/or predation by wasps on lizards).	13 Origin of organism (*Enterococcus*) – how did it get to C.I.?	5 (GG) Assess whether fenced areas are useful for GG conservation.
	8 Assess Cadmium impacts on CI reptile spp.	32 Off target impacts of fipronil on BTS and LG.	27 (WS) Community driven control e.g. bounty.	
			34 Meso-predator interactions of rats following cat eradication.	
Unknown				7 (blind snake) Investigate husbandry.

APPENDIX I. BIG IDEAS SESSION - COMMUNITY SUPPORT & URBAN RELEASES

Objective: CKI and CI community are aware of, supportive of and involved in, the conservation of native CI reptiles.

Table 4. Potential opportunities for supporting the achievement of Objective XX., as identified by participants at the 2023 workshop.

Proposed Initiative	Cocos (Keeling)	Christmas Island	Stakeholders	Actions/Priority
Urban Release	Not in Scope..	Experimental urban release of blue-tailed skinks on Shire land (decommissioned park area) such as Lower Poon Saan Park.	○ Christmas Island Shire ○ Parks Australia ○ CIDHS ○ Community	CKI – release some lizards in West Island (link to App and citizen science).
Tours	Canoe Tours for the Home Island Elders to see the BTS on Pulu Blan	Tours of Lizard Lodge conducted by small groups of CI Junior Ranger students.	○ Cocos Island Adventure Tours (LEADING) ○ CI Junior Rangers ○ CIDHS ○ Cocos (Keeling) DHS (in future)	Priority 1, easy win, within 3 months. .
Tourism	○ Volunteer Tourism . ○ Donation/Info Point at Tourism Shop – BTS Badge. ○ Citizen Science.	○ Volunteer Tourism ○ Donation /Info Point at Tourism Shop- BTS Badge. ○ Citizen Science.	○ Cocos (Keeling) DHS. ○ CIDHS. ○ Tourism Association (CI &CKI).	○ Lower priority. ○ Initiate educational activity through a citizen science program. ○ Establish donation/info point at CKI/CI . ○ Junior rangers to lead on CI..

Proposed Initiative	Cocos (Keeling)	Christmas Island	Stakeholders	Actions/Priority
Citizen Science	Continue with existing Citizen Science Program for BTS.	○ Establish Citizen Science programs for giant geckos. ○ Wolf Snakes if possible.	○ Parks Australia. ○ CIDHS. ○ CI Junior Rangers ○ Cocos (Keeling) Island Adventure .Tours.	○ Establish Citizen Science programs for giant geckos. ○ Wolf Snakes if possible on CI – Junior rangers/Parks Australia. ○ Continue existing Citizen science program at CKI – easy win, already happening.
Documentary	Video of Canoe Tour and BTS counts (Citizen Science)-played at Tourism.	Video of Daily Reptile Keeper duties and conservation program – played at local cinema.	○ Cocos (Keeling) Island Adventure Tours ○ CI Tourism – Sarah (Marketing Manager) ○ CIDHS ○ Cocos (Keeling) DHS ○ Parks Australia (CI and CKI) – content/Fact	○ Create a short video as an education tool and engagement piece . ○ about BTS and LG – school and CI Junior Rangers. ○ CIDHS and CKIDHS leading – embed in curriculum.
Surveys to gauge community knowledge/perceptions.	In Person- door to Door Approach – delivered/discussed by trusted local Ask about feelings about BTS on more islands across the atoll.	Survey Monkey Online – School/youth. Questions to be developed.	○ Shire – which Shire? ○ Parks Australia ○ Community ○ School	○ CI community/Shire – rangers??gauge information on egg management. ○ Develop surveys for local communities. ○ Low priority for CKI, a few years down the track (to gauge understanding after initial actions).

Proposed Initiative	**Cocos (Keeling)**	**Christmas Island**	**Stakeholders**	**Actions/Priority**
Investigate possibility of developing artwork (e.g. Murals) + QR Code	On Home Island QR code links to kids video about the reptile conservation program.	Existing mural at Boong Trading retrofitted with QR code or interpretive sign.	○ Cocos Keeling Shire (Community Art Funding) ○ Community ○ School	○ Easy win in CI, existing. ○ CKI – another art program about BTS/LG.
Apps Within 1 year	Redevelop Snap Send Solve app (used by Shire) for this purpose. Could have fish, turtles and reptiles added.	○ Redesign Birds of CI App. ○ Add reptiles, including invasives (wolf snakes), cats, rats etc. ○ Geo location ○ Photo Upload.. ○ To record sightings.	○ Shire – which Shire? ○ Parks Australia ○ Tourism (CI &CKI)	○ Redevelop App with conservation content (CKI Tourism) ○ CI- expand App with conservation content (CI Tourism).
Write articles/stories Promotion/Publicity/ Education	○ Atoll – Newspaper. ○ Parks Australia Newsletter. ○ Facebook/Social. Media – Cocos (Keeling) Blackboard. ○ Tourist INFOsheet (in hotel).	○ Islander Newsletter. ○ Parks Australia Newsletter. ○ Facebook/Social Media – CI Blackboard. ○ Radio program – updates by JR. ○ Tourist INFO sheet (In hotel).	○ Shire – which Shire? ○ Parks Australia. ○ Junior Ranger. ○ Cocos (Keeling) DHS ○ CIDHS. ○ Tourism Association. (CI &CKI) Radio 6RCI	CI and CKI – create time for Parks Australia staff to present/update on conservation content (junior rangers/CI and School/CKI)

Proposed Initiative	Cocos (Keeling)	Christmas Island	Stakeholders	Actions/Priority
Organise a Design Challenge	Perhaps for Lister's options.	Local engineers, contractors brainstorm on innovative solutions to presented issues for SRS. Fabrication of innovative ideas generated at workshop.	○ CIP – Mine. ○ CI Shire. ○ Local Contractors.	CK1- Within year 1.
Add Information Stall	○ At airport on plane days? ○ At Tourism Centre. ○ Outside Parks Australia Office (Home Island).	○ At Events e.g.: Territory Week. ○ At Tourism Centre. ○ At Airport on Plane Days.	○ Parks Australia. ○ Tourism Association (CKI&CI). ○ CIDHS ○ Junior Ranger.	CKI Create informative brochure about conservation program – Parks Australia create and Adventure tours share – easy win. Within 2months

Program idea: Urban Release

Experimental urban release of blue-tailed skinks on Shire land (decommissioned park area) such as Lower Poon Saan Park. This option preferred over private property to reduce management issues. Joint management with Parks Australia /Shire (which Shire) with high levels of community engagement.

Interpretive signs installed on site to 'complete' picture for visitors about the program.

Shire (which Shire?) to provide:

- Land in public space – decommissioned park deemed suitable for BTS
- access to and maintenance of proposed site:
- Labour and equipment

Parks Australia to provide:

- Information
- Expertise
- Advice on habitat and husbandry

School to provide:

- Promotion of Urban Release initiative
- Education through Junior Ranger program

Community members join ‘Friends of blue-tailed skinks group’:

- make a donation towards reptile conservation programs AND/OR:
- commit to habitat creation/maintenance;
- regular monitoring;
- BTS friends active participants in BTS release and
- Participants receive BTS badge.

Table 5. Draft summary of the options for managing surplus lizards with, for each, specified benefits, constraints and scenarios of when to apply.

Option	Benefits	Constraints	Scenario when to use
Egg Management	• Decision not impacting a sentient being as action taken <50% incubation. • Capacity to effectively manipulate program management to meet demographic and genetic goals, e.g., equalise family sizes, equalise founder contributions. • Cost efficient, space efficient and labour efficient. • Low risk for population management and welfare, ie realised potential – healthy and efficient population. • Easy to implement and reverse. • Supports natural reproductive behaviours.	• Ethical/ cultural position on "killing" and denying future life. • Limited opportunity to utilise a potential "animal resource" for other activities such as wild release • Potentially lost opportunity for critically endangered species ie difficulty in reconciling decision externally and internally not to hatch animals for a species considered extinct in the wild and by definition has low overall population numbers) • Could result in aging population if insufficient recruitment or unintended sex skew through chance selection of eggs for management	• When population is approaching or exceeded capacity (biosecurity, facilities and management does not support housing excess animals). • When viable populations are established in captive, fenced and other sites, and requirements to generate animals for these sites not required. • To maintain reproductive potential and fitness by allowing ongoing opportunities to breed

Option	Benefits	Constraints	Scenario when to use
Sex separation	• Minimises egg management required.	• Future reproductive performance and success may be compromised. • Risk of reproductive pathologies, e.g., egg binding. • Sperm retention could mean eggs are still produced after separation. • Potential risks for behavioural management eg Increased risk of aggression and mortality in all-male BTS populations; and disease transmission • Reintroduction BTS of males/females may result in female mortality. • Disrupts established social relationships. • Sexing techniques are not 100% accurate can be ineffectual • Potentially more resource intensive and requires careful management.	• When animal facilities are adequate to meet program objectives and the ability to house animals separately exists • If males are contributing to high mortality in females. • To minimise egg production
Egg releases: predator controlled sites (Fenced Sites or Cocos)	• Less resource intensive compared to animal releases. • Gives a perceived ethical purpose to excess eggs. • Provides an outlet for breeding program. • Potential research opportunities. • Cost effective and space efficient.	• Releasing one age class of animals. • Juvenile mortality is generally higher than adult mortality and animal need to survive for 12-18mths before maturity and contributing to the population. • Unknown if eggs will reliably hatch, therefore would be difficult to monitor survival and population changes. • Possibly disease transmission through eggs.	• When there is strong evidence that the threats that caused any previous extinction have been correctly identified and removed/controlled (IUCN guidelines) • When the habitat is fit for animals released at all life stages, ie habitat supports egg through to adults.. • To supplement existing population when sufficient recruitment uncertain • To create minimal disruption to existing age structure and social structure of recipient population • When a conservation purpose exists beyond releasing excess captive stock..

Option	Benefits	Constraints	Scenario when to use
Animal releases : predator controlled - Fenced Site (and Cocos release)	• Provides outlet for breeding program, • Minimises egg management. • Possible research opportunities.	• Could result in death of sentient being released into the wild through predation from existential threats that remain in wild. • Resource intensive (incubation, rearing and housing of animals). • Requires monitoring to evaluate research questions • Disease risk (non-*Enterococcus*). • Limited number of individuals can be released due to carrying capacity, available habitat and resourcing.	• When there is strong evidence that the threat(s) that caused any previous extinction have been correctly identified and removed or sufficiently reduced (IUCN guidelines).When release will not compromise source population and will benefit or at least not detriment source population. • When a conservation purpose exists beyond releasing excess captive stock.
Animal releases: wild releases (hard release CI)	• Provides outlet for breeding program, • Minimises egg management. • Possible research opportunities.	• Could result in death of sentient being released into the wild through predation from existential threats that remain in wild. • Resource intensive (incubation, rearing and housing of animals). • Requires monitoring to evaluate research questions • Potential disease risk (non-*Enterococcus*).	• When there is strong evidence that the threat(s) that caused any previous extinction have been correctly identified and removed or sufficiently reduced (IUCN guidelines). • When the release will answer a valid research question and resulting suitability monitored and will be used to refine further release designs and any unacceptable impacts can be mitigated or reversed. • When release will not compromise source population.

Option	Benefits	Constraints	Scenario when to use
Aged animal euthanasia. (Selective killing, hard retirement)	• Minimises egg management. • Maximises genetic contribution. • Facilitates more recruitment.	• Ethical/cultural position on "killing" • Loss of social relationships. • Requires individual animals or age cohorts to be identifiable. • Resource intensive – record keeping, individual identification, difficulty in determining whether individuals are breeding or not.	• When aged animals are no longer contributing to the breeding program. • When animals have health concern (eg age-related illness) • When population is reaching or exceeded capacity.
Eggs and animals are all retained	• Minimises ethical/ cultural position on "killing" and denying future life. • No killing.	• Could result in unstable age structure (aged skewed). • Labour intensive. • Cost prohibitive. • Risks undesirable outcomes if available resources exceeded, eg mortality events, disease outbreaks • Compromises delivery of genetic and demographic goals of breeding program if holding capacity is reached or exceeded. •	• When animal facilities have not reached capacity or can be expanded to meet program objectives) • In preparation for a planned translocation event requiring a large number of animals for transportation and release.
Contraception	None, since ineffectual with current technologies.	• Ineffectual. • Technology not developed/available. • Requires expertise in contraception application; • cost of administration. • Animal welfare concerns, relating to reproductive pathologies	• If all options are exhausted and this procedure becomes available.

Appendix III. Big Ideas Session - Fenced Sites

In the wild

Discussion scope: design, location and role of Fenced Sites for blue-tailed skink and Listers geckos on Christmas Island, including:

- Potential experts to engage.
- Fundamental design of a fence that keeps snakes out and lizards in.
- Suitable location.
- Habitat enhancements/management.
- Monitoring options.

Ideas

- Engage NZ Xcluder Team for fence design.
- Targeted engineering challenge for design.
- Further research into Van der Waals force (the means by which geckos stick to walls).
- Moated island on private, community owned land.
- Fence with combination of multiple electrical barriers, baffles (fence lip), multiple fences (min 2).
- Alarm system to alert for breaches, trees, animals etc.
- Predator alert system.
- Minimum of 8m buffer from fence to vegetation.
- LG – effective fence to keep them in.
- LG dome, fully self-contained and fit for purpose.
- BTS urban fenced site.
- Segregated urban fenced site for both species.

Recommendations

1. Expert consultancy on fence design and feasibility (brief is to keep out predators and keep in LGs).
2. If a fence proves futile for keeping in LGs, consider bolstering the captive LG population via multiple extra tents or fewer, larger dome tents.
3. Consider options for urban-like habitat as a location for a BTS fenced site.
4. Research Van der Waals force.
5. Identify a suitable location for LG fenced site, once the fence is proven to work.

In captivity

Scope of discussion: define solutions for invasive-gecko-free facilities for BTS and LG in captivity, including:

- Facility design or upgrade.
- Biosecurity protocols.

Ideas

- Retro fit Lizard lodge: line internal walls with crim-safe mesh, replace roof with fibre glass panels.
- Build new LG facility – demountable or equivalent.
- Modify Lizard Lodge enclosures: Perspex to replace wire walls, baffle any gaps in enclosures, implement lid modifications.
- Implement further biosecurity measures: treat materials storage away from vectors.
- Exclosure ideas:
    - LGs no change.
    - Retro-fit existing shade cloth over existing fenced site.
    - Install tents in existing pods with light and heat (note - have to consider rain).
    - Remove the need for exclosures by modifying population management so that goals can be met with fewer animals.

RECOMMENDATIONS

Exclosures:

- Retro-fit BTS exclosures with covering that excludes geckos
  OR
- Re-work metapopulation management so that exclosures for BTS are not required.

Lizard Lodge:

- Retrofit by lining the entire building with invasives-proof crim-safe mesh

AND

- Implement biosecurity measures such as sterilising materials.

APPENDIX IV. BIG IDEAS SESSION - WOLF SNAKE, GIANT GECKO, BLIND SNAKE DISCUSSION GROUP

GIANT GECKO

Goal: Prevent extinction

What: 1) Detect change in abundance and decline in distribution and respond if required.
2) Understand the status of the giant gecko.

How:

- Get access to historical data, repeat the survey, expand the survey area and analyse.
- Agree trigger points for further action.
- Identify threats and assess impacts.
- Investigate husbandry methods and agree triggers for captive breeding.
- Assess feasibility of fenced site-based conservation.
- Implement Citizen Science program (e.g. frequent presence-absence surveys) .

Research:

- Determine population abundance and distribution over time.
- Identify threats and control options.
- Investigate husbandry methods.
- Establish life history/biology/ecology.
- Assess whether fenced areas are useful for giant gecko conservation.

BLIND SNAKE

Goal: Prevent extinction

What: 1) Literature review on blind snake ecology/biology/detection.
2) Establish detection and monitoring program – trial eDNA.
3) Identify and manage threats.

How: Based on detection, either:

- Assess for conservation breeding.
- Research artificial shelters.
- Accept status.
- Look for blind snake DNA in predators – cat, rat.
- Establish Citizen Science program.

Research:

- eDNA validation and utility.
- Identify threats and management.
- Assess utility, costs and benefits of conservation breeding.

WOLF SNAKE

Goals: 1) Eradicate Wolf Snake.
2) Control in small experimental area.
3) Keep wolf snakes from entering/establishing on Cocos (Keeling).

What:

- Ensure snake distribution, biology, ecology, disease status, predators, population drivers are understood and knowledge is sufficient to inform management.
- Develop effective monitoring, both broadscale and in fenced areas.
- Develop effective biosecurity methods for Cocos (Keeling).
- Develop "giving up" triggers.
- Control mechanisms are established.

How:

- Research options for control – gene drive, bio-control, lure and trap.
- Develop research partnerships.
- Build on existing knowledge from in-house experiments and honours thesis.
- Do a cost-benefit analysis to support funding proposals and continue the program.
- Collaborate with agencies who have wolf snake knowledge in Reunion, Mauritius, etc.
- Explore community driven control options.

Research:

- eDNA monitoring/detection/biosecurity.
- gene drive.
- snake biology, ecology.
- bait development.
- lure, trap development.
- Biocontrol.
- community driven control.

Health and Disease Research opportunities

- Ecology and impacts of cadmium on CI reptiles - underway
- Assess host susceptibility/resilience to *Enterococcus lacertideformus* a) by species; b) by housing type, including:
    - MHC diversity
    - Immune function
- For the *Enterococcus* organism, resurrect the PCR test as a basis for further research. Consider:
    - Environmental reservoirs? Ecology of the organism in the environment
    - Transmission methods – soil, water, food, substrate, mesh contact
    - Additional attempts to grow in culture to potentially underpin additional experimental infection trials – incubation periods for each species – antibiotic and disinfectant susceptibility.
- Biosecurity - identify the best methods for conservation breeding program:
    - best methods to prevent incursion of additional invasive species.
    - best communication methods to drive behaviour change and increase detection of invasive species.

- New bacterium LG11 – identify and characterize the organism – antimicrobial sensitivity and lifecycle/transmission routes (fecal-oral, water, food-borne – to hint at control mechanisms).

APPENDIX V. POPULATION VIABILITY ANALYSIS TOOLS FOR CHRISTMAS ISLAND BLUE-TAILED SKINKS (*CRYPTOBLEPHARUS EGERIAE*) AND LISTER'S GECKO (*LEPIDODACTYLUS LISTERI*)

PVA TOOLS TEAM: *C. LEES, C. FORD, M. VAN SLUYS, L. CAVANAGH, J. P. EMERY, K. SCHUBERT*[1].

INTRODUCTION

The conservation planning workshop held in March 2023, discussed current challenges to, the recovery programme for Christmas Island Blue-tailed Skinks (*Cryptoblepharus egeriae*) and Lister's Gecko (*Lepidactylus listeri*), and planned recovery directions and activities for the coming decade. Neither of these species can persist in the wild at present and therefore both are managed as metapopulations comprising multiple sites and management systems. The program has moved on since these systems were first instated and one of the key recommendations identified during the workshop was the development of comprehensive new plan for management of the metapopulation, to ensure that it is keeping pace with the evolving needs, challenges and opportunities related to recovery. Workshop participants identified a series of questions and information gaps related to this recommendation, some of which could benefit from population viability analysis tools. Anticipating this outcome, a small group was convened in advance of the workshop to customise a suite of tools for use with the two target species. The aim of the "PVA Tools Working Group" was to develop simulation models and other relevant tools for use before, during and after the March workshop, to support decisions about meta-population management for these two species. The work of this group is documented here and falls into three categories:

- VORTEX[2] simulation models (for *ex situ* and free-living populations)
- PMx models and metrics (for intensively managed *ex situ* populations)
- Empirically or theoretically-derived "Rules of Thumb" (for *ex situ* and free-living populations)

PRELIMINARY QUESTIONS IDENTIFIED

When reduced to low numbers, the dynamics of wildlife populations (both captive and free-living) are disproportionately affected by good and bad luck – that is, by stochastic genetic and demographic forces, that have little impact when populations are large. This can make population-level growth and declines harder to predict, increasing the difficulty of decision-making for managers. Further to this, where populations are intensively managed, more elements of population dynamics can be controlled or manipulated, increasing the frequency and number of decisions that must be made. Population

[1] This was previously a stand alone document and still carries its own internal numbering.
[2] Vortex and PMx are software tools developed by the Species Conservation Toolkit Initiative and freely available for download with associated guidance.

Viability Analysis (PVA) models, formulae and science-based rules of thumb, can provide clarity and support to managers in these circumstances.

Prior to the March workshop, the following PVA-related questions were identified and some preliminary work on these is reported below:

- In captivity: should the species be managed pair-wise or run in larger, more polygynous groups?
- All systems: what population size/carrying capacity is recommended (both Lister's Geckos and Blue-tailed Skinks)
- Captive populations: how much harvest could be supported?
- How big does a Fenced Site need to be for long-term viability?
- How big do wild populations need to be for long-term viability?
- How many sites and how much connectivity will confer the required level of viability for the meta-population?
- What should the triggers be, for winding down captive populations?
- What should the conditions be for wild release on Xmas Island?

Only some of these questions have been considered so far and additional questions were added at the meeting, however with a small amount of additional work the tools assembled to date should be sufficient to enable a new metapopulation plan to be developed.

VORTEX POPULATION MODELS

Computer modelling can be a valuable tool for quantitatively assessing risk of decline and extinction of wildlife populations, both free ranging and managed. They allow complex and interacting factors that influence population persistence and health to be explored, including natural and anthropogenic causes. Models can also be used to assess the relative impact of alternative management strategies, to help identify the most effective conservation actions for a population or species, and to identify research needs. VORTEX is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events, on small wild or captive populations. VORTEX models population dynamics as discrete, sequential events that occur according to defined probabilities (see Fig. 1). The program begins by either creating individuals to form the starting population, or by importing individuals from a studbook database. It then steps through life cycle events (e.g., births, deaths, dispersal, catastrophic events), for each individual and typically on an annual basis. Events such as breeding success, clutch size, sex at birth, and survival are determined based upon designated probabilities that incorporate both demographic stochasticity and annual environmental variation. Consequently, each run (iteration) of the model gives a different result. By running the model hundreds of times, it is possible to examine the probable outcome and range of possibilities. For a more detailed explanation of VORTEX and its use in population viability analysis, see Lacy (1993, 2000) and Miller and Lacy (2005).

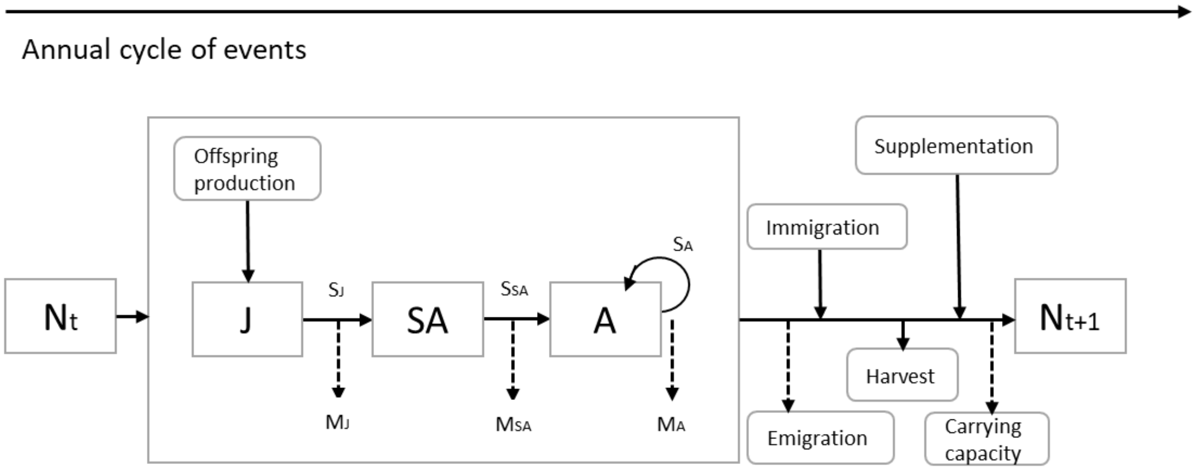


Figure 1. Diagram showing the series of events making up a typical annual cycle or timestep in VORTEX, that result in a simulated change in population abundance from Nt to Nt+1. The enclosed section of the diagram begins with the production of juveniles (J) followed by their transition through Subadult (SA) and Adult (A) life-stages. Mortality is imposed on each age-class cohort (Mx), the severity of which is determined by age-specific survival rates (Sx). On the right of the diagram, processes above the timeline act to increase abundance, while those beneath act to decrease it. The aggregate effect of these demographic processes results in a new population abundance at the end of the timestep (diagram by P. Miller, CPSG).

BASELINE MODELS

Current metapopulations of BTS and LG comprise populations distributed across different sites and management systems. Each populations has its own set of characteristics and risk profile. Additional populations are proposed but not yet operational. To accommodate all of this, eight baseline VORTEX simulation models were built to emulate each of the populations under benign conditions. These are listed below with the relevant team member assigned:

1. The Taronga **captive population** of Blue-tailed Skinks (BTSs) – C. Ford;
2. The Taronga **captive population** of Lister's Geckos (LGs) – M. Van Sluys;
3. The Christmas Island **captive population** of BTSs (just the breeding population) – C. Ford;
4. The Christmas Island **captive population** of LGs (just the breeding population) – M. Van Sluys;
5. A generic **Fenced Site** population of BTS – C. Lees;
6. A generic **Fenced Site** population of LGs – C. Lees;
7. A generic Cocos Islands **Free-living population** of skinks (initially just one model though at least two may be needed (Cocos 1 & Cocos 2), pending further quantification of differential risks) – P. Emery;
8. A hypothetical **Free-living population** of geckos (no specified location) – P. Emery.

Parameters for the models were drawn initially from a PhD thesis by Dr. Jon-Paul Emery in which VORTEX models were used to simulate populations of the two species. These model parameters were reviewed and where necessary revised by the PVA Tools Working Group, based on analysis of, and insights from, more recent data and observations. There remain some areas of uncertainty and these are identified in this report. Tables 1 & 2 below show the values used in the Baseline models and the rationale or source used. **Once built, these models can be used to test options for management and varied risk scenarios.**

Table 1. VORTEX parameters and their justification for Captive, Fenced Sites and Free-living population models of *C. egeriae* (as of February 2023).

Parameter	Captive TZ	Captive CI	CI FS (1&2)	Cocos 1	Cocos 2	Justification
Number of years (in 1-year timesteps)	25	25	25	25	25	Planning period is 10 years but captive models run for 25 years to illustrate longer-term genetic trends. Cocos Islands where free-living skinks reside may be inundated in less than 50 years (JP Emery pers. comm.) so the same time period is used for these pops.
Extinction definition	1 sex remains	1 sex remains	1 sex remains	1 sex remains	1 sex remains	Standard definition – can vary it for specific applications if needed.
Inbreeding depression (severity expressed as number of Lethal Equivalents)	3.14	3.14	6.29	6.29	6.29	Affects degree of fitness depression in populations accumulating homozygosity. VORTEX default values are drawn from studies of multiple populations (Ralls & Ballou 1988 for captive; O'Grady et al, 2006 for wild). Any SRS models are assigned wild defaults as additional stresses are expected.
Breeding system	Polygynous	LT Polygynous	Polygynous	Polygynous	Polygynous	In captivity, males breed with multiple females. Groupings are more stable in CI facilities so Long-term Polygyny option is selected.
Age at reproduction (median, not the first possible)	1 year	1 year	1 year	1 year	1 year	In captivity, both females and males breed at about 15 months of age. No corresponding data for wild populations.
Maximum age	10 years	10 years	4 years	4 years	4 years	Taronga value taken from captive records and extrapolated to C.I. (Note: Lx=10% for M/F at 5/7yrs). No information on maximum age in the wild and 4 yrs is assumed based on Pike et al. 2020 who found that the closely related *C. pulcher* lives for at least three years.
Maximum age of reproduction	10 years	10 years	4 years	4 years	4 years	No evidence of senescence.
% Breeding females (SD)	50% (2.5%)	50% (2.5)	100 (5)	100 (5)	100 (5)	Taronga value estimated from captive records. Same estimate is used for CI. Mark re-capture studies show typically 45% of females are gravid at point of re-capture – not yet clear what can be inferred from this about annual female breeding rates in the wild but it is assumed that they are high. 100% is assumed with some variation.
% Breeding males (percentage of males given an opportunity to breed and, therefore, potentially contributing to the gene pool)	25%	43%	100%	100%	100%	Emery's previous models assumed 80% in captivity, 100% in the wild. 25% for Taronga was calculated from captive records; 43% for CI is based on the presence of 60 males & 140 females in the breeding pool at any one time. In SRS and wild populations all males are assumed to have the opportunity to breed in a typical year.
Sex ratio at birth (% male)	50	50	50	50	50	No evidence of skewed sex-ratios from captive breeding or from wild populations.
Clutches per year	1=50%; 2=50%;	1=50%; 2=50%;	1=10% 2=10% 3=50% 4=30%	1=10% 2=10% 3=50% 4=30%	1=10% 2=10% 3=50% 4=30%	In captivity, females breed all year, with a pulse in the wet season (October-February). Values here are designed to emulate egg management which reduces average female contribution to roughly 1-2 clutches per year. Does not affect other mgmnt systems. Clutch number distribution for SRS and wild = provisional estimate.

Parameter	Captive TZ	Captive CI	CI FS (1&2)	Cocos 1	Cocos 2	Justification
Clutch size % 1 egg % 2 eggs % 3 eggs	 11 80 9	 11 80 9	 2.5 95 2.5	 2.5 95 2.5	 2.5 95 2.5	Taronga values re-calculated from captive data. Female *C. egeriae* usually lay two eggs, but occasionally lay one or three (Cavanagh per. comm.). Unlike clutch number this reflects biological potential. Same is assumed for CI. SRS and wild models retain original Emery model estimates (no new data).
Mortality % (SD) for 0-1 year age-class	Males & Females 25%+/-5 (range 15-32)	Males & Females 25%+/-5 (range 15-32)	63% (CI 44-77) SD=7 (males might be slightly lower)	63% (CI 44-77) SD=7 (males might be slightly lower)	63% (CI 44-77) SD=7 (males might be slightly lower)	Taronga value calculated from recent data. Husbandry changes over time have reduced mortality and these lower values should continue. CI values are assumed to be the same. SRS value is from re-analysed mark recapture data. Note: pattern is that founder animals die more often. This is not included in the models. Note that in the current models "birth" is defined from the egg stage, whereas PMx life-table data (the easiest route to these data) start at the hatchling stage. 100% hatching success is currently assumed which may be optimistic (Emery's study assumed 93%).
Adult females (Age 1+)	17+18*(A>3)+ 17*(A>4)	17+18*(A>3)+ 17*(A>4)	62% (range 46-73) SD=7	62% (range 46-73) SD=7	62% (range 46-73) SD=7	For Taronga, estimates are aimed at approximating observed Lx limits (i.e. observed proportion of all animals that survived to 10 yrs of age) while at the same time emulating recent, higher early survival. Standard deviation is set to 5% of mean – can be as low as 0 in captive populations so this is precautionary. For ages 1-4 yrs, life-table values are averaged across those age-classes. Q(x) values for the older age-classes (Age 4+), for which captive sample sizes are smaller and therefore less reliable, are manually adjusted to ensure few animals reach 10 yrs. Same values are assumed for CI. SRS value from re-analysed mark-recapture data.
Adult males (Age 1+)	18+17*(A>3)+ 17*(A>4)	18+17*(A>3)+ 17*(A>4)	62% range 46-73 Males may be slightly lower. SD=7	62% range 46-73 Males may be slightly lower. SD=7	62% range 46-73 Males may be slightly lower. SD=7	As above.
Initial population size (varied depending on modelling scenario)	100 (for initial comparisons)	100 (for initial comparisons)	100 (for initial comparisons)	100 (for initial comparisons)	100 (for initial comparisons)	Captive: 66 recruited from the wild. Not all bred before dying. Taronga received 83 (19 founders and the remainder captive born, though only some were offspring of the 19 accompanying founders).
Carrying Capacity	100 (for initial comparisons))	100 (for initial comparisons)	100 (for initial comparisons)	100 (for initial comparisons)	100 (for comparison)	CI breeding population: the breeding enclosures where recruitment comes from are only 10 enclosures of 6 males to 14 females. So a total of 200 animals are breeding and being recruited from, of which 42.8% are males. In the last 2 years (since Feb 2020) we have lost 63 breeding skinks, which have

Parameter	Captive TZ	Captive CI	CI FS (1&2)	Cocos 1	Cocos 2	Justification
						been supplemented from their offspring in maturing enclosures to maintain sex ratios and enclosure pop size. In the Baseline this complexity is captured by setting K to 280 and male monopolisation to 43%, which should allow for approximately 60 males to breed with approximately 140 females, and for minimal use of bachelor males due to the Long-term Polygynous setting (so breeding males will monopolise the same group of females until he or members of the group die, whereby they will be replaced).
Catastrophes: note that this is an area of considerable uncertainty and is only an initial attempt at quantifying this set of risks.						
In the models "catastrophes" operate with a specified frequency and manifest as an extreme variation in the rate of mortality and/or reproduction in the year of occurrence. Catastrophes can be positive or negative. Examples of catastrophes in this programme include (from J.P. Emery): In 2014 there was an outbreak of a novel *Enterococcus* virus (Rose et al. 2017) which resulted in some death and quarantining of *C. egeriae*. In 2017, wolf snakes invaded outdoor breeding exclosures, and >100 lizards were lost (likely eaten). Several candidates were identified, some with estimated values.						
Cat 1: Disease Annual frequency (%) Severity (as a proportion of "normal" survival/reproduction)	None	Exclosure animals only: once every 10 years. 0.9/0.9	Once every 5yrs 0.9/0.9.	None(?)	None(?)	On CI, hits exclosure animals only – which are not part of the breeding population. Breeding population is quarantined, bachelor population is culled.
Cat 2: Wolf snake Annual frequency (%) Severity (on survival)	None	Exclosure animals only: Once every 10 years 0.7	Once every 2 years 0.25	None	None	Emery: empirical data used to calculate FS risk on CI as follows: in two years, there was 1 incursion by wolf snakes. So, to extrapolate to a max of 25 calendar years (the length of the entire simulation) the following equation was used (1/2) * 25 = 12.5. To estimate the severity, I estimated the population was reduced by nearly 75% when wolf snakes went undetected in early 2021.
Cat 3: YCA super-colony events (potential)	No	No	No	Not in baseline	Not in baseline	Schubert pers. comm.: YCA numbers increasing to supercolony can impact survival - estimated loss of 46% of population at 6 weeks post-release on Cocos Island with supercolony (pop est. 136 [95% C.I. 99,186] from 296 released). Deaths would be expected to continue without intervention. Cocos 1 is thought to be less likely to have super colonies form as fewer flowering tree species to support ants. Parks estimate we will have to bait island every 2 years to prevent supercolonies from emerging. YCAs are managed on CI.
Cat 4. Rats (potential)	No	No	No	Not in baseline	Not in baseline	Schubert pers. comm.: rats have reinvaded both Cocos release islands, there is a risk they will start preying on skinks (possibility that could already be happening as we are seeing some preliminary negative impacts to the population at the

Parameter	Captive TZ	Captive CI	CI FS (1&2)	Cocos 1	Cocos 2	Justification
						second release island, where there are more rats, but cannot ascertain cause yet). An MSc study is underway. Impact not quantified.
Cat 5. Wildfire (potential)	No	No	No	Not in baseline	Not in baseline	Wildfire (popular recreational islands, camping and high visitation). Potential impact not quantified.
Cat 6. Cyclone (potential)	Not in baseline	Not in baseline	Not in baseline	Not in baseline	Not in baseline	Potential but impact unknown.
Cat 7. Tsunami (potential)	Not in baseline	Not in baseline	Not in baseline	Not in baseline	Not in baseline	Potential but impact unknown.
Cat 8. Macau Paper Wasps (potential)	Not in baseline	Not in baseline	Not in baseline	Not in baseline	Not in baseline	Potential but unknown.

Table 2. VORTEX parameters and their justification for Captive and Wild population models of *L. listeri* (as of February 2023).

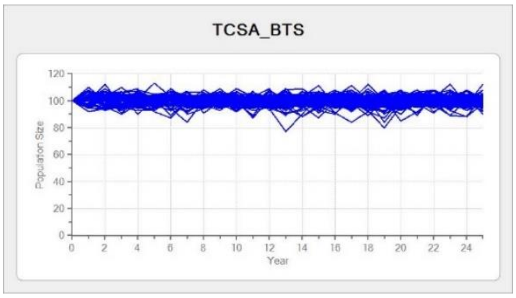
Parameter	Captive Taronga (MK managed)	Captive XI	SRS	Hypothetical Wild	Justification
Number of years (in 1-year timesteps)	25	25	25	25	Planning period is 10 years but captive models run for 25 years to illustrate longer-term genetic trends.
Extinction definition	1 sex remains	1 sex remains	1 sex remains	1 sex remains	1 sex remains
Inbreeding depression	3.14	3.14	6.29	6.29	Fitness depression expected in populations accumulating homozygosity. VORTEX default values are drawn from multiple populations (Ralls & Ballou 1988 for captive; O-Grady et al, 2006 for wild). Note: 2022 Taronga population mean inbreeding F=0.0184 when calculated with founder generation relationships calibrated to 0.
Breeding system	Short-term monogamous	Polygynous	Polygynous	Polygynous	In captivity, females and males breed multiple times. Taronga animals are held as pairs that are rearranged regularly.
Age of reproduction (median, not the first possible)	Females: 2 years Males: 2 years	Females: 2 years Males: 2 years	2 2	2 2	From Taronga Studbook: Females: 1.23 youngest reproducing female ever; 2.06 (median age of first reproduction). Males: 0.95 youngest reproducing male ever; 3.06 (median age of first reproduction). Data skewed by past management – 2 yrs applied for both sexes.
Maximum age	13 years	13 years	8 years	8 years most dead by 6.	From 2022 Taronga Studbook: Females: 12.7 yrs (Lx 10%=10.6 yrs); Males: 12.6 yrs (Lx 10% 12.5). Wild: Estimate 8 years maximum age with Lx 10% = 6 years.
Maximum age of reproduction	13 years	13 years	8 years	8 years	No evidence of senescence.
% Breeding females (SD)	100 (10)	100 (10)	100 (10)	100 (10)	Wild: almost all females breed, with some females occasionally missing a breeding event (Emery pers. comm.). From Taronga Studbook & Pairings: All females available for breeding but recruitment into breeding pool varies depending on release options.

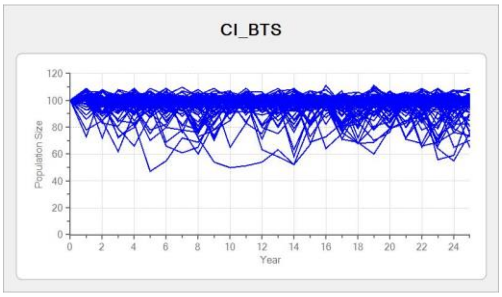
% Breeding males	100	100	100	100	In captivity, all males have access to females.
Sex ratio at birth (% male)	50	50	50	50	No evidence of skewed sex ratios.
Clutches per year	1=50% 2=50%	1=62% 2=27% 3=9% 4=2%	1=10% 2=10% 3=50% 4=30%	1=10% 2=10% 3=50% 4=30%	Schubert pers. comm: CI laying is typically September to October, hatching in November. On average, females lay four clutches a year (maximum 5). Cavanagh pers. comm: distribution of clutch number calculated for Taronga = 1=62%; 2=27%; 3=9%; 4=2%; 5=0.5%. 1=50%; 2=50% used for Taronga reflecting management practice.
Clutch size % one egg % two eggs	 5 95	 5 95	 5 95	 5 95	Captive breeding data show that *L. listeri* almost exclusively lay clutches of two eggs, but occasionally lay one.
Mortality schedule % (SD) 0-1 year	M: 23% F: 19%	M: 23% F: 19%	38 (5)	38 (5)	Taronga data from Studbook & extrapolated to CI captive programme. 38% from Emery thesis (using data from 2015-2016).
1-2yrs	M: 9.5% F: 13%	M: 9.5% F: 13%	19 (1.9)	19 (1.9)	Taronga & CI values from studbook. 19% = double the captive value (rule of thumb applied in Emery thesis).
Adults	M: 11% F: 19%	M: 11% F: 19%	23 (5)	23 (5)	Taronga data from SB (see Figure 2 and Table 5 below):
Initial population size	100 (for comparison)	100 (for comparison)	100 (for comparison)	100 (for comparison)	43 came in from wild. After breeding, 54 went to Taronga (22 founders and the rest captive bred though not necessarily from those same 22 founders). KS: CIRC SRS: 2019: 160 LG; EW SRS: 2020: 200 LG
Carrying Capacity	100 (for comparison)	100 (for comparison)	100 (for comparison)	100 (for comparison)	CI: Last count, 637 animals part of breeding population.
Catastrophes: note that this is an area of considerable uncertainty and is only an initial attempt at quantifying this set of risks.					
Cat 1: Disease 1 - Enterococcus Annual frequency (%) Severity (on survival and reproduction)	No	Yes One every 10 years 0.9, 0.9			
Cat 2: Disease 2 - Other bacterial disease Annual frequency (%) Severity (on survival and reproduction)	No	Yes One every 10 years Not in Baseline			Hit one enclosure only (one of 20 – with 40 animals in it) 1200 animals in total. Last count, 637 animals part of breeding population Big proportion in tents– once in tents, geckos don't come back into the breeding population.
Egg management		Truncate surplus animals <1?			Select (e.g.) top 10 breeding pairs – 2 eggs per clutch – both are hatched (can't separate) – take second clutch in case of sperm storage from previous male. Animals paired by mean kinship (taking account of phenotype/behaviour) – eggs managed if offspring below average MK – roughly 33% of eggs are kept. Turn on breed to K and MK management (dynamic)

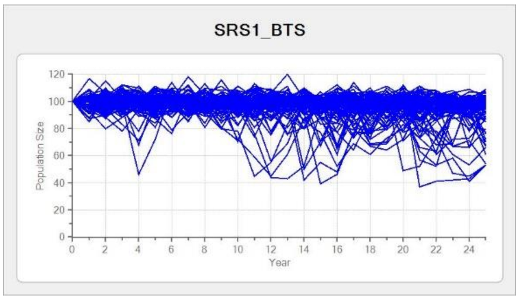
Comparison of baseline models

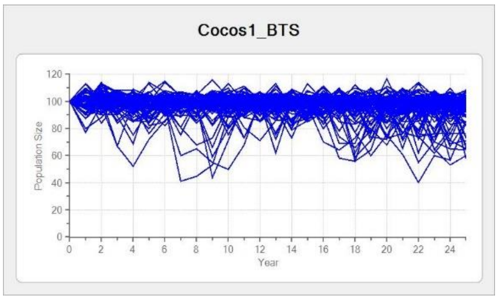
Differences in performance between the eight Baseline Models is illustrated below (graphs show 100 iterations of each Baseline model, tables report results of 1000 iterations):

Blue-tailed Skinks









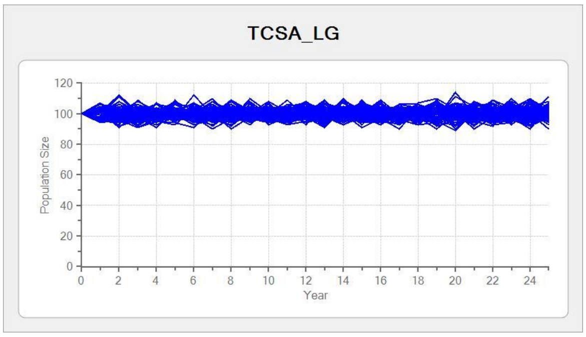
Scenario	stoch-r	SD(r)	PE	N-all	SD(N-all)	GeneDiv	MeanTE
TCSA_BTS	0.2344	0.1176	0	99.6	3.64	0.9154	0
CI_BTS	0.1841	0.1688	0	96.55	8.94	0.8976	0
SRS1_BTS	0.2609	0.2284	0	95.07	11.93	0.8678	0
Cocos1_BTS	0.2575	0.2305	0	94.15	13.34	0.8694	0

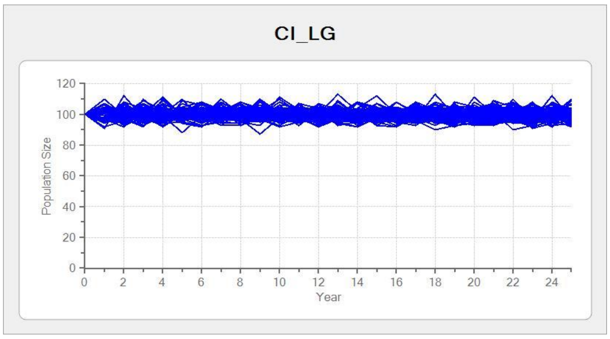
Where Stoc-r=instantaneous growth rate; PE=P(Extinction); N-all=mean number living at year 25 across all iterations, including those that went extinct during the period; MeanTE=mean time to extinction for those populations that did not survive the 25 years.

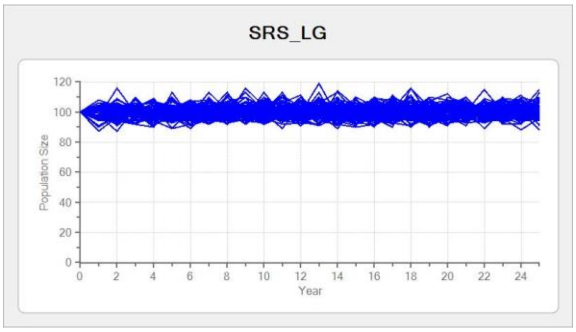
The Taronga captive population maintains strong growth throughout and numbers rarely drop below carrying capacity. The Christmas Island captive populations have similar characteristics but growth is slower and population size less stable, due to occasional disease outbreaks. Neither of these models illustrate the full growth potential of the captive populations – they are designed to emulate populations under current management, which is designed to limit surplus in non-release years.

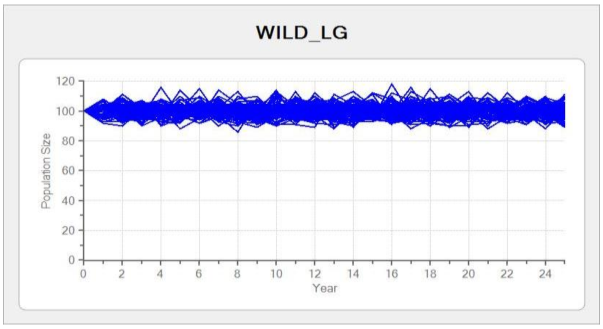
In these models, the performance of the FS and Cocos Island populations is similar, showing fluctuating population size and a gradual decline in fitness over time due to inbreeding accumulation and other stochastic influences. **The catastrophes observed within the FS are not included in this model – when they are included, populations generally plummet to extinction within 5 years.**

LISTER'S GECKO









Scenario	stoch-r	SD(r)	PE	N-all	SD(N-all)	GeneDiv	MeanTE
TCSA_LG	0.4889	0.0877	0	100.16	3.52	0.9599	0
CI_LG	0.4787	0.1069	0	100.11	3.56	0.9572	0
SRS_LG	0.6927	0.1315	0	99.74	4.36	0.9430	0
WILD_LG	0.6914	0.1331	0	99.97	4.54	0.9424	0

Where Stoc-r=instantaneous growth rate; PE=P(Extinction); N-all=mean number living at year 25 across all iterations, including those that went extinct during the period; MeanTE=mean time to extinction for those populations that did not survive the 25 years.

As currently modelled both the (managed) captive and free-living gecko models grow faster than those for the skinks. Despite reduced maximum lifespan and increased early mortality, the FS and Free-living models grow faster because annual clutch number per female is not constrained by management. FS and Free-living models currently carry the same parameter values - there are no data for free-living/wild gecko populations. This should be treated as a starting point only.

Preliminary questions & analyses

1. Is it better to pair-wise breed or run in larger enclosures?

In captive populations there are trade-offs between managing species as breeding pairs versus in larger groups. Pair-wise management allows precise control over potential matings with the aim of improving gene diversity and minimising inbreeding accumulation. It provides certainty of parentage of any resulting offspring and the potential for more individuals to contribute to the gene pool (improving long-term genetic outcomes). In some instances this can mean that the same genetic/demographic goals can be met with fewer animals. However, it is usually more expensive in terms of facilities and labour and for some species breeding rates may be lower (e.g. where this system runs counter to species biology). Maintaining animals in larger, multi-sex groups can be more space and labour-efficient and can lead to improved breeding performance where this mirrors species biology (e.g. by allowing mate-choice or multiple matings). It can also allow more animals to be held for the same cost, improving resilience to catastrophes. On the downside there is reduced ability to optimise pairings, allowing some animals to dominate breeding, accelerating inbreeding accumulation and reducing gene diversity retention. Parentage of eggs/offspring is less certain and, depending on circumstances, there can be increased aggression leading to extra mortality. Models were applied to help quantify some of these trade-offs, in particular the trade-off between keeping more animals on the one hand and allowing more male monopolisation on the other. Model scenarios considered the impact on population performance of shifting from monogamous to increasingly polygynous breeding (operational sex-ratio: 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8) for a range of population sizes (100-700 at increments of 100). Starting Size (Ni) and Carrying Capacity (K) were maintained equal in all models. Models were run for both species and for both Taronga and CI intensive facilities (CI has larger capacity and catastrophes are included – see Tables 1 & 2).

Taronga Blue-tailed Skinks – Stochastic Growth Rate (r):

Stoc-r Population Size (Ni= K)	Male:Female Sex-Ratio							
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
100	0.2363	0.2305	0.2256	0.2205	0.2197	0.2137	0.2117	0.2094
200	0.2472	0.244	0.2417	0.2387	0.2358	0.2353	0.2333	0.2306
300	0.251	0.2483	0.2466	0.2458	0.2443	0.2432	0.2411	0.2402
400	0.253	0.2522	0.2496	0.2487	0.2481	0.2473	0.2461	0.2447
500	0.2539	0.2531	0.2514	0.251	0.2505	0.249	0.2487	0.2481
600	0.2552	0.2535	0.2536	0.2518	0.2512	0.2506	0.2504	0.2494
700	0.2552	0.2546	0.2545	0.2525	0.2528	0.2517	0.2509	0.2516

Taronga Blue-tailed Skinks – Gene Diversity Retention at 25 years (GD)

GD Population Size (Ni=K)	Male:Female Sex Ratio							
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
100	0.9221	0.9024	0.8846	0.8661	0.849	0.8328	0.818	0.8085
200	0.9603	0.9493	0.9411	0.9323	0.9257	0.9172	0.9083	0.8992
300	0.9732	0.9661	0.9603	0.9548	0.9491	0.9451	0.9388	0.9337
400	0.9797	0.9745	0.9701	0.9661	0.9625	0.9585	0.9547	0.9512
500	0.9838	0.9794	0.976	0.9728	0.9697	0.9665	0.9641	0.9605
600	0.9865	0.9827	0.9799	0.9775	0.9749	0.9724	0.9698	0.9676
700	0.9884	0.9853	0.9828	0.9805	0.9784	0.9761	0.9743	0.972

For Taronga Zoo, as expected, larger populations with a 1:1 operational sex-ratio retained the most gene diversity. To maintain more than 95% of starting GD required 200 individuals with a 50:50 sex-ratio, and between 300-500 for operational sex-ratios of 1:2 – 1:8. Growth rates followed the same pattern, with rates decreasing due to more rapid inbreeding accumulation in populations with more skewed sex-ratios. However, it should be noted that this is because models are seeded with an even number of males and females. Models seeded with more females than males to create the biased operational sex-ratio would be expected to grow faster, at least initially, because females are the rate limiting resource (except in very small populations where stochastic events can result in males being limiting). A similar pattern is seen throughout this section for gene diversity retention and growth. For CI populations at N=100 population viability is more marginal than at Taronga because of the additional catastrophes included.

<u>There is no obvious interpretation for the 1.1 sex-ratio columns in the stochastic growth tables below, which is counter-intuitive. These models require more work.</u>

CI Blue-tailed Skinks – Stochastic Growth Rate (r):

Stochastic R Population Size (Ni, K)	Male: Female Sex Ratio							
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
100	0.1034	0.1831	0.1802	0.1756	0.1699	0.1658	0.1627	0.1619
200	0.1269	0.1982	0.1951	0.1921	0.1935	0.1875	0.1877	0.1829
300	0.1342	0.2043	0.2021	0.2009	0.1987	0.1967	0.1956	0.1933
400	0.139	0.2063	0.204	0.2042	0.2015	0.2006	0.2013	0.1999
500	0.1424	0.2075	0.2077	0.2065	0.2058	0.2041	0.201	0.2036
600	0.1444	0.21	0.208	0.2078	0.2056	0.2061	0.2043	0.2036
700	0.1438	0.2095	0.2086	0.2087	0.2084	0.2071	0.2061	0.2058

CI Blue-tailed Skinks – Gene Diversity Retention at 25 years (GD)

GD Population Size (Ni, K)	Male:Female sex ratio							
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
100	0.9127	0.8928	0.8722	0.8548	0.8324	0.8179	0.7992	0.7906
200	0.9575	0.9454	0.9358	0.925	0.9185	0.9064	0.897	0.8843
300	0.9713	0.9632	0.9567	0.9501	0.9442	0.9380	0.9332	0.9254
400	0.9786	0.9721	0.9668	0.9627	0.9582	0.9537	0.95	0.9452
500	0.9830	0.9777	0.9736	0.9700	0.9665	0.9635	0.9597	0.9566
600	0.9858	0.9813	0.9780	0.9749	0.9722	0.9691	0.9665	0.9634
700	0.9878	0.9839	0.9811	0.9787	0.9762	0.9738	0.9712	0.9688

Taronga Lister's Gecko – Stochastic Growth Rate (r):

Stoc-r Population Size (Ni, K)	Male: Female Sex-Ratio 1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
100	0.296	0.3852	0.384	0.3829	0.3806	0.3787	0.3779	0.3752
200	0.3046	0.3975	0.3937	0.3923	0.3925	0.3903	0.39	0.3891
300	0.3072	0.3941	0.3967	0.3963	0.3958	0.3951	0.3947	0.3942
400	0.3082	0.3994	0.3988	0.3978	0.3976	0.3971	0.3969	0.396
500	0.3091	0.3996	0.3989	0.3991	0.399	0.3985	0.3979	0.3979
600	0.3092	0.4006	0.4002	0.3994	0.3993	0.3988	0.3989	0.3989
700	0.3098	0.401	0.4005	0.4005	0.4001	0.3999	0.3999	0.3994

Taronga Zoo Lister's Gecko – Gene Diversity Retention at 25 years (GD)

GD Population Size (Ni, K)	Male: Female Sex Ratio 1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
100	0.9374	0.9217	0.9126	0.9022	0.8934	0.8815	0.8736	0.866
200	0.968	0.9728	0.9546	0.9501	0.9458	0.9407	0.9364	0.9312
300	0.9784	0.959	0.9695	0.9664	0.9633	0.9606	0.9576	0.9542
400	0.9837	0.9793	0.9768	0.9747	0.9724	0.9703	0.9679	0.9658
500	0.9869	0.9835	0.9814	0.9796	0.9778	0.9762	0.9744	0.9726
600	0.9891	0.9861	0.9845	0.983	0.9814	0.98	0.9785	0.9772
700	0.9906	0.9881	0.9867	0.9854	0.9842	0.983	0.9816	0.9804

CI Lister's Gecko – Stochastic Growth Rate (r):

Stoc-*r* Population Size (Ni, K)	Male:Female Sex-Ratio. 1.2	1.3	1.4	1.5	1.6	1.7	1.8
100	0.4764	0.475	0.4755	0.4757	0.4737	0.474	0.4704
200	0.4848	0.4835	0.4824	0.4844	0.4826	0.4828	0.4836
300	0.4864	0.4875	0.4861	0.4868	0.4861	0.4864	0.4849
400	0.4884	0.4873	0.4881	0.4866	0.4884	0.4847	0.4872
500	0.489	0.4885	0.4889	0.4899	0.489	0.4877	0.4889
600	0.4888	0.4899	0.4888	0.4898	0.4889	0.4881	0.4886
700	0.4905	0.49	0.4891	0.4897	0.4895	0.4883	0.4885

CI Lister's Gecko – Gene Diversity Retention at 25 years (GD)

GD Population Size (Ni, K)	Male: Female Sex Ratio 1.2	1.3	1.4	1.5	1.6	1.7	1.8
100	0.9554	0.9526	0.9503	0.9473	0.9433	0.9418	0.9391
200	0.9773	0.9761	0.9744	0.9736	0.9723	0.9713	0.9698
300	0.9848	0.9839	0.983	0.9824	0.9815	0.9807	0.98
400	0.9885	0.9879	0.9873	0.9867	0.9862	0.9855	0.985
500	0.9908	0.9903	0.9898	0.9894	0.9889	0.9884	0.9879
600	0.9923	0.9919	0.9915	0.9911	0.9908	0.9904	0.99
700	0.9934	0.9931	0.9927	0.9924	0.9921	0.9917	0.9914

2. WHAT POPULATION SIZE/CARRYING CAPACITY IS RECOMMENDED FOR LISTER'S GECKOS AND BLUE-TAILED SKINKS IN CAPTIVITY?

To be cost effective, carrying capacity in captivity should be tailored to meet program goals, which are usually described in terms of gene diversity retention, extinction risk and, often, ability to generate a harvest of a particular size, all over a specified timeframe. For captive populations which are relatively sheltered from environmental fluctuations, gene diversity retention goals often impose the maximum limit on size. Therefore, following calculations assign a target for gene diversity retention over a given period, and then use standard formulae to calculate what population size, population growth rate and starting gene diversity would be required to meet that target, assuming a population-specific level of efficiency in transmitting gene diversity from one generation to another (using the concept of genetically effective population size). The bigger the genetically effective size, the greater the retention, therefore, for a fixed population size, retention is greater where the effective size to census size ratio (Ne/N) is larger. These calculations can be performed using the PMx software produced by SCTI.

Note that the formula for Ne selected for calculations is designed to correct for sex-ratio skews only: $\mathbf{N_e = 4N_mN_f/(N_m + N_f)}$. A more accurate reading is likely from an equation that corrects for life-time family sizes (Harris & Allendorf 1989) but this information is not currently available for either species.

LISTER'S GECKOS

Calculations for Taronga are based on the PMx-generated Ne/N of 0.26 and starting GD of 96% (both calculated from studbook data). This Ne/N value is conservative. PMx calculates Ne from the operational sex-ratio, using the number of breeding adults. Due to the practice of egg removal/management some breeding individuals will not register as such in the studbook. As a result, the Ne value calculated by PMx reflects management rather than population potential. There are actually 59 male and 66 female proven breeders in the population of 180 (instead of the studbook registered 23.23), which would give a potential Ne/N=0.68 in absence of egg management.

Calculations for the CI population assume Ne=120 and N=467 in Lizard Lodge **(Ne/N=0.26).** Starting GD = 96% (calculated based on 21 founders). Without egg management Ne 200 is achievable (100 males and 100 females). Generation time is set at T=4. When factoring in egg management, possible Ne values range from 40-200 depending on the protocol applied (i.e. the number of breeding individuals from which eggs are reared for the breeding program).

TZ Lister's Gecko	Population size 200	Population size 250	Population size 300	Population size 450
TZ captive Ne/N: 0.26 90% gd for 25 yrs T=4.4	Achievable 29yr	Achievable for 36 yrs	Achievable for 44 yrs	-
TZ captive NeN: 0.26 95% gd for 25 yrs T= 4.4	Not achievable 4yrs	Not achievable 5yrs	Not achievable 6yrs	-
CI captive Ne/N 0.26 90% gd for 25 yrs T= 4	Achievable for 26 years	Achievable for 33yrs	Achievable 40yrs	Achievable 60 years
CI captive Ne/N .0.26 95% gd for 25 yrs T =4	No achievable 4 yrs	No achievable 5yrs	Not achievable 6 yrs	Not achievable 9 yrs
FS Ne/N 0.1 90% gd for 25 yrs	Not achievable 10yrs	Not achievable 12yrs	Not achievable 15yrs	Achievable 23yr
FS Ne/N 0.1 95% gd for 25 yrs	Not achievable 1 yr	Not achievable 2 yr	Not achievable 2 yr	Not achievable 3 yr
FS Ne/N 0.2 90% gd for 25 yrs	Not achievable 20 yrs	Achievable	Achievable 30yr	Achievable 46rs

FS Ne/N 0.2 95% gd for 25 yrs	Not achievable 3yrs	Not achievable 4yrs	Not achievable 5yrs	Not achievable 6yrs

- Taronga requires minimum population size of 170 geckos to maintain 90% GD for 25 years (based on starting GD of 96% (from studbook).
- SRS assumed Ne/N 0.1 requires 544 geckos to maintain population GD 90% for 25 years (based on starting GD of Taronga captive population of 96 % from studbook)
- SRS assumed Ne/N 0.2 requires 222 geckos to maintain population GD 90% for 25 years (based on starting GD of Taronga captive population of 96 % from studbook)

Blue-tailed Skinks

The challenge of estimating Ne for BTS is that animals are kept in groups and so it is not known for certain how many males or females are contributing to the gene pool. Instead, a range of possible values have been estimated using a series of assumptions. Calculations for the CI BTS population are based on Ne=95 and N=430 animals in lizard lodge, with starting GD=96.5% based on 36 founders and a standard formula for calculating GD from this (GD=1-1/2XNo.fdrs). Ne/N is estimated to be 0.22, factoring in the current egg management strategy. A population could have Ne=168 if all 60 males and 140 females were contributing, to give GD=97.4% (calculated based on 36 founders), this is the best-case scenario. When factoring in a range of outcomes that could result from egg management (i.e. the total number of adults contributing eggs to the living population) the potential Ne range becomes 40-150.

Calculations for the TZ BTS population are based on Ne=66 with N=212 animals (Ne/N=0.3), with starting GD 94.4%. This factors in egg management. Without egg management, Ne=108 could be achieved (40 males and 85 females). When factoring in a range of potential outcomes of egg management (i.e. minimum and maximum number of individuals that could be contributing based on egg output), the possible Ne range becomes Ne=32-100.

CI BTS	Population size 200	Population size 250	Population size 300	Population size 450/600
TZ captive Ne/N 0.3 90% gd for 25 yrs T=4	Not achievable 22 years	Achievable 28 years	Achievable 34years	Achievable 68years
TZ captive Ne/N 0.3 95% gd for 25 yrs T=4	Not achievable	Not achievable	Not achievable	Not achievable
CI captive Ne/N: 0.22 90% gd for 25 yrs T=4	Achievable 27yrs	Achievable for 34 yrs	Achievable for 41 Yrs	Achievable 62yrs
CI captive NeN: 0.22 95% gd for 25 yrs T=4	Not achievable 8yrs	Not achievable 10yrs	Not achievable 13yrs	Not achievable 19yrs
FS Ne/N 0.1 90% gd for 25 yrs T=3.5	Not achievable 12	Not achievable 15yrs	Not achievable 18yrs	Achievable 27yr
FS Ne/N 0.1 95% gd for 25 yrs	Not achievable 3yrs	Not achievable 4yrs	Not achievable 5yrs	Not achievable 8 yr
FS Ne/N 0.2 90% gd for 25 yrs		Achievable 31 yrs	Achievable 37 yrs	Achievable 56rs
FS Ne/N 0.2 95% gd for 25 yrs	Not achievable 7 years	Not achievable 9 years	Not achievable 11 years	Not achievable 17yrs

Explanation of Ne and Ne/N estimates

Genetically effective size for CI BTS is assumed to be Ne=168 (based on a breeding population of 60 males and 140 females), and a total population of N=430 (Lizard Lodge enclosures only), giving Ne/N=0.39. However, under partial egg management for a population of 450, 20 eggs are recruited from each breeding enclosure each year, or 200 eggs for the year (100 clutches). In this time males are rotated once (eggs are retained in clutches i.e. pairs). This would make the breeding population best case scenario 60 males and 100 females (Ne/N 0.34). This assumes all females and males have an opportunity to breed. But since recruitment is approximately one clutch per month, the number contributing could be as low as 20 females (Ne/N 0.1). Selecting the median (roughly 60 females) gives Ne=120 and Ne/N=0.26. **We have assumed Ne = 120-150, Ne/N=0.26-0.34 (~0.31).**

CI LG: Ne assumed to 200 (based on breeding population of 100 males and 100 females) – total population 467 (lizard lodge enclosures only) so Ne 200 Ne/N 0.43. However, under partial egg management population 750, 20 eggs recruited from each breeding enclosure, or 200 eggs/year (100 clutches). In this time males are rotated once (eggs are retained in pairs ie full clutch). This still permits each female to deliver 1 clutch and represents best case scenario, worst case scenario could be as low as 20 females breeding (Ne 40). If median selected say 60 females and 60 males Ne 120, Ne/N 0.26. **Assume Ne 40-200**, Ne/N 0.08-0.43 **(Ne 120 ~0.26)**

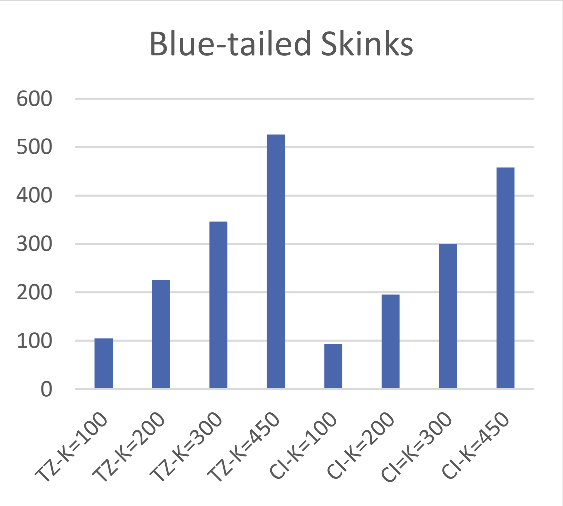
TZ LG: Ne/N determined to be **0.2642 Ne 46.8**. calculated by PMx (59 male/66 female bred each year, gives Ne=124 and Ne/N=0.69, but egg managed with eggs retained each year=30 (15 clutches), could mean as few as 15 females breeding, (Ne=30-60). From PMx we can determine 23 males and 23 females with the opportunity to breed (as a result of PMx being blind to the breeding potential of individuals that are not registered in the studbook as having produced eggs). Without egg management Ne=124.

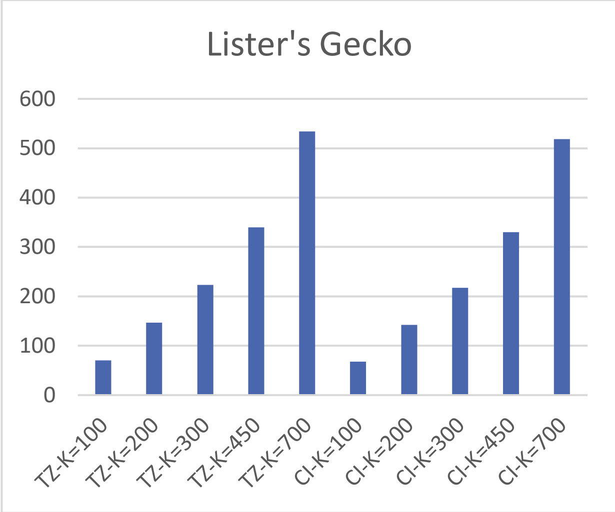
TZ BTS: Ne/N determined to be based on 40 males and 85 females breeding each year. Ne=108, with total population=212, so Ne/N=0.5, which seems very high (ie without egg management). With egg management, eg in 2022, 68 eggs were recruited, so as few as 34 clutches. Ne=68, Ne/N 0.32**.** Could be as few as 16 females and 16 males breeding (Ne 32) in worst case scenario, or in best case scenario 68 females and 40 males (since eggs are split), giving Ne=100. Assume Ne=32-100; Ne/N=0.15-0.47/ **(Ne 66 and Ne/N 0.3)**

- TZ LG: 22 founders initially. Ho = 97.73% Ht =0.96 (PMx)
- TZ BTS: 19 founders initially Ho = 97.4% (Ne 32-100 under egg management) **Ne 66 Ht=94.4**% (no egg management Ne 108)
- CI LG 21founders Ho 97.62% (Ne 40-200 under egg management) **Ne 120 Ht 96.0%.** (No egg management Ne 200)
- CI BTS 36 founders (plus 11 that died in first 12mths so excluded) Ho 98.62%. Under egg management Ne 40-150. **Ne 95 assumed 96.5%** (no egg management Ne 150)

3. What sizes of regular harvest (for release) should be possible?

Scenarios were run for both the Taronga Zoo and Christmas Island intensively managed populations, to explore potential sizes of annual harvest for skinks and for geckos. The results are illustrated below. Potential harvests for both species are large and consistently so (see standard deviation in the accompanying tables) and they are larger for skinks than for geckos.





BTS	Mean	SD
TZ-K=100	104.6632	8.236134
TZ-K=200	226.106	8.612952
TZ-K=300	345.9527	9.668592
TZ-K=450	525.9787	10.67017
CI-K=100	93.32024	5.978201
CI-K=200	195.5663	7.086416
CI=K=300	300.0268	8.265585
CI-K=450	457.7214	10.3027

LG	Mean	SD
TZ-K=100	70.38952	2.521754
TZ-K=200	146.5421	2.683499
TZ-K=300	223.4065	2.572294
TZ-K=450	339.4718	3.209165
TZ-K=700	534.0834	4.012615
CI-K=100	68.16204	2.421268
CI-K=200	142.4229	2.980661
CI-K=300	217.6164	3.005558
CI-K=450	329.9338	3.367388
CI-K=700	518.1659	3.897588

For Blue-tailed Skinks, the modelled Christmas Island harvest rates are lower than Taronga Zoo's because of the inclusion of a disease catastrophe. However, a density-dependent increase in mortality at Taronga is not currently included in the model, which would decrease Taronga's harvest capability.

4. How big does a Fenced Site need to be for long-term viability?

A series of models were run to consider the size of FS needed to overcome downward pressure from stochastic processes, in absence of major catastrophes such as disease outbreak. Incursion by wolf snakes is excluded from the models illustrated here because all scenarios including wolf snakes went rapidly extinct. Scenarios here are all run for 50 years to consider long-term consequences. Site carrying capacities are varied from K= 25 – 500 and populations are initiated at full capacity. At present, FS and Free-living models carry the same parameters and so the results of these scenarios cover both FS and Free-living scenarios.

Blue-tailed Skink

In absence of catastrophes such as disease outbreak and wolf snake incursion, Blue-tailed Skink models with N≥200 survive reliably for 50 years. Those of N=100 or below do not, with extinction risk ranging from PE=0.9%-100%.

Scenario	stoch-r	SD(r)	PE	N-all	SD(N-all)	MTE
Ni=K=25	0.0362	0.3812	1.00	0.00	0.03	22.2
Ni=K=50	0.0719	0.3176	0.679	5.9	11.25	38.9
Ni=K=75	0.1424	0.2664	0.107	44.85	26.17	42.6
Ni=K=100	0.1936	0.2374	0.009	84.43	22.74	44.8

Ni=K=200	0.2715	0.2098	0	194.07	18.07	0
Ni=K=300	0.3001	0.2028	0	295.18	21.94	0
Ni=K=400	0.3167	0.1979	0	393.57	23.82	0
Ni=K=500	0.325	0.1982	0	493.99	26.96	0

Lister's Gecko

In contract to the scenarios for Blue-tailed Skinks, all Lister's Gecko models persisted for 50 years in absence of catastrophes. The difference is attributable to the longer lifespan and higher age-specific mortality. Again, these models are optimistic as they do not include catastrophes. All models that included wolf snakes (not shown here) declined rapidly to extinction.

Scenario	stoch-r	SD(r)	PE	N-all	SD(N-all)	MTE
Ni=K=25	0.4951	0.2351	0	25.04	1.97	0
Ni=K=50	0.5931	0.1753	0	50.04	2.94	0
Ni=K=75	0.6332	0.147	0	74.89	3.61	0
Ni=K=100	0.6548	0.1334	0	100.19	4.42	0
Ni=K=200	0.6929	0.1075	0	200.1	6.2	0
Ni=K=300	0.7082	0.0977	0	299.81	7.73	0
Ni=K=400	0.7144	0.0928	0	399.94	8.9	0
Ni=K=500	0.7194	0.0891	0	500.65	9.96	0

It should be noted that these estimated sizes may be optimistic. These species, and the areas where they live, have only been under intense study for a relatively short time period compared to the 50 years projected. Additional, unknown sources of catastrophe may be operating that are not included in the models.

References

Harris, R. B., & Allendorf, F. W. (1989). Genetically effective population size of large mammals: an assessment of estimators. *Conservation Biology*, *3*(2), 181-191.

DATA SUPPLEMENT 1: POPULATION SIZE AND GROWTH STATISTICS

The following data, estimates and observations were taken into account when building models and running analyses.

TARONGA BLUE-TAILED SKINKS

Provided by Claire Ford & Lisa Cavanagh

The following table provides observed population sizes and mean growth rates for the TCSA Skink population.

Year (Dec)	Population size (enclosure and exclosure but not eggs)	Lambda
2014	402	
2015	494	1.22
2016	1030	2.08
2017	1265	1.22
2018	1025	0.81
Mean lambda		**1.33**
R for lambda =1.33		**0.28**

CI BLUE-TAILED SKINKS

Provided by Kristin Schubert

Total population breakdown for **Blue-tailed Skinks** (from Kristen Schubert):

- PH: 540 (Nov 2022)
- TZ: 227 (June 2022)
- Madar: 503 [95% CI 409,618] Oct 2022
- Blan: 1240 [95% CI 923,166] Sept 2021
- Circuits SRS: 0
- EW SRS: minimum 12 (likely less than 50) Nov 2022
- Total min: 2522

Counts for CI total captive population (managed breeding population and exclosures)

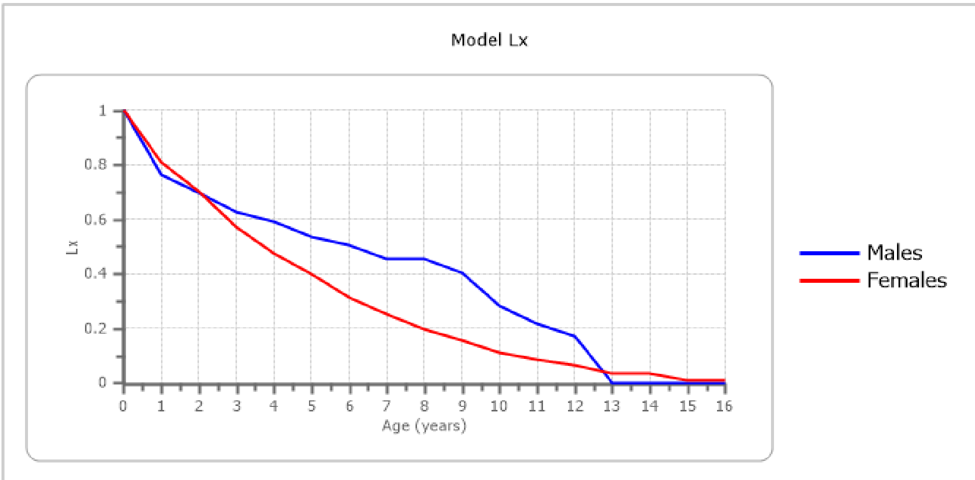
DATE	MALES	FEMALES	BACH. MALES	total males	Total adult	Total maturing	Total all
Nov-22	73	171	88	161	332	171	503
Aug-22	97	220	101	198	418	267	685
May-22	108	272	111	219	491	148	639
Feb-22	89	200	137	226	426	124	550
Nov-21	59	138	149	208	346	85	431
Aug-21	80	165	60	140	305	165	470
May-21	135	215	60	195	410	243	653
Feb-21	158	275	85	243	518	46	564
Nov-20	122	267	75	197	464	96	560
Aug-20	86	208	73	159	367	262	629
May-20	165	309	67	232	541	331	872
Feb-20	153	369	67	220	589	317	906

DATA SUPPLEMENT 2: MORTALITY DATA

TCSA (LISTER'S GECKO)

Provided by Claire Ford

TCSA AGE-SPECIFIC MORTALITY FOR LISTER'S GECKO (2011-2022)



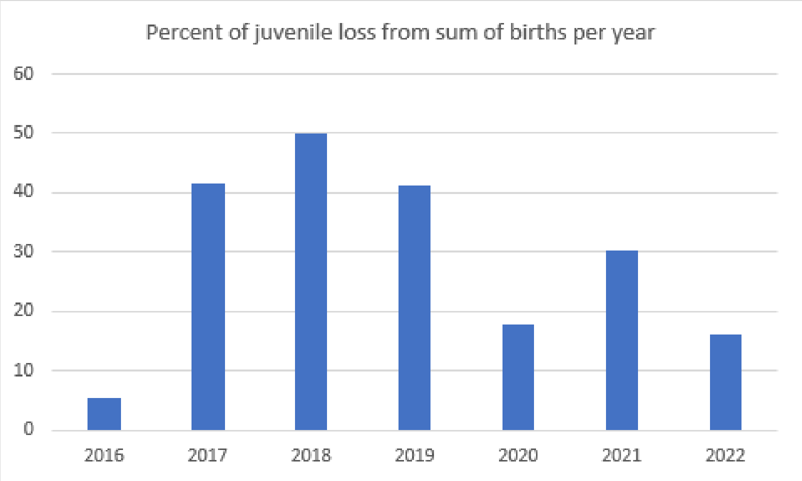
TCSA AGE-SPECIFIC MORTALITY AND SURVIVORSHIP FOR LISTER'S GECKO (2011-2022)

	Females				Males		
Age	Qx	Number	Lx		Qx	Number	Lx
0	0.194	100	1		0.236	100	1
1	0.128	80.6	0.806		0.085	76.4	0.764
2	0.19	70.2832	0.703		0.104	69.906	0.699
3	0.169	56.92939	0.569		0.057	62.63578	0.626
4	0.159	47.30832	0.473		0.09	59.06554	0.59
5	0.212	39.7863	0.398		0.057	53.74964	0.537
6	0.2	31.35161	0.314		0.107	50.68591	0.506
7	0.211	25.08128	0.251		0	45.26252	0.452
8	0.214	19.78913	0.198		0.105	45.26252	0.452
9	0.273	15.55426	0.156		0.303	40.50995	0.405
10	0.25	11.30795	0.113		0.229	28.23544	0.282
11	0.2	8.48096	0.085		0.2	21.76952	0.218
12	0.5	6.784768	0.068		1	17.41562	0.174
13	0	3.392384	0.034		1	0	0

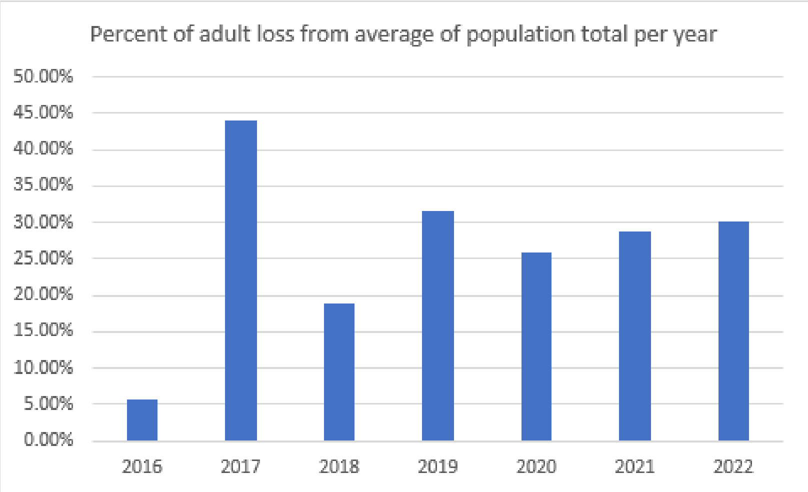
Christmas Island Lister's Geckos

Provided by Kristen Schubert

Juvenile LG mortality has varied between the years (see below). Suggested estimate for juvenile mortality = 30% The average loss (mortality) of adult Lister's Geckos in captivity from 2016-2022 was 26%. We lost more adult LGs in the last two years due to disease (see below).



	2016	2017	2018	2019	2020	2021	2022
Sum of Births	448	316	156	196	575	391	409
Sum of total lost	24	131	78	81	103	118	66



year	2016	2017	2018	2019	2020	2021	2022
total (average)	563	458	512	441	758	1059	1079
total loss per year	32	201	96	139	196	305	324

Cocos Islands – Blue-tailed Skinks

Provided by Kristen Schubert & Jon-Paul Emery

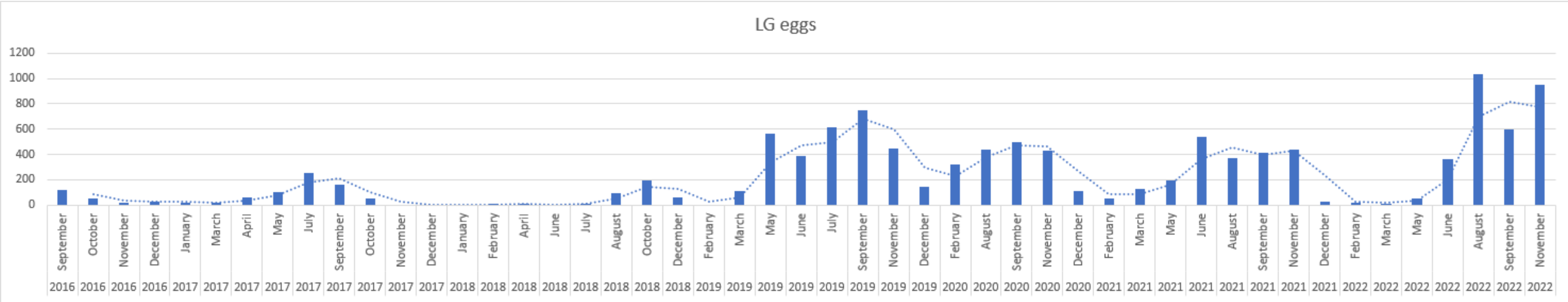
Post-release survivorship

Data from three sessions between 2019-2020 (6 wks, 6 mnths and 12 mnths post-release). Survival estimates between these periods was 79% [95% CI 60,90] and 75% [95% CI 59,87].

DATA SUPPLEMENT 3: REPRODUCTION DATA

CHRISTMAS ISLAND EGG PRODUCTION (LISTER'S GECKO)

LG egg production peak roughly between August-November



DATA SUPPLEMENT 4. NOTES ON CATASTROPHES FOR SRS

[From K. Schubert]

Very tricky to estimate severity/frequency catastrophes and threats to SRS as it's been difficult to pin-point cause of decline, and we have had varying fence designs that also vary in efficacy of excluding predators.

WOLF SNAKES

In October 2021 we found an adult wolf snake with 1 BTS in her belly in the EW SRS, we removed it and euthanised it but we now know they can get into the site (therefore frequency of incursion would be higher at this site in its current state). Since October, the BTS population has continued to decline at a very slow & gradual rate and we rarely see juveniles. It's been over a year now that this decline has been occurring. While a risk assessment would show that snakes are likely to be the cause, there could be a number of hypotheses about what's driving this and without being able to detect/understand the threat we can't manage it well, and it seems very unlikely the population will be able to recover (so survival would be 0%).

If we were going to release lizards into this site again in the future it would essentially be a new site as we would have to start from scratch with habitat removal and rebuild, and a new fence design.

In the Circ SRS which failed in 2021, we detected a decline and lost most of the population over ~ 8 months before the remaining 180 BTS were evacuated. The site was thoroughly searched throughout the 8 months and it wasn't until half the habitat was removed after the skinks had been evacuated that we found evidence of at least 2 wolf snakes at the site.

In summary, if a snake/s gets in survival will be 0% because it's EXTREMELY difficult to detect and remove them. Once in it's proof that the fence is penetrable therefore even if you remove them the site has essentially failed.

So far each of the 3 SRS trials has failed within 3 years and snakes have been found in the SRS at both sites. We cannot definitively determine if they climbed the fences when we found them or got in another way but they are excellent climbers and a slippery smooth surface alone and a low voltage zap has been proven not to be enough in mock fence trials.

In the next SRS trial we have a new double-fence design with additional measures in place to prevent incursion though a level of risk still remains, hopefully frequency of WS incursion will be a lot less for this site

GECKO DISEASE

In Oct 2021 we had an outbreak in the LG breeding enclosure of a novel bacterium. We individually quarantined the remaining 8 animals for over 3 months (until mid-January 2022) then released them back into their enclosure which had remained empty and was disinfected and given new habitat, topping up with an additional 13 LGs to make the population 21. In May, we found 12 had died in that enclosure so the remaining animals were put back into quarantine. 6 more died during quarantine of the novel bacterial disease and we decided to euthanise the last 3 animals in quarantine to prevent further spread. We haven't had the disease pop up again since but all we know is its bacterial, not *Enterococcus*, and seems to be easily transmissible and lethal. Also - since 2021, we have had *Enterococcus* outbreaks in two BTS exclosures (Bachelor and EX 1).

DATA SUPPLEMENT 5: RULES OF THUMB AND USEFUL FORMULAE

RULES OF THUMB AND THEORY-BASED CALCULATIONS

"Rules of thumb" derived either from empirical studies or calculated from theory, can be useful tools for supporting decisions about meta-population management. These can be particularly valuable for quickly identifying sensible orders of magnitude, for setting defensible targets, and in situations where key data about a species or its circumstances are not available, making it difficult to construct plausible models. This Appendix includes formulae, tools and rules of thumb either used in this document or of potential use to the PVA Tools Team during the planning workshop in March.

CONVERTING LAMBDA (ANNUAL GROWTH RATE) TO R (INSTANTANEOUS GROWTH RATE)

Lambda=e^r; r=ln[lambda]

ESTIMATING GENE DIVERSITY RETENTION

The formula for estimating gene diversity retained over time (where loss is through drift)

$$\overline{H}_t = \overline{H}_0 \left(1 - \frac{1}{2N_e}\right)^t.$$

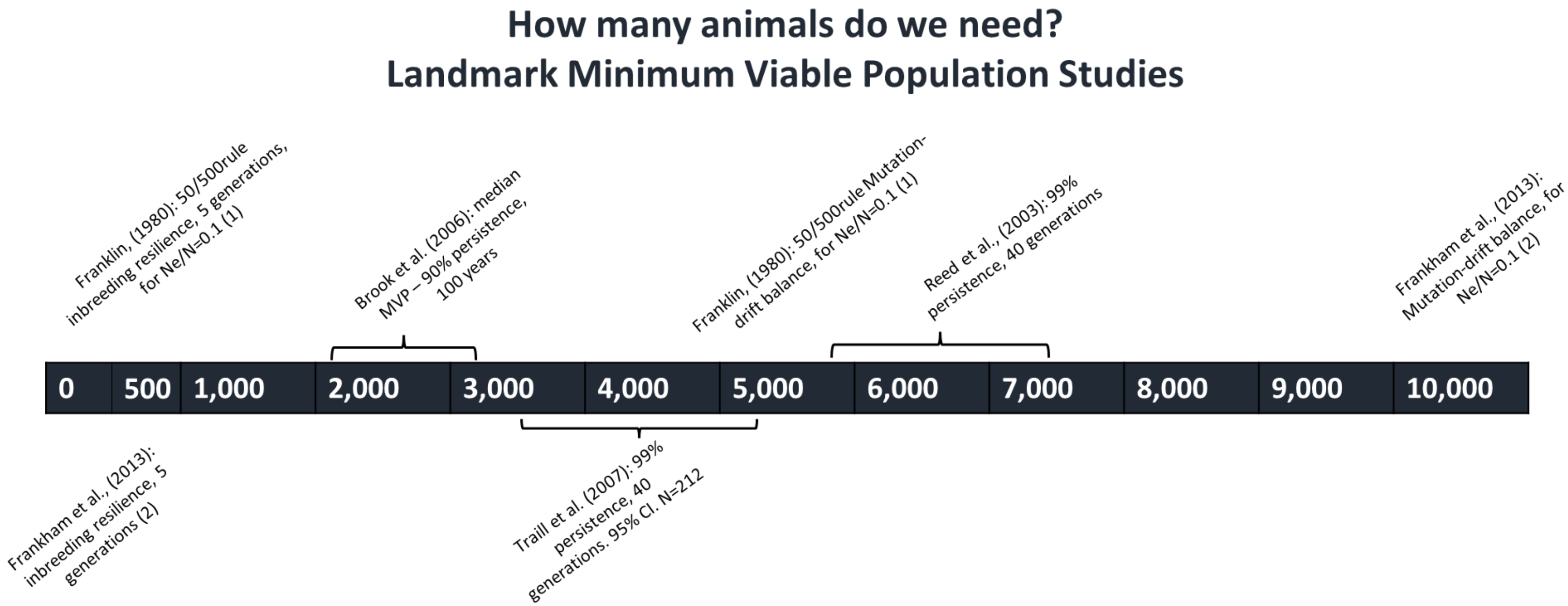
CALCULATING GENETICALLY EFFECTIVE POPULATION SIZE

There are several approaches to calculating effective population size this and these are reviewed in Harris & Allendorf, (1986). Different methods require different types of data and rely on different assumptions.

A commonly used formula and that applied in PMx calculations is based on sex-ratios:

$\mathbf{N_e = 4N_mN_f/(N_m + N_f)}$, where Nm is the number of males and Nf is the number of females (i.e. ADULT BREEDERS)

If the calculations are proving too difficult (e.g. due to violation of the required assumptions), suggest assuming Ne/N=0.3 for both species for captive populations, Ne/N=0.1 and 0.2 for SRS and Ne/N=0.1 for wild as there is literature and precedents for these values.



NOTE: Focus is on PERSISTENCE & GENE DIVERSITY RETENTION
Does not consider:
- Former distribution
- Ecosystem function
- Other wider conservation goals

APPENDIX VI. WORKSHOP BRIEFING PAPERS

CPSG Christmas Island Lizards Conservation Planning Workshop Briefing Paper: History of Christmas Islands Reptiles - Status, threats, habitat.

Background

- Historically the reptile fauna of Christmas Island in the Indian Ocean comprised five endemic species: two skinks; the blue-tailed skink (*Cryptoblepharus egeriae*) and forest skink (*Emoia nativitatis*), two geckos; the giant gecko (*Cyrtodactylus sadleiri*) and Lister's gecko (*Lepidodactylus listeri*), one blind snake; the Christmas Island blind snake (*Ramphotyphlops exocoeti*) and one native, non-endemic skink, the coastal skink (*Emoia atrocostata*),
- In the decade starting 1990, declines in populations' numbers for *C. egeriae* (BTS) were reported (Andrew et al 2016, Emery et al 2021). By 2012, four of these species had disappeared from the wild. This included the extirpation of *E. atrocostata* from Christmas Island and with the disappearance of *E. nativitatis*, the first recorded extinction of an Australian reptile species since European settlement.
- While little research was undertaken to form an empirical basis for evaluating the why the species were disappearing, the reason for decline was primarily thought to be due to the predation and competition pressures of introduced species.
- There are five introduced terrestrial reptiles on Christmas Island that are now common and widely distributed across most island habitats; grass skink (*Lygosoma bowringii*), barking gecko (*Hemidactylus frenatus*), mute gecko (*Gehyra mutilata*), flowerpot blind snake (*Ramphotyphlops braminus*) and the Asian wolf snake (*Lycodon capucinus*).
- Other introduced threatening species include the giant centipede (*Scolopendra subspinipes*), yellow crazy ant (*Anoplolepis gracilipes*), cats and rats.
- Following the steep decline in population numbers for both species, a captive breeding program was initiated in 2009 for BTS, LG and FS. The captive colonies of BTS and LG rapidly expanded, while a captive colony of FS unfortunately could not be established.
- Retrospective assessment deemed the wolf snake to be the most likely cause of decline as its temporal and spatial spread across the island closely matched patterns of lizard disappearances (Emery et al 2021).
- A National Recovery Plan was developed for LGs (Cogger 2006).
- Conservation Advice was drafted for both species in 2022.

Description and Habitat

BTS

- BTS is a small, insectivorous, and brightly coloured diurnal skink (average snout-vent length for adult is 44mm). The species favours areas where sunlight penetrates the forest canopy, such as a tree fall, with complex and interconnected layers of logs, rocks and vegetation that offer basking opportunities in the sunlight. Under ideal conditions, the species is capable of reaching very high densities (Cogger 1983).
- BTS is moderately arboreal found climbing into the forest canopy, though is far more common within 2m of ground level.
- BTS is also an active species, moving between basking sites, with interactions (biting, chasing) frequently observed between individuals (Cogger 1983).
- Historically, the BTS were abundant and easily found in several different habitats across the island (Parks 2014). It was particularly abundant in the settled area in 1979 (Cogger 1983). It is a generalist species capable of thriving in pristine forests, to coastal riparian vegetation, to degraded and urban landscapes,
- The last confirmed sighting of BTS was at Egeria point in 2010.

LG

- LG is a small (average snout-vent length for adult is 43mm) insectivorous gecko with highly variable dorsal markings from marbled to spotted, but always in shades of brown, yellow and off-white.
- LG has always been considered the least common and widespread of the endemic reptiles (Cogger 1983), more cryptic and harder to find (Parks 2014) but also occurred in different habitats favouring dense vegetation including pandanus, vine thickets and scrub. When the species was more widespread it was described as most abundant on the plateau area in primary rainforest, but readily adapted to disturbed habitats including secondary forest growth as well as being least abundant from the terraces and absent from all mined areas (Cogger 1983).
- While more commonly encountered within 2m of ground level, LG is mostly arboreal, though in low vegetation and areas with large limestone boulders the species could be found at ground level.
- LG forms loose colonies with a patchy distribution.
- The last confirmed sighting of L. listeri was 1987 before being rediscovered in 2009, however since 2012 it has not been sighted in the wild again.

Current Status

Cryptoblepharus egeriae **(blue-tailed skink)**		
Last confirmed sighting in the wild	**August 2010**	Parks Australia, 2014
IUCN Red List	**Extinct in the Wild**	Last assessment: 20 February 2017. Accessed: 11 January 2023. https://www.iucnredlist.org/species/102327291/102327566
EPBC Act (1999)	**Critically Endangered**	Effective 03 January 2014. Department of the Environment (2023).
Conservation advice	In effect from Jan 2014. Recovery Plan deemed not required (20/03/22) http://www.environment.gov.au/biodiversity/threatened/species/pubs/1526-conservation-advice.pdf	
Lepidodactylus listeri **(Lister's gecko)**		
Last confirmed sighting in the wild	**October 2012**	Parks Australia, 2014
IUCN Red List	**Extinct in the Wild**	Last assessment: 20 February 2017. Accessed: 11 January 2023. https://www.iucnredlist.org/species/11559/83321765
EPBC Act (1999)	**Critically Endangered**	Effective 03 January 2014. Department of the Environment (2023).
Conservation advice	In effect from Jan 2014. http://www.environment.gov.au/biodiversity/threatened/species/pubs/1711-conservation-advice.pdf.	

Issues/Challenges

- All the known and potential threats persist in the wild on Christmas Island, although cat eradication works and yellow crazy ant control activities are underway.
- It is very difficult to detect wolf snakes in the wild, or even small, manipulated environments, and there is no known method for trapping or baiting wolf snakes that won't have an impact on native fauna,
- There is no known method for baiting centipedes that won't have an impact on native fauna,
- Substantiating the role of each potential threat to the reptile species has proven difficult,
- The rugged Christmas Island landscape and crab fauna provide many unique challenges to implementing management and monitoring programs. The lack of comparable world examples makes it hard to draw on the experience of others.

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Appendix

Table from Emery et al. 2021.

Factor	Date threat first identified	Mechanism for driving decline	Evidence for (on Christmas Island)	Evidence for (global or other case studies)	Evidence against
1. Habitat loss and fragmentation	~1888	Loss of habitat	25% of the island has been cleared for phosphate mining and civic purposes since 1888.	Land clearing and habitat loss have been major contributors to four modern reptile extinctions and a major contributor to worldwide reptile population declines.[2,3]	Most clearing on the island took place in the 1960s and 1970s before declines were observed. There has been little clearance since the 1980s. All species except for the coastal skink used rehabilitated mining areas. Additionally, coastal skink habitat (littoral areas) was not cleared or modified. The blue-tailed skink was most abundant in the settlement where the most disturbance has occurred.[1]
2. A decline in habitat quality facilitated by yellow crazy ant (YCA) supercolonies	YCA detected as early as the 1930s, however, the first supercolony was detected in 1989, and patchy but widespread by mid-1990s.[4,5]	Decline in habitat suitability	YCA's increased substantially in the 1990s in spatial extent, approximately coinciding with the first reptile declines.[5] Some evidence that YCA supercolonies excluded the blue-tailed skink and Christmas Island forest skink from areas where they co-occurred.[6]	YCA's were linked to the disappearance of an endemic skink in the Seychelles.[7]	There is no spatial correspondence of the decline of reptiles matching patterns of outbreaks of YCA supercolonies. The largest supercolonies were located in the western portion of the island where these reptiles remained until 2010–2012. Much of the island remained without YCA supercolonies.

Factor	Date threat first identified	Mechanism for driving decline	Evidence for (on Christmas Island)	Evidence for (global or other case studies)	Evidence against
3. Predation by giant centipedes (*Scolopendra subspinipes*)	Early 1900s[8]	Predation	Circumstantial evidence suggests giant centipedes became more abundant in the 1980s (in some areas) and into the 2000s, possibly via YCA suppressing red crabs. This resulted in better habitat for giant centipedes. Centipedes are voracious predators and been observed eating the Christmas Island giant gecko, common wolf snake, blue-tailed skink and Lister's gecko on Christmas Island	*Scolopendra* species prey upon vertebrates larger than themselves including microbats, snakes, amphibians and lizards.[9,10,11,12]	The giant centipede was widespread by 1940.
4. Predation by wolf snake (*Lycodon capucinus*)	First detected in 1987, but likely early to mid 1980s[13]	Predation	Temporal expansion of the common wolf snake fits well with the decline of all four reptile species. Early wolf snake specimens collected in the settlement had blue-tailed skinks, common house geckos and four-clawed geckos in their stomachs. Snakes reached densities in the settlement area between 45–500 snakes per hectare.[14] In the mid-2000s and 2017 over 200 common wolf snakes have been dissected, and many had reptiles in their stomachs.[6,15]	In the Mascarenes, the Indian wolf snake (*Lycodon aulicus)* is believed to have been instrumental in the decline and extinction of an island population of Bojers skink (*Gongylomorphus bojerii)*.[16] Brown tree snakes (*Boiga irregularis*) in Guam are responsible for large scale declines, extirpations and extinctions of birds, mammals and reptiles. Decline in species on Guam resembles those on Christmas Island with respects to a spatial spread	Other reptiles (Christmas Island giant gecko, common house gecko, four-clawed gecko, Bowring's supple skink) persist on Christmas Island. There is limited evidence on the spatial spread of the common wolf snake; likely due to it being cryptic, semi-arboreal and limited targeted monitoring.

Factor	Date threat first identified	Mechanism for driving decline	Evidence for (on Christmas Island)	Evidence for (global or other case studies)	Evidence against
				of decline from a point of origin.[17,18]	
5. Predation by black rats (*R. rattus*)	September 1900[19]	Predation		Black rats have been involved in extinctions of other island reptiles in the Caribbean and Pacific.[3] A review in 2015 found that black rats have caused notable impacts on tropical island herpetofauna through predation.[20]	Little temporal and spatial evidence. Black rats were most abundant in the settlement where blue-tailed skinks were most common.
6. Predation by feral cats (*F. catus*)	~1900[8]	Predation	Stomach analyses in the late 1980s revealed cats consumed blue-tailed skinks, Christmas Island forest skink and the coastal skink.[21]	Cats have been the major contributor to at least two modern reptile extinctions.[22]	Little temporal and spatial evidence. Feral cats were likely more abundant in the settlement. Cats also consume the Christmas Island giant gecko, common house gecko and Bowring's supple skink, but these did not decline.[21]
7. Competition with invasive lizards	Common house gecko~1930s Four-clawed gecko~1950s Bowring's supple skink~ first detected in 1979, but likely earlier.[1]	Competition for resources (refuge and food) and predation	Recent stomach analysis of ~400 common house geckos on Christmas Island found that nearly 15% of individuals contained reptiles in their stomachs.[23]	Common house geckos have been implicated in declines of other geckos where it has been introduced (e.g., mourning geckos, *Lepidodactylus lugubris*).[24]	All three invasive lizards were common in the settlement well before the decline.

Factor	Date threat first identified	Mechanism for driving decline	Evidence for (on Christmas Island)	Evidence for (global or other case studies)	Evidence against
8. Yellow crazy ant disturbance	~1989 but more widespread by mid 1990s[5]	Predation and behavioral change.	Supercolonies consume a significant amount of invertebrate biomass. YCA increased substantially in the 1990s in spatial extent, approximately coinciding with the first reptile declines. Some evidence that YCA supercolonies excluded blue-tailed skinks and the Christmas island forest skink from areas where they co-occurred.[5,6]		No spatial correspondence of the decline of reptiles matching patterns of outbreaks of YCA supercolonies. Much of the island remained without YCA supercolonies. The largest supercolonies were located in the western portion of the island where these reptiles remained until 2010–2012.[6]
9. Fipronil use	~2001 widespread Fipronil use occurred until about 2009[5]	Bioaccumulation, food reduction and direct ingestion	From 2001, large scale Fipronil poisoning occurred across the island (to control YCA supercolonies).	Variable evidence on the effects of fipronil poisoning on reptiles. Under lab conditions, lizards exposed to food contaminated with fipronil had a mortality rate of 62.5%. However, unknown under field conditions.[25]	Reptile declines preceded the use of fipronil. Large scale fipronil application was undertaken in the western portion of the island in 2001 where lizards persisted until 2010–2012. A study found a minimal impact of fipronil on blue-tailed skinks and Christmas island forest skink populations, but sample sizes were low. Some evidence that blue-tailed skinks recovered after YCAs were controlled with fipronil.[6] Post baiting assessments in 2012 found no evidence of bioaccumulation of fipronil.[26]

Factor	Date threat first identified	Mechanism for driving decline	Evidence for (on Christmas Island)	Evidence for (global or other case studies)	Evidence against
10. Disease	~N/A	Increased mortality	In 2014 (post extirpation), a novel enterococcus bacterium (*Enterococcus lacertideformus*) was discovered on Christmas Island affecting Lister's geckos, blue-tailed skinks, common house geckos, four-clawed geckos with a 100% mortality rate.[27]	Disease is well-known to drive rapid species declines. Two endemic rodents on Christmas Island were driven to extinction by disease[19] and the incremental spatial spread of declines loosely resembles how a disease outbreak would occur.	Disease and pathogen tests were undertaken in 2010 and found no evidence of significant disease occurrence in the reptile fauna.[28]
11. Climate change	Decline in habitat suitability; changes in prey availability; physiological stress	~N/A	Some very dry years at the beginning of the decline in the late 1980s and early 1990s.	Climate change is a primary threat to reptiles globally.[2]	Drier years did not continue throughout the period of reptile decline.
12. Loss of prey	Reduced food availability	Mid-1990s	Fipronil and the outbreak of YCA's.	There is evidence of reduced invertebrate (ant) abundance on and near YCA supercolonies.[29]	No declines in other reptile species that consume similar prey items.

Table from Emery et al. 2021.

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Native/Endemic Reptiles:

Blue-tailed Skink (*Cryptoblepharus egeriae*)

Endemic species. Listed as Critically Endangered under the EPBC Act, January 2014.

Formerly widespread across the island including settled areas. No extant populations in the wild are now known. Two independent unconfirmed sightings were reported in 2013. A captive population is maintained on Christmas Island and at Taronga Zoo.

Last confirmed wild sighting was on 12/08/2010.

Coastal Skink (*Emoia atrocostata*)

Native species. Currently unlisted under the EPBC Act.

Formerly widespread along the coastal terrace within the intertidal zone. There are now no known extant populations in the wild.

Last confirmed wild sighting was on 28/09/2009.

Forest Skink (*Emoia nativitatis*)

Endemic species. Listed as Extinct under the EPBC Act, March 2021.

Formerly widespread across the island. No extant populations in the wild are now known.

Last confirmed wild sighting was on 12/08/2010.

Giant Gecko (*Cyrtodactylus sadleiri*)

Endemic species. Listed as Endangered under the EPBC Act, January 2014.

Currently still widespread across the island except in cleared areas. Though widespread, status (and particularly trends) of the population remains poorly resolved.

Lister's Gecko (*Lepidodactylus listeri*)

Endemic species. Listed as Critically Endangered under the EPBC Act, January 2014.

Formerly widespread across the plateau and terraces mainly in primary rainforest. The last confirmed sightings in the wild were at Egeria Point (October 2012) and Northwest Point (October 2012).

A captive population is maintained on Christmas Island and at Taronga Zoo.

Christmas Island Blind Snake (*Ramphotyphlops exocoeti*)

Endemic species. Currently listed as Vulnerable under the EPBC Act.

Cryptic in nature and status unknown. Last confirmed wild sighting was on 31/07/2009; few previous records

Introduced Reptiles:

Grass Skink (*Lygosoma bowringii*)

Introduced from south-east Asia around 1979.

Originally found only in cleared areas, this species can now be found in primary forest sites across the island.

Barking Gecko (*Hemidactylus frenatus*)

Introduced most likely from Asia by the 1940s.

Very abundant, widely distributed and common across all island habitats.

Mute Gecko (*Gehyra mutilata*)

Introduced most likely from Asia during World War II.

Distributed widely distributed across all island habitats including settled areas.

Flowerpot Blind Snake (*Ramphotyphlops braminus*)

Introduced from either the Australian mainland or Asia by the 1940s.

Cryptic in nature but commonly found throughout all island habitats including settled areas.

Asian Wolf Snake (*Lycodon capucinus*)

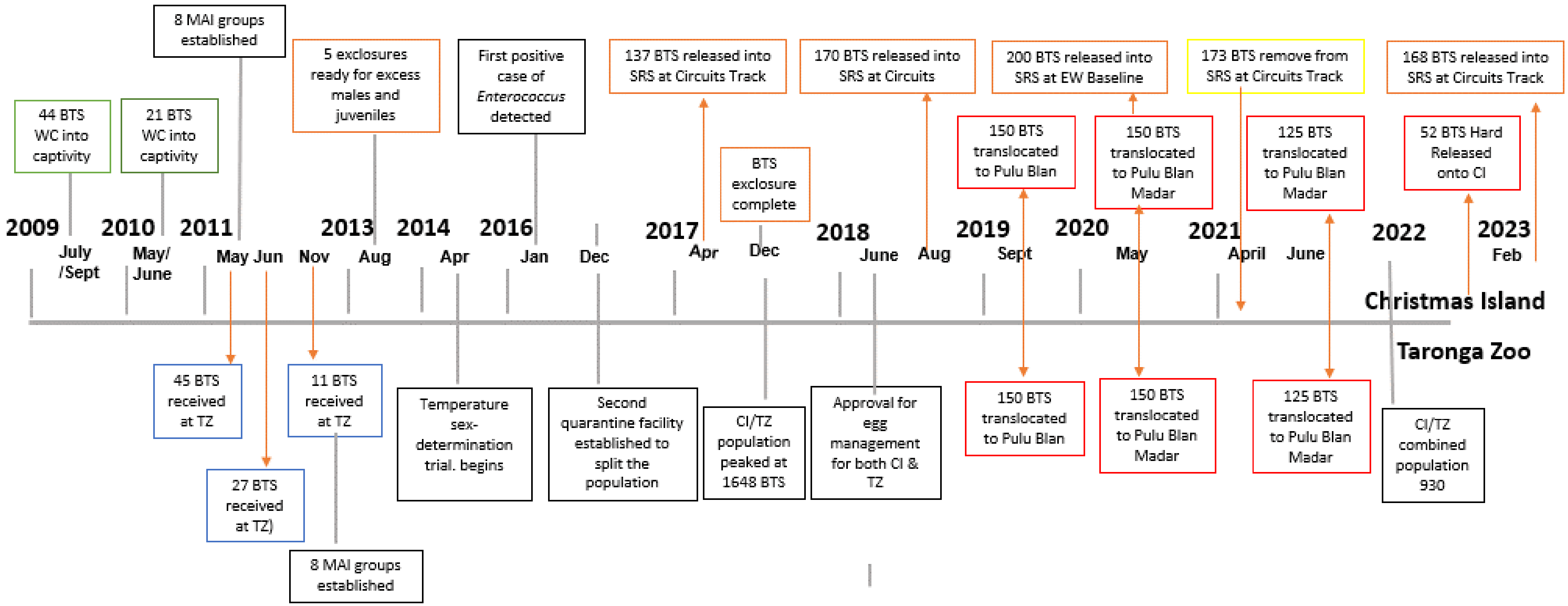
Introduced from Asia around 1987.

Widely distributed across all island habitats.

CPSG Christmas Island Lizards Conservation Planning Workshop Briefing Paper: Christmas Island & Taronga Zoo Blue-tailed Skink (*Cryptoblepharus egeriae)* Captive Population

Summary

- 65 Blue-tailed skinks (BTS) *Cryptoblepharus egeriae* were collected from the wild in 2009/2010 to form a captive breeding program.
- 83 BTS transferred to Taronga Zoo in 2011, 45 skinks – 6 May, 27 skinks – 10 June and 11 skinks – 11 November.
- The breeding program is managed through a Maximum Avoidance of Inbreeding (MAI) scheme. MAI is a low intensity genetic management strategy that involves multi-male and multi-female groups with rotation or exchanges of individuals to minimise or delay inbreeding whilst maximising effective population size. Tends to be most suitable for social groups for which pedigree information is lacking. 8 groups were initially established at Christmas Island and 8 groups at Taronga Zoo.
- Current population size CI: 715; Carrying capacity CI: 450
- Current population size TZ: 215: Carrying capacity TZ: 250 (up to 500 resources permitting)
- Transfers (harvests) from captive program
    - BTS released into SRS (soft release sites) - 677 skinks (CI origin)
        - 2017 - 137 to Circuits Track
        - 2018 - 170 to Circuits Track
        - 2020 - 200 to W Baseline Site
        - 2023 - 168 to Circuits Track
    - BTS released to Cocos (Keeling) Island - 425 skinks
        - 2019 - 300 to Pulu Blan (150 CI origin; 150 TZ origin)
        - 2020 - 300 to Pulu Blan Madar (150 CI origin; 150 TZ origin)
        - 2021 - 50 to Pulu Blan Madar – translocation top up (125 CI origin; 125 TZ origin)
    - BTS hard released to Christmas Island
        - 2023 – 52 (CI origin)

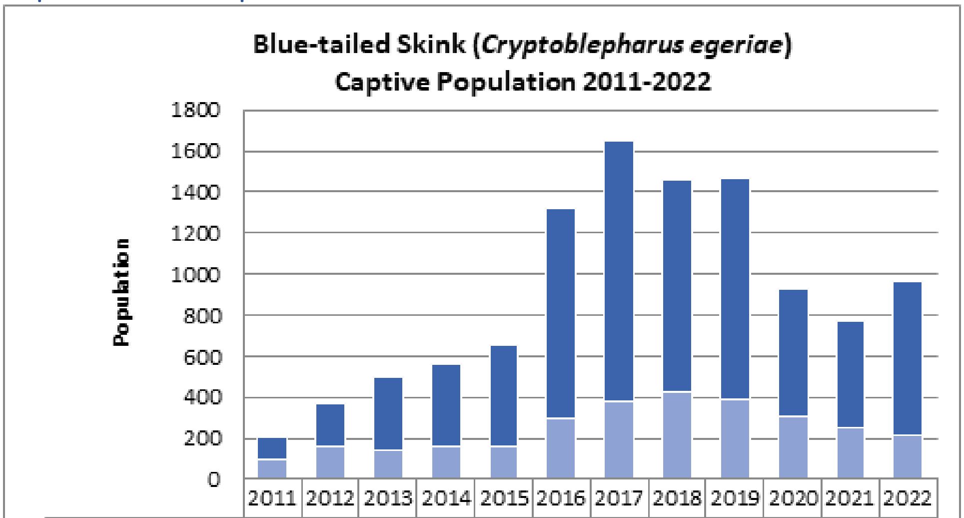


Christmas Island & Taronga Zoo Blue-tailed Skink Timeline

Goals

- To maintain a population for 10 years retaining 90% of starting Genetic Diversity [GD].
- To keep intergenerational inbreeding coefficient [F] at zero and prevent intra-generational inbreeding coefficients rising above 0.125.
- To maintain the population in evolutionary stasis with neither selection nor adaptation.

Population Development



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CI POPULATION	109	204	357	402	493	1026	1265	1034	1085	623	522	755
TZ POPULATION	98	163	141	164	164	294	383	423	387	306	247	212

Biology/Life History

- BTS, discovered in 1888 and endemic to Christmas Island.
- Typically grows to a snout-vent length (SVL) of 4-5cm.
- It can be identified by its small black body with two yellow stripes running down the skink's back and onto its vibrant blue tail.

- Males can and do become aggressive towards other males and also towards females during breeding.
- BTS are diurnal, active and spending their time climbing and basking.
- They are a sociable skink, which allows them to be housed together. There is an apparent hierarchical system.

Reproduction/Breeding

- Females typically lay 2 eggs per clutch, although 1 or 3 egg clutches do occur.
- Incubation is around 60 days, although the maximum incubation time is 128 days and can vary.
- Females are given the opportunity to breed all year round even if breeding is not required by the program to prevent the occurrence of reproductive issues. This has been observed in other species of reptiles that haven't had the opportunity to breed.
- An incubation trial in 2014 conducted at Taronga Zoo demonstrated that sex is not temperature determined at the incubation stage. During the trial, the eggs were divided between 2 incubators, one a Perspex-made box maintained at room temperature and the other a Thermoline Incubator set to 26°C.
- The results of post-mortem reports have shown that females can retain sperm and some females have laid eggs 3 months after being housed separately from males.
- Taronga house breeding females and males separately and rotate the males through the female breeding tanks for breeding periods (~3mths) (Historically, males were introduced to females every 4-6 week for 24-hr period). To manage the risk of female mortality a female sex bias is maintained. Additionally, females are rested between male cycles to manage sperm retention and ensure parentage can be attributed to current cycling males.
- Christmas Island maintain breeding females and males together year-round in the breeding tanks at a ratio of 6 males to 14 females.

Diet/Water

Christmas Island

- Fed on Monday, Wednesday and Fridays.
- Adults are fed a variety of insects that are collected in sweeps, also fed captive bred crickets and wild termites. Juveniles are fed exclusively with termites and pinhead crickets.
- Crickets are dusted with calcium and multivitamin powder.
- Each enclosure has 2 water bowls provided, they are also sprayed daily to provide moisture droplets to drink from and to maintain humidity levels.

Taronga Zoo

- Fed on Monday, Wednesday and Fridays.
- Adults are fed a variety of cricket sizes, usually weaners and pinheads, and juveniles fed pinhead and mini pinhead crickets.
- Crickets are dusted with Repashys Superfoods Calcium Plus on each feed.
- Crickets are captive bred, not wild collected due to quarantine requirements.
- In more recent years skinks are also offered slaters and black soldier fly larvae as enrichment and another calcium source.
- Each enclosure has a water bowl provided, they are also sprayed daily to provide moisture droplets to drink from and to maintain humidity levels.

Lighting/Heating

Christmas Island

- UV fluorescent lights and basking lights inside tanks are controlled by clock timers.
- Enclosures experience natural ambient island temperature and humidity.

Taronga Zoo

- UV fluorescent lights and basking lights inside tanks are controlled by clock timers.
- Room temperature is set to change throughout day to mimic natural environment, approximately min 23°C and max 29°C (no lower than 22°C and not higher than 31°C)

Health

Christmas Island

- *Enterococcus* was first detected in the CI reptile population in 2014 and is an ongoing health-related issue. (For further details refer to Disease Briefing Paper)
- Post-mortems and disease investigations for infected animals are conducted as required at Taronga Zoo (Australian Registry of Wildlife Health).
- Gout is observed in the BTS population.

Taronga Zoo

- Routine faecal samples are collected yearly.
- Gout seems to be main medical issue and can be hard to detect in the skinks in the early stages. Common symptoms are swollen joints and paralysis in the hind legs.
- Known causes of gout in lizards are diet water/humidity deficiency. The diet has been analysed and daily sprays are provided but still have cases of gout through the population, in some as young as 8 months old.

Room/ Enclosure Configuration

Christmas Island

Lizard Lodge

- Consists of 10 large breeding enclosures that house up to 20 adult skinks, and 8 maturing enclosures of 20-30 skinks
- Juveniles are hatched/processed and cared for in smaller enclosures.
- Juvenile/Sub adults form overflow/maturing tanks to top up breeding tanks.

Lizard Lodge – External Lizard Lodge - Internal

Exclosures

- Eight exclosures can be used to house male and female overflow BTS at the Pink House (currently only 1 of the 8 exclosures is in use housing bachelor males, though previously up to 2 male-only exclosures have been used).

Exclosures

Taronga Zoo

Wildlife Intensive Care (WIC) Building

- The main breeding facility, it comprises of 8 large breeding tanks with the capacity to hold 20-30 skinks each tank. The tanks can also be divided in two, they currently house no more than 20 skinks.
- Six smaller tanks with potential to hold 10-15 adults or 15-20 juveniles.

Christmas Island Room - WIC Building (Taronga Zoo)

Bughouse

- Generally, a non-breeding facility for skinks, this room was set up in 2016 to assist with the expanding population, it also helps spread the population across two locations.
- Juveniles are hatched/processed and cared for in bughouse.
- There are 18 tanks that can house 15-20 adults and 20-25 juveniles.

Christmas Island Room – Bughouse (Taronga Zoo)

Quarantine

Christmas Island

- A 90-day quarantine period is required for animals that are being translocated or transferred from Christmas Island.
- A 120-day quarantine period is required for an animal that presents with signs of *Enterococcus*, they are housed in a quarantine facility that is serviced at the end of the day so no overlap with Lizard Lodge facility servicing, gloves are required to be worn and changed between penpals.
- Current quarantine management includes a staff member dedicated to care of quarantine animals.

Taronga Zoo

- Management of BTS complies with DAWE Approved Arrangement (AA) facility. Gumboots must be worn when entering the facilities and gloves worn to work with BTS.
- All waste is placed in a bio secure waste bin and taken to a bio secure facility to be destroyed.
- Staff are required to be AA accredited by completing biosecurity awareness certification.

Limitations/Constraints

Christmas Island

- Staff (remoteness, hard to get and retain staff, loss of information/corporate knowledge through changing staff).
- Disease exposure risks, i.e., use of BTS exclosures where infected invasive geckos can interact.
- Severe weather events (cyclone) could put facility at risk.
- Supply of materials to island can be difficult, maintenance and building projects can take a long time to complete.
- Must breed own crickets and food supply options are limited.
- Lizard Lodge only capable of housing 400 of each species
- Exclosures can hold up to 1500 LG and 2000 BTS (physical capacity) in addition to Lizard Lodge enclosures, however there are some physical limitations that would require significant maintenance and there is not sufficient staff resourcing capacity to care for such a large number of animals.

Taronga Zoo

- Space is the major limitation. Also challenge associated with being able to house both sexes together and in other cases unable to house males of the same group together, some enclosures house only 2 males as they are known to fight.
- Recreating a natural habitat can be a challenge. Constantly improving on heat and humidity provisions and seasonal variation.

References

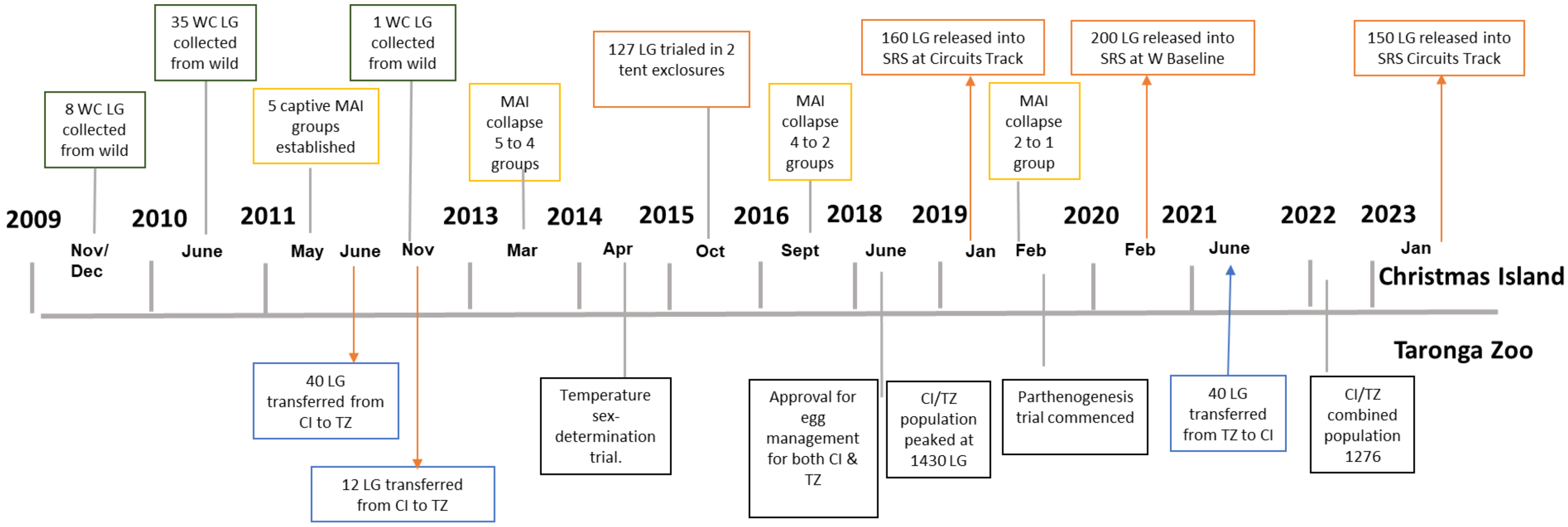
Harlow P, McFadden M and Andrew P (2011) Captive Husbandry and Genetic Management Plan for the Christmas Island Blue-tailed skink (*Cryptoblepharus egeriae*) and Lister's Gecko (*Lepidodactylus listeri*). Taronga Conservation Society Australia.

CPSG Christmas **Island Lizards Conservation Planning Workshop Briefing Paper:** Christmas Island & Taronga Zoo Lister's Gecko (*Lepidodactylus Listeri)* Captive Population

Summary

- 44 Lister's gecko (LG) *Lepidodactulus listeri* collected from the wild in 2009/2010/2011 to form a captive breeding program on Christmas Island.
- 52 LG transferred to Taronga Zoo in 2011 (40 geckos – 10 June and 12 geckos – 11 November).
- Current population size Christmas Island: 1123 (Feb 2023)
- Current population size Taronga Zoo: 183 (Feb 2023)
- Carrying Capacity Christmas Island: 1000
- Carrying capacity Taronga Zoo: 180 however potentially over 200 geckos, if needed.
- Christmas Island population is managed through Maximum Avoidance of Inbreeding (MAI), a low intensity genetic management breeding scheme that involves multi-male and multi-female groups with rotation or exchanges of individuals to minimise or delay inbreeding whilst maximising effective population size. Tends to be utilised for social groups for which pedigree information is lacking.
- Taronga Zoo population is managed through pair-wise Mean Kinship (MK). MK is a measure of the relatedness of an individual to every living individual in the population. Priority for breeding is given to individuals with low mean kinship values (and few relatives) with the intention to equalise founder representation.

- Transfers (harvests) from captive program
  - LG released into SRS (soft release site) - CI-origin LGs
    - 2019 – 160 to Circuits Track
    - 2020 – 200 to W Baseline Site
    - 2023 – 150 to Circuits Track
  - 40 LG transferred to Christmas Island from Taronga Zoo June 2021 to form four separate breeding colonies.

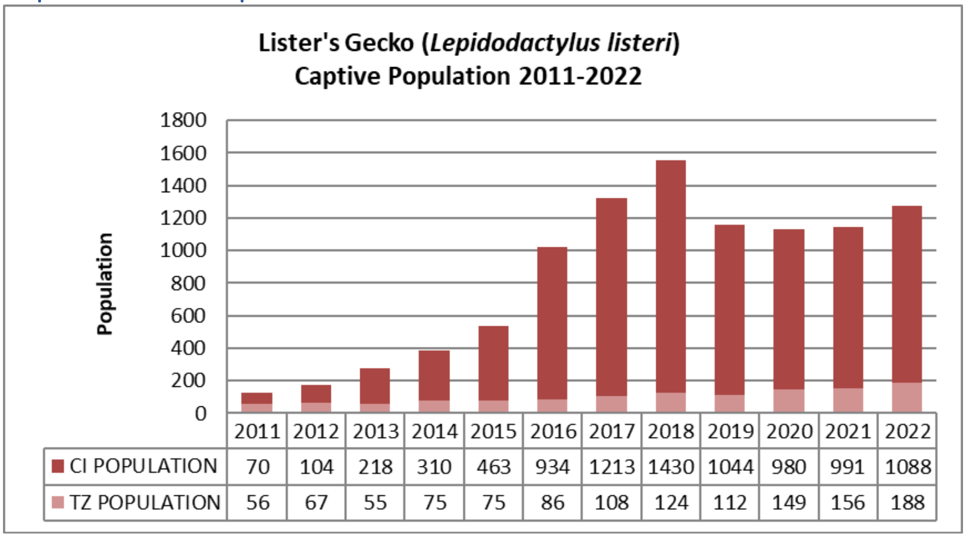


Christmas Island & Taronga Zoo Listers Gecko Timeline

Goals

- To maintain a population for 10 years retaining 90% of starting Genetic Diversity [GD].
- To keep intergenerational inbreeding coefficient [**F**] at zero and prevent intra-generational inbreeding coefficients rising above 0.125.
- To maintain the population in evolutionary stasis with neither selection nor adaptation.

Population Development



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CI POPULATION	70	104	218	310	463	934	1213	1430	1044	980	991	1088
TZ POPULATION	56	67	55	75	75	86	108	124	112	149	156	188

Biology/Life History

- LG discovered in 1888 and endemic to Christmas Island.
- Typically grows to a snout vent length (SVL) of 5cm.
- It has a broad, pale fawn/grey vertebral stripe which expands to cover the top of the head and matches the colour and pattern of the tail.

Behaviour

- LG is predominantly a nocturnal species but can be frequently out during the day as well.
- They are a quite active gecko that can be observed out during the day although the majority of their day is spent hiding in pipes or foliage.
- They can be maintained in larger groups of both males and females, and males can be housed together without aggression.

Reproduction/Breeding

- Females typically lay 2 eggs per clutch, but 1 egg per clutch does occur.
- Typically, a female lays around 2-3 clutches per breeding season. On Christmas Island peak egg laying occurs from May through to October. Taronga has recorded a few individuals that have laid 5 clutches in a season.
- Females are given the opportunity to breed all year round even if breeding is not required by the program to prevent the occurrence of reproductive issues. This has been observed in other species of reptile when they haven't had the chance to breed.
- Incubation period is around 90 days. The maximum incubation time was 139 days.
- An incubation trial in 2014 demonstrated that the species sex is not temperature-determined at the incubation stage. During the trial, the eggs were divided between two incubators, one a Perspex-made box maintained at room temperature, and the other a Thermoline Incubator set to 26°C.
- Through post-mortem investigations it has been determined that females have sperm retention and have been observed laying eggs 3 months after being housed separately from males.
- Questions were raised in 2018/2019 as to whether females were parthenogenic (have the ability to lay fertile eggs without a male). Taronga Zoo had the opportunity to house females only for a period of 2 years with no fertile eggs being laid.

Diet/Water

Christmas Island

- Fed on Monday, Wednesday and Friday.
- Adults are fed a variety of insects that are collected in sweeps, they are also fed captive bred crickets and termites. Juveniles are fed exclusively with wild termites and pinhead crickets.
- Crickets are dusted with calcium and multivitamin powder.
- Each enclosure has a water bowl provided, they are also sprayed daily to provide moisture droplets to drink from and to maintain humidity levels.

Taronga Zoo

- Fed on Monday, Wednesday and Friday.
- Adults are fed a pinhead crickets and juveniles fed 2–3-day old crickets which are bred at Taronga and mini pinhead crickets.
- Crickets are dusted with Repashys Superfoods Calcium Plus on each feed.
- Crickets are bred, not wild collected due to quarantine requirements.
- Each enclosure has a water bowl provided, they are also sprayed daily to provide moisture droplets to drink from and to maintain humidity levels.

Lighting/Heating

Christmas Island

- UV fluorescent lights and basking lights inside tanks are controlled by clock timers.
- Enclosures experience natural ambient island temperature and humidity.

Taronga Zoo

- UV fluorescent lights are suspended above the tanks and are controlled by clock timers.
- Room temperature is set to change throughout day to mimic natural environment, approximately min 23°C and max 29°C (no lower than 22°C and not higher than 31°C)

Health

Christmas Island

- *Enterococcus* was first detected/observed in the population in 2014 and has been an ongoing health-related issue. For further details refer to Disease Briefing Paper.
- Post-mortems on infected animals are conducted as required at Taronga Zoo (Australian Registry of Wildlife Health).
- Gout is observed in the LG population.
- A new unknown bacterium was discovered in the LG population for the first time in August 2022.

Taronga Zoo

- Routine faecal samples are collected yearly.
- Gout seems to be the only medical issue. Common symptoms are swollen joints and large white urate nodules in mostly the joints but also on the face and chest. For further details refer to Disease Briefing Paper.
- Known causes of gout in lizards are diet and water/humidity deficiency. The diet has been analysed and daily water sprays but still have cases of gout through the population. Gout has been detected in some Lister's Geckos as young as 8 months old.

Room/ Enclosure Configuration

Christmas Island

Lizard Lodge

- Consists of 11 breeding enclosures.
- Juveniles are hatched/processed and cared for in smaller enclosures.
- 7 maturing enclosures
- 4 breeding enclosures of Taronga-origin geckos

Pink House Exclosures

- Consists of 7 tent exclosures for overflow.

Christmas Island Pink House - Exclosures

Taronga Zoo

Wildlife Intensive Care (WIC) Building

- 24 tanks which can hold a breeding pair or up to 4 geckos at any time.

Taronga Zoo Christmas Island Room – WIC Building

Bughouse

- 36 tanks are housed in this room, the majority are breeding pairs for the season, some hold up to 4 geckos.
- Hatchlings and juveniles are hatched/processed and cared for in bughouse. They have specially designed lids to avoid escapes. There are 9 juvenile tanks that can house up to 4 geckos each.

Taronga Zoo Christmas Island room - Bughouse

Quarantine

Christmas Island

- A 90-day quarantine period is required for animals to be translocated or transferred from Christmas Island.
- A 120-day quarantine period is required for an animal that presents with signs of *Enterococcus*, they are housed in a quarantine facility that is serviced at the end of the day, gloves are required to be worn and changed between each penpal.
- Current quarantine scenario includes a staff member dedicated to care of quarantined animals.

Taronga Zoo

- Management of geckos complies with DAWE Approved Arrangement (AA) facility. Gumboots must be worn when entering the facilities and gloves worn to work with geckos.
- All waste is placed in a bio secure waste bin and taken to a bio secure facility to be destroyed.
- Staff are required to be AA accredited by completing biosecurity awareness certification.

Limitations/Constraints

Christmas Island

- Staff (remoteness, hard to get and retain staff, loss of information/corporate knowledge through changing staff)
- Potential disease exposure risks, i.e., *Enterococcus*; understanding of disease transmission routes.
- Severe weather events (cyclone) could put facility at risk.

- Supply of materials to island can be difficult, maintenance and building projects can take a long time to complete.
- Must breed our own crickets and food supply options are limited.
- Lizard Lodge capable of housing 400 of each species
- Exclosures can hold up to 1500 LG and 2000 BTS (physical limitations) on top of Lizard Lodge enclosures, however staff resource capacity does not allow for caring for that number of animals.

Taronga Zoo

- Space is the major limitation.
- Recreating a natural habitat can be a challenge. Constantly improving on heat and humidity requirements and changing with the seasons.

References

Harlow P, McFadden M and Andrew P (2011) Captive Husbandry and Genetic Management Plan for the Christmas Island Blue-tailed skink (C*ryptoblepharus egeriae*) and Lister's Gecko (*Lepidodactylus listeri*). Taronga Conservaton Society Australia.

CPSG Christmas Island Lizards Conservation Planning Workshop Briefing Paper: Review of Program Goals

Background

Christmas Island National Park Reptile and Conservation Plan 2014-2024

The objective of the CINP Reptile Conservation Program is to:

1. Conserve and restore populations of native reptile species on Christmas Island, with all extant species persisting in the wild. This will be achieved through subsidiary objectives, including to:

2. Determine threats that have been responsible for declines in the wild and manipulate or manage threats at particular sites to levels that allow persistence of native reptile species;

3. Increase captive populations of Blue-tailed skink (BTS) *Cryptoblepharus egeriae* and Lister's gecko (LG) *Lepidodactylus listeri* (and other native reptile species if there is a need and opportunity (i.e. Forest Skink (FS) *Emoia nativitatis*) to target populations of up to 5000 within 10 years; and

4. Successfully reintroduce BTS and LG back into the wild.

The reptile conservation work associated with this Plan will help restore and enhance the island's natural conservation values, reinstate ecological functions and processes and in particular assist in the recovery of the native reptile fauna

Objective	Performance Criteria	Status Update 2023
Objective1	a) Mitigation of priority threats is achieved within 10 years including	
	i. Eradication of cats from Christmas Island;	On track to eradicate cats from the island by 2025.
	ii. Yellow Crazy Ant super-colonies cease to form and/or are controlled so that they do not increase in size	YCA continue to form super colonies on Christmas Island however methods to control super-colonies (including biocontrol: wasp introduction and baiting) have had some success. A reduction in the total area deemed super-colony was observed after biocontrol was put in place. Improved methods to control super-colonies on a large-scale continue to be trialled i.e. drone-baiting. The last island-wide baiting campaign was 2019, and since then only small-scale hand-baiting and drone-baiting trials have been conducted in 2022. Outcomes of last 10 years of YCA control methods will soon be reviewed to understand future management needs and actions.

	iii. A centipede and wolf snake threat abatement plan is prepared, and trial control options are implemented.	Not achieved. Plans/implementation of the control of centipedes have only been trialled in the SRS. Methods used would be unfeasible in the wild as there is no centipede-selective pesticide and there would be significant impact to invertebrate population. Wolf snake detection using eDNA analysis in SRS's and in the wild will begin in 2023.
	b) Stable and viable populations of native reptiles occur in the wild.	BTS – not achieved LG – not achieved
	c) Stable and viable populations of reintroduced native reptiles persist in the wild	No persisting reintroduced native reptiles on Christmas Island. BTS assisted colonisation to Cocos (Keeling Island) Pulu Blan and Pulu Blan Madar.
Objective 2	d) Research demonstrating the relative impact of known threats causing reptile declines and cost-effective mechanisms to address those priority threats is completed by 2016	Retrospective expert elicitation to rank potential factors that contributed to loss of CI reptiles was carried out and it was determined wolf snake was most likely the major cause of decline. (Emery et al 2021) More recent impacts of wolf snakes (on a small population reintroduced into the wild in February 2023) and SRS trials. Giant centipedes demonstrated to negatively impact BTS survival and body condition suggesting Giant centipedes are a generalist reptile predator on CI (Emery et al 2020). YCA impacts on CKI (first evidence of YCA impacting CIs reptiles.) Cost effective mechanisms to address priority threats (other than cat and YCA management, and planning trials of eDNA detection of wolf snakes) not achieved.
Objective 3	e) Populations of *C. egeriae* and *L. listeri* (and other native reptiles) successfully reproduce in captivity and increase in population size to a target captive population of up to 5000 individuals.	Populations of BTS and LG successfully reproduce in captivity however facility capacity and resource availability prevents growth to 5000 individuals. Captive program across both TZ and CI facilities care for 930 BTS and 1306 LG managed through a Maximum Avoidance of Inbreeding (MAI) strategy for BTS and MAI for LG on CI and Mean Kinship (MK)

		strategy at TZ. Although the effective population size is far smaller than census population size these breeding strategies perform better than unmanaged (random) populations.
Objective 4	f) Establishment of genetically diverse populations of *C. egeriae* and *L. listeri* (and other native reptiles) back into the wild within 10 years.	No established populations of BTS and LG reintroduced to wild on CI. Genetically diverse populations BTS and LG have persisted for up to 3 years in trials of fenced predator controlled exclosures (SRS) on CI Genetically diverse population of BTS persist through assisted colonisation to Cocos (Keeling Island) Pulu Blan and Pulu Blan Madar. (Inference that populations are genetically diverse is based on structured breeding schemes and can be validated through molecular genetics.)
	g) Maintain over 90% of the genetic diversity of the founder population.	Modelling suggests achieved. 90% goal based on small population management theory. Through examining number of founders, likely number of generations and number of males and female in the functional breeding population calculations suggest this goal has been met over last 10 years for MAI populations. Genetic diversity for LG (TZ) managed through MK pedigree-based management modelled to be 96% (PMx).

Threat Mitigation

Prioritisation of threat abatement actions has largely been prioritised through a risk assessment process and includes: 1. Continue Yellow Crazy Ant control programs and monitoring 2. Investigate and trial control options for centipedes and wolf snakes 3. Continue cat and rat control until eradication is possible 4. Continue habitat restoration activities

		2023 Status update
YCA - To significantly reduce the impact of Yellow Crazy Ants on Christmas Island's biodiversity (including reptiles) through the control of supercolonies.		
Monitor YCA densities and spread	Undertake an Island-Wide Survey biennially unless otherwise advised by CASAP	YCA densities have been monitored in 2014, 2017, 2019 and 2022.
Control YCA supercolonies	Aerial bait YCA supercolonies approximately every 3 years if	Aerial baiting was last undertaken in 2019, followed by a very small trial via drone in 2022.

	area exceeds 500ha (in the absence of biological control) Hand bait in accessible areas for asset protection annually or as required Trial alternative baits Implement indirect biological control on scale insects from 1 July 2013 If needed, target YCA control in areas adjacent to identified	Hand baiting occurred in 2019, 2020 and a small, targeted area in 2022. Biological control of scale insects was implemented with the release of wasps in 2018.
Competition Non native reptiles - To monitor the abundance and distribution of native and non-native reptiles and document impacts of competitive behaviour.		
Through existing diurnal and nocturnal monitoring programs record abundance and spread of introduced competitors	Undertake regular diurnal and nocturnal reptile surveys as per monitoring guidelines outlined in this plan Incorporate reptile detections in annual nocturnal flying fox census. Support PhD project that incorporates mesopredator/competition experiments to determine level of competition and possible predation between native and non-native reptiles and other identified predators	Diurnal and nocturnal monitoring occurred in areas where target reptile populations persisted, or recently existed (mostly Egeria point from 2009). Using a broad spectrum of techniques. Frequency of monitoring reduced from weekly in 2009 to yearly by 2015. Reptile detections have been included in flying-fox nocturnal surveys. Island-wide surveys were last completed in full in 2013. Surveys after 2013 were a subset of past surveys, focusing primarily on YCA. No further monitoring of giant gecko or invasive reptiles has been completed.
Habitat disturbance and fragmentation: To restore rainforest on abandoned minefields to create bio-diverse, resilient and selfsustaining ecosystems that provides or enhance habitat for native flora and fauna (including reptiles).		
Forest rehabilitation	Continue minesite to forest rehabilitation program to recover and extend habitat availability as per the Christmas Island Minesite to Forest Rehabilitation Management Plan 2012-2020	Rehabilitation activities tracking as per management plan.
Climate Change To monitor the impacts of climate change on reptile ecology and biology.		
Focus on addressing known threats	Adaptively implement the identified threat mitigation actions to increase the ecological resilience of the island's ecosystems	No works to identify or address climate change impacts on ecosystems has occurred. A project to address this specifically is underway for 2023/2024.

Cats and Rats To reduce the impacts of cats and rats on Christmas Island's threatened reptiles by: 1. Controlling or eradicating feral cats across the island using proven and other evidence-based techniques; 2. Controlling rats in seabird rookeries around the settlement and other priority areas; and 3. Continuing community education programs including on pet cat ownership laws		
Eradicate or control cats	Continued annual cat control in settlement and light industrial areas as per the Christmas Island Cat and Black Rat Management Plan until further funding is secured to expand the program island-wide Source additional funding for cat eradication across island or broader scale ongoing control PhD investigating multi-species interactions and species recovery based on cat eradication Implement an island-wide cat control or eradication program within 3-5 years (i.e. by 2018) If needed, targeted cat control in areas identified for reintroduction Support PhD project that incorporates meso-predator/competition experiments to determine level	Cat removal has been ongoing and is now occurring island wide, driven by funding received in 2020 to scale to eradication intensity. We are currently in the 2nd year of the "knockdown" phase of this program and are progressing well towards a 2025 eradication goal. A PhD student (R Willacy; UQ, NESP TSR Hub) completed research from 2016 to 2021, focusing on the need for rat control. Rat densities on CI were found to be relatively low and were negatively related to crab abundance. Using native birds as a focus, rat impacts were also found to be low. There was no increase to rat impacts with cat removal for this species. To ensure the expected cat eradication benefits are realised, ongoing monitoring of the rat population is a priority (mid-term), as is understanding rat impacts to other potentially vulnerable species such as invertebrates and giant gecko.
Centipedes and Wolf Snakes: To reduce the impacts of centipedes and wolf snakes on Christmas Island's threatened reptiles by: 1. Investigating the role of centipede and wolf snakes in the decline of native reptiles; 2. Investigating and trialling options for control particularly in areas identified for reintroduction.		
Investigate and trial centipede and wolf snake control methods	Literature review on centipede and wolf snake biology and control options Develop control performance measures and conduct field trial control options by 2016 Targeted centipede and wolf snake control (if possible) in areas identified for reintroduction Support PhD project that incorporates mesopredator/competition experiments to determine level of possible predation	A basic internal literature review was drafted for wolf snakes in 2021. And an honours project was done on wolf snake ecology. No feasible control methods have been identified and trialled yet

	between native reptiles and identified predators	
Red Jungle Fowl: To restrict distribution of Red Jungle Fowl to settlement areas.		
Community education	Through local media, encourage community to not dispose of roosters/hens in remote areas of the Park	Sporadic updates but none for some time.
Disease/Parasites: To minimise the risk of disease transmission within extant and captive populations of native reptiles.		
Monitor health of captive population	Monitor health of animals in captivity and consult with Taronga Zoo if health issues are identified; and during the biannual census identify if any animals have external parasites and quarantine them until parasites have fallen off	Achieved

Captive Breeding Management Plan

The genetic goals of the captive breeding program are to:

	Goal	**Status Update**
1	Maintain a population for 10 years retaining over 90% of starting Genetic Diversity [GD].	Modelling suggests 90% gd retained. 90% goal based on small population management theory. Through examining number of founders, likely number of generations and number of males and female in the functional breeding population calculations suggest this goal has been met over last 10 years for MAI populations. Genetic diversity for LG (TZ) managed through MK pedigree-based management modelled to be 96% (PMx). The MAI scheme is designed to minimise inbreeding and as individual pedigrees have not been determined the intergenerational inbreeding coefficients cannot be determined but assumed. Maintaining population in evolutionary stasis without
2	Keep inter-generational inbreeding coefficient [F] at zero and prevent intra-generational inbreegding coefficients rising above 0.125.	
3	Maintain the population in evolutionary stasis with neither selection nor adaptation	

		selection or adaptions whilst a goal can not be verified. The populations have been cared for more than 10 years in a controlled environment with a view to minimise adaptation to captivity.

National Recovery Plan for *L. listeri*

Action		**Status Update 2023**
Actions 1,2, 3	Survey and monitor the two listed species (*L. listeri* and *R. exocoeti*) as well as other native reptiles to track changes in the distribution and relative abundance over time and learn more about their biology and ecology	LG considered extinct in the wild. Captive population have established captive husbandry and learnings about biology and ecology from SRS.
Actions, 4, 5, 6	Investigate the role of introduced species such as wolf snakes, cats and rats as potential threats and review and maintain existing control efforts for Yellow Crazy Ants	YCA control efforts have been maintained and a review is underway to determine future needs and actions
Action 7, 8	Reassess conservation status if not detected within 2 years of implementing Actions 1 and 2 (Action 7) and review bio-security on the island	2017 IUCN Redlist assessment EW -Extinct in the Wild.

References

- Parks Australia. 2014. Christmas Island National Park Reptile Conservation Plan 2014-2024. Commonwealth of Australia 2014.
- Harlow P, McFadden M, Andrew P 2011 Captive Husbandry and Genetic Management Plan for the Blue-tailed skink (Cryptoblepharus egeriae) and Lister's Gecko (Lepidodactylus listeri), Taronga Conservation Society Australia
- Harlow H, Andrew P, Lees C 2013 Christmas Island Blue-tailed Skink and Lister's Gecko: captive program review and recommendations for 2013
- Cogger, H. (2006). National Recovery Plan for Lister's Gecko Lepidodactylus listeri and the Christmas Island Blind Snake Typhlops exocoeti. Department of the Environment and Heritage, Canberra**.**
- Emery, JP., Valentine, L.E., Hitchen, Y. *et al.* Survival of an Extinct in the Wild skink from Christmas Island is reduced by an invasive centipede: implications for future reintroductions. *Biol*

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CPSG Christmas Island Lizards Conservation Planning Workshop Briefing Paper: Genome and Molecular Genetics

Background

Genetic diversity is important for maintaining adaptive potential and fitness of individuals and populations.

- A range of questions/issues that can be answered or guided by genetic analysis:
    - Population genetic diversity and inbreeding
    - Genetic status of various populations (captive, wild, translocated)
    - Is gene supplementation required, i.e. accumulation of inbreeding
    - Reproductive contribution of translocated individuals to populations
    - Founder relationships
    - Resolve unknown parentage
- Genetic diversity can be studied using a range of molecular genetic tools that allow the study of both functional and neutral regions of the genome, using DNA extracted from blood, skin, fur, scats, toeclips etc. Population genetics is a powerful tool for determining relatedness of unpedigreed individuals and is also used to assess genetic diversity and accumulation of inbreeding overtime.
- A reference genome for a species is the equivalent of having a puzzle box lid. It permits us to easily interpret and understand the data produced for population genetic studies. A genome permits us to infer historical demography e.g. historical population sizes, genetic load and disease susceptibility, adaptive potential of a population through functional gene diversity e.g. immune genes, behaviour genes, and both short-term and long-term inbreeding effects.

Genome

Reference genomes for the Blue-tailed skink (BTS) *Cryptoblepharus egeriae* and the Lister's Gecko (LG) *Lepidodactylus listeri* have been assembled and annotated through the Threatened Species Initiative. Globally, this is the first Scincidae reference genome and second Geckkota.

DNA and RNA extractions were carried out by the University of Sydney Wildlife Genomics team from two skinks and two geckos that were euthanised for medical reasons at Taronga Zoo. These extractions permitted high quality genomes to be assembled and annotated. The genomes and transcriptomes have been accessioned to the public database NCBI and are available under PRJNA926684 (gecko): https://www.ncbi.nlm.nih.gov/bioproject/PRJNA926684 and PRJNA924831 (skink): https://www.ncbi.nlm.nih.gov/bioproject/PRJNA924831. All authors of the scientific paper (due to be published in next two months) are listed as contributors to the projects publicly.

The mitochondrial genomes for both species have also been assembled meaning that this is now an available resource for phylogenetic analyses with other reptile species, assessing matrilineal relatedness and for the development of species specific eDNA monitoring studies.

Blue-tailed skink

The BTS assembly was 1.40Gb, 72 contigs with 99% of genome contained within 18 contigs longer than 10Mb meaning it is a highly complete genome. There is high genome-wide heterozygosity in BTS (0.007 heterozygous sites per base-pair), inferring a large historical population size. However, nearly 10% of the BTS reference genome falls within long (>1Mb) runs of homozygosity (ROH) meaning that the species has significant inbreeding. A critically important immune gene region, the major histocompatibility complex (MHC), falls completely within a run of homozygosity meaning there is no variation at this region for the individual that was used for the reference genome. The long ROH lengths infers that related skinks may have been used to establish the captive populations and that there was recent inbreeding before the skinks were brought into the captive breeding program. MHC and TLR genes contribute to reptiles' strong innate immune systems. Further investigation of population-level immune gene diversity beyond the individual sampled for the reference genome will be a priority if disease is an ongoing concern for the species.

The sex chromosomes were identified as an XY chromosomal system, which is helpful for developing a molecular sexing tool before phenotypic sexing can occur (i.e., ~1 year-old).

Lister's Gecko

The gecko genome was larger 2.35 Gb and 381 contigs. 96.2% contained within 22 scaffolds. There was also high genome-wide heterozygosity in LG (0.005 heterozygous sites per base-pair), inferring a large historical population size. Unlike the skinks, there was only a single ROH in the LG. Although we did not detect high ROH abundance in the reference LG, we cannot rule out the possibility that other geckos in the population are inbred. Further population analysis is required to ascertain this.

The sex chromosomes were not identified for the gecko.

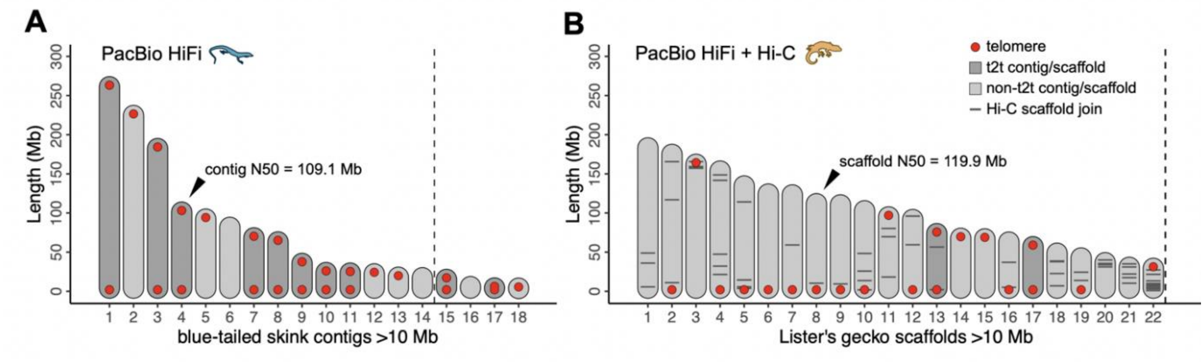


Figure 1. Genome assemblies of Christmas Island reptiles. A) 18 longest contigs of BTS genome assembly, representing >99% of assembled sequence, ordered by length. Contig 4 denotes the shortest contig for which longer and equal length contigs cover ≥ 50% of the assembly (contig N50). Red dots denote approximate telomere locations. 10 dark grey contigs represent telomere to telomere contigs (i.e., potential chromosomes). Vertical dashed line denotes expected karyotype (n=14) based on closest karyotyped relative *Cryptoblepharus boutonii* (2n=28). B) Longest 22 scaffolds of Lister's gecko genome assembly, representing >96% of assembled sequence, ordered by length. Scaffold 8 denotes the shortest scaffold for which longer and equal length scaffolds cover ≥ 50% of the assembly (scaffold N50). Dark grey scaffolds denote telomere to telomere scaffolds. Horizontal bars denote contig joins based on Hi-C contacts. Vertical dashed line denotes expected karyotype (n=22) based on closest karyotyped relative *Lepidodactylus lugubris* (2n=44 and 3n=66).

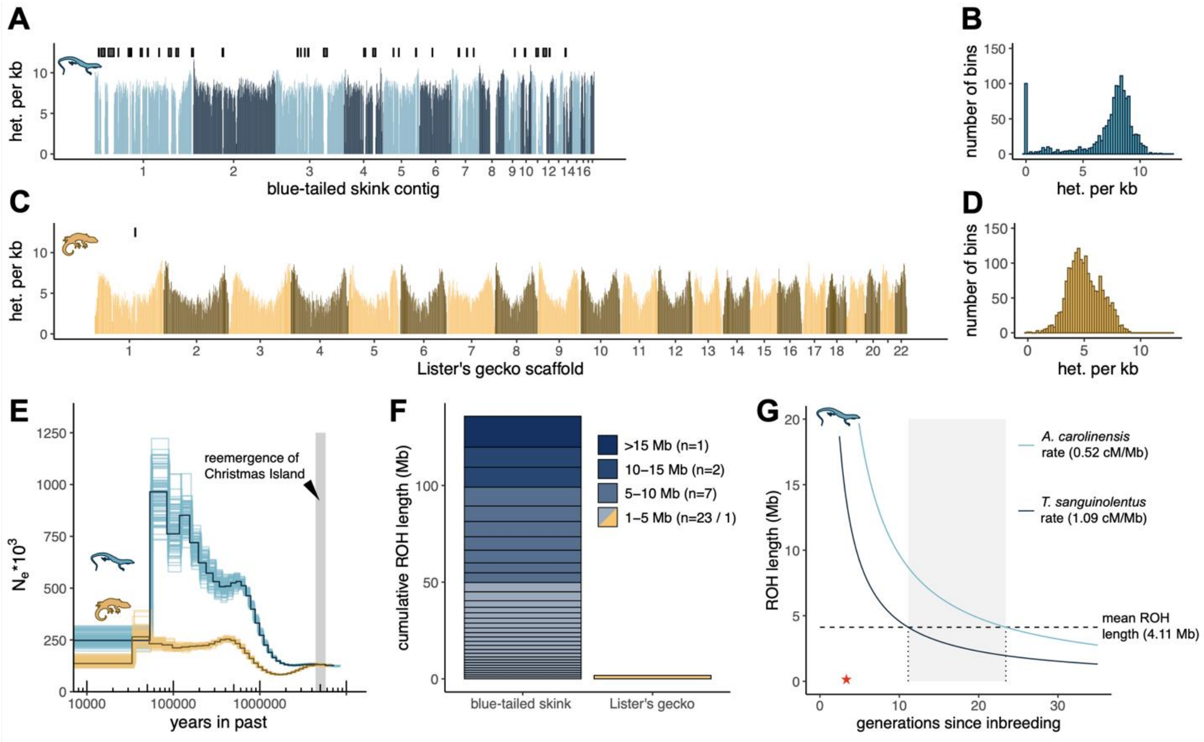


Figure 2. Patterns of heterozygosity reveal ancient demography and recent history of inbreeding. A) Heterozygous sites per kilobase (kb) in bins of 1 million called sites across blue-tailed skink genome. Contigs are coloured in an alternating pattern to aid visualization. Locations of 33 called runs of homozygosity (ROH) displayed in grey blocks above contigs. The 15 Mb X-linked structural variant on contig 8 is masked. B) Histogram of heterozygous sites per kb in bins of 1 million called sites across skink genome. C) Heterozygous sites per kb in bins of 1 million called sites across Lister's gecko genome. Scaffolds are coloured in an alternating pattern to aid visualization. Locations of 1 ROH displayed in grey block above scaffold 1. D) Histogram of heterozygous sites per kb in bins of 1 million called sites across gecko genome. E) PSMC plot, blue represents skink, yellow represents gecko, with lighter colours denoting 100 bootstraps. PSMC plot is scaled with generation time θ=3.5 and median squamate mutation rate of $\rho=6.125 \times 10^{-9}$. Grey bar is estimated re-emergence of Christmas Island from Indian Ocean 5 million years before present (Ali & Aitchison, 2020). Overlap in population size ~5 million years ago does not reflect true coalescence, as species diverged > 200 million years before present. F) Cumulative lengths of skink and gecko ROH, coloured by 4 length categories: 1-5mb, 5-10mb, 10-15mb, >15mb. G) Models used to estimate ROH length decay per generation with recombination rates from *Anolis carolinensis* and *Trapelus sanguinolentus*. Grey box shows estimated number of generations ago autozygous segments were in the same ancestor. Red star shows average number of generations in captivity for blue-tailed skinks. Note: Panels A & C are scaled to their respective genome sizes (A: 1.40 Gb, C: 2.35Gb) to permit easy comparison of the ROH in the two species.

Population Genetics

- DNA extraction had mixed results. From the more than 700 samples sent to University of Sydney, 100 gecko samples and 250 skink samples were of sufficient quality and size that DNA could be extracted.
- The DArTseq sequencing has been completed. Only one skink sample and two gecko samples failed sequencing. The samples that failed had lower quality DNA.

- The sequencing data is in the process of being uploaded to the Bioplatforms Australia TSI portal: https://data.bioplatforms.com/organization/threatened-species. Once that is complete, we can get started on analysis.
- The analysis for the skinks will take some time and there are many different questions to ask and answer. The workshop may be able to highlight the most immediate and important questions that need answers as a starting point for producing something useful for management purposes.

Questions that could be explored with population genetics are:

- How effective has BTS skinks captive program been at TZ and CI (both MAI, but different sized pops)?
- How effective has LG been at TZ and CI (MAI vs MK)
- Genetic profile of skinks released at Pulu Blan 2019 and then subsequent sampling to make decisions on future translocations. Establish baseline data for future monitoring and decision making (GD, inbreeding, NE etc).
- Genetic profile of skinks released at Pulu Blan Madar in 2020: 300 released but population declined to 88-150 skinks and supplemented with 250 skinks 2021. Samples should show us if genetics persisting from original release or just 2021 release. Establish baseline population profile data for future monitoring and decision making.
- In captive colonies with multi male and multi female groups, are one or two males dominating all the breeding opportunities? (Sampling required)

Issues and Recommendations

- Recommendation - Future molecular sampling (toeclips) use DaRTseq to inform management actions
- Further investigation of inbreeding in BTS CI and TZ populations, to determined due to test population significance of ROH observed in the reference individual
- For low intensity management scenarios e.g. Cocos Island releases suggest toeclip sampling 30 individuals every few generations to observe changes in heterozygosity and accumulating inbreeding. Could assist with triggering actions such as supplementation.

References

Dodge T, Farquharson K, Ford C, Cavanagh L, Schubert K, Schumer M, Belov K, Hogg C (2023) Genomes of two Extinct-in-the-Wild reptiles from Christmas Island reveal distinct evolutionary histories and conservation insights (In Print)

CPSG Christmas Island Lizards Conservation Planning Workshop Briefing Paper: Disease: *Enterococcus* and unknown infections in Lister's Geckos and Blue-tailed skinks

Background

- A thorough assessment of health status of exotic and native reptiles was undertaken in 2010 (Hall et al., 2011), following significant declines in native reptile species populations. The aim was to assess whether disease could be a key threatening process for the island's native herpetofauna.
- Disciplines included in the study were gross, clinical and histopathology, toxicology, bacteriology, virology, and parasitology.
- Mixture of general and targeted diagnostic techniques were used across multiple host species
- Minimally invasive investigations were conducted in native species, and extensive testing was undertaken in exotic reptiles under the premise that if pathogens or disease processes were causing multi-species declines, they would not be host specific and might be detected in exotic species. Large numbers of invasive species could be examined, to detect potential pathogens present at low prevalence.
- No evidence was detected of a highly pathogenic organism capable of causing the identified decline of native populations of several species (Hall et al., 2011).
- A range of healthy host-parasite relationships were documented in the native species, which proved useful to guide other conservation actions (translocations).
- In October 2014, an emerging syndrome of progressive facial deformity, emaciation and lethargy was identified in the Christmas Island breeding population of, first LG and, later BTS. The first diagnostic samples were submitted for examination April 2015, provoking immediate concern regarding the possible presence of a novel organism. This organism has also been found in free-ranging feral reptiles (e.g., Asian House Gecko and Mute Gecko). It has not been observed in the endemic Giant Gecko.
- The syndrome was associated with massive swellings around soft tissues of the head which disseminated throughout each organ system (Agius, 2021), and caused substantial mortality in both species.
- In the region, this bacterial disease has only been identified on Christmas Island and is not currently present in the Taronga Zoo population, nor mainland Australian reptiles. It was not identified in the initial health assessment (Hall et al., 2011).
- The novel bacterial pathogen was difficult to characterise, as it does not grow on traditional or non-traditional nor in embryonated eggs and reptile cell lines. Using molecular techniques, the organism was described as *Enterococcus lacertideformus* (Rose et al., 2017).
- This organism is very similar, if not identical, to that reported in confiscated Singapore house geckos from Malaysia that presented to the Bronx Zoo 1988-89. Similar organisms and lesions were less well characterised in a variety of small lizards at a zoological institution in the Netherlands (Zwart, 1972). These outbreaks were controlled through biosecurity and no further evidence of infection was observed in the collections.
- A 2015 health assessment, undertaken as part of the disease risk analysis of the translocation of BTS from the breeding population to Cocos Islands, found that all populations (CI, Taronga Zoo and Cocos Island) harboured a similar complement of pathogens and parasites (Agius and Phalen,

2018). The translocation had an overall low risk (Agius and Phalen, 2018). *Enterococcus lacertideformus* was only found on Christmas Island.

- More recently an organism with 100% genetic similarity to Christmas Island *Enterococcus lacertideformus* has been identified in free ranging populations of anole in Florida (Anoles'https://www.askjpc.org/wsco/wsc_showcase2.php?id=ajB3c1djTTI3dDNjOHU1SlFYUnN5Zz09)
- The initial infection source for the conservation breeding program animals was linked to escaped reptiles that likely mingled with free-ranging feral reptiles before being re-captured and returned to Lizard Lodge enclosures without quarantine. Subsequent outbreaks of infection have been linked to incursions of free-ranging feral reptiles into breeding enclosures, predominantly exclosures and tents. The rate of new outbreaks in exclosures has accelerated, necessitating multiple quarantine initiatives and localised depopulations. The bacterium is considered an ongoing threat to the CI breeding program.
- The presentation of infection varies somewhat between host species. Native and invasive geckos tend to develop large, irregular subcutaneous, expansile, pale masses, predominantly around the gingiva, sides of the head and around the neck, but ultimately animals become emaciated and can develop subcutaneous nodules along the body wall and tail. Blue-tailed skinks have thicker and tighter skin, making it more challenging to detect infections. Bulging eyes and V-shaped ulceration (presumed bite wounds) along the skin of the chin or neck area, along with emaciation are common presentations. Histologically, BTS *E. lacertideformus* infections can contain fewer organisms and these can be surrounded by more inflammatory cells than seen in infected gecko tissues.
- The prevalence *of E. lacertideformus* in the wild is estimated at 2%. It is difficult to conduct surveillance to understand the ecology of this organism in the environment because the organism does not grow in culture, and no PCR test is currently available. Lack of an available PCR test also limits the capacity to confirm cases suspected to have *E. lacertideformus* infection based on distinctive histopathological lesions. Nonetheless, enterococci are known to exploit a wide range of environmental conditions for long periods of time and an environmental reservoir is likely.
- To investigate means of transmission Dr. Jess Agius challenged small groups of Asian house geckos with a single dose of *E. lacertideformus* via the following routes: oral, application to abraded oral mucosa, application to a skin laceration, subcutaneous injection, coelomic injections, or co-housing with an infected animal. Each route of transmission resulted in disease of at least 40% (n=2) of the exposed animals, and 100% of animals became infected when organisms were inoculated via skin laceration or abraded oral mucosa. Incubation periods of infection ranged between 54 and 102 days.
- This organism has many features that make it challenging to control: a low Ro value, a long incubation period, abundant shedding of organisms (via the respiratory tract, faeces and skin), likely transmission through courtship (frequency rather than density dependence driven transmission), having no accurate diagnostic test in live animals, and no effective treatment.
- During the *Enterococcus* investigations, two new papillomaviruses have also been discovered in native and exotic geckos (Agius, 2021). Although interesting due to their phylogenetic profile as archaic viruses, and due to the first known presence of papilloma in internal organs, the infections are considered to be incidental to the health of their hosts.

Current Status

<u>Christmas Island Population</u>

- *Enterococcus lacertideformus* was detected in an enclosure (LG11) for the first time in December 2022, raising concerns that transmission of disease from invasive reptiles to captive animals may not be limited to direct contact.
- CINP has an *Enterococcus* and infectious disease protocol that guides management decisions during an outbreak. In the event one animal has a confirmed *Enterococcus* infection, all co-housed animals exposed to that individual must be placed in quarantine for 120 days or must be euthanised. CINP can house a maximum of ~150 animals in quarantine, with additional labour resources provided.
- As of 7th March 2023. there are 11 LGs and 130 BTS in quarantine. An additional quarantine-focused staff resource was approved in January to support with the husbandry and welfare of these animals.
- In February 2023 an exceptional approval was granted for the hard release of 53 male and female BTS that had been exposed to one individual with *Enterococcus* in December 2022, but had no visible symptoms. This decision was made to preserve life (alternate option to euthanasia) and maximise the learning a potential hard release offers.
- Disease risk management in both BTS and LG populations is ongoing, and many procedures are adjusted in response to emerging disease risk.

<u>BTS Disease Outbreaks</u>

- Since BTS exclosures were first established in 2013 and used to house captive animals, *Enterococcus* outbreaks had only occurred in male-only exclosures, where territorial aggression occurs more frequently, until 2022.
- Historically there has also been *Enterococcus* outbreaks in male-only (bachelor) exclosures in 2019 and in 2020. The males exposed were euthanised and the outbreak was contained to the one impacted exclosure .
- *Enterococcus* was first transmitted into a mixed male/female BTS exclosure (EX 1) sometime prior to August 2022. Additional animals with visible *Enterococcus* symptoms were found in September 2022 and the remaining population was quarantined. In November 2022, one animal from each of the other remaining mixed-sex BTS exclosures presented with disease and all exclosure animals were put in quarantine. One male-only (bachelor**)** BTS exclosure currently remains.
- From the beginning of 2022 to date (February 2023), a total of 296 BTS's either quarantined (143), euthanised with symptoms (24), euthanised without symptoms (25 – bachelor males exposed), found dead (4), were missing and presumed dead (47) or hard released (53). This represented an approximate proportion of 40% of our total BTS population average in captivity on CI (throughout 2022).
- *Enterococcus* was detected in a bachelor exclosure of male BTS in May 2022. The current outbreak of *Enterococcus* impacting exclosure BTS may go back to then.

<u>LG Disease Outbreaks</u>

Enterococcus:

- *Enterococcus* first detected in LG in October 2014. At the time of infection, the impacted geckos were housed in glass terrariums covered with a plexiglass top and mesh covered holes in the plexiglass, allowing for ventilation (and the potential for exposure to feral reptiles). This set up is similar to the enclosures in the lizard lodge now.

Disease History in LG11 (2021-2022):

- October 2021: 6 found dead, 15 quarantined of which 7 euthanised/died in quarantine. **Bacterial disease could not be identified (not *Enterococcus*)**
- In Feb 2022 remaining 8 LG removed from quarantine and put back into LG11, topped up with 13 healthy animals.
- May 2022: 4 missing, 8 found dead (one found dead in March), remaining 8 put back into quarantine. Too desiccated to sample.
- By August 2022, 6 had died in quarantine. **Unknown bacterial disease found and was not consistent with *Enterococcus*.** The remaining 3 in quarantine were euthanised precautionarily.
- As LG11 enclosure had remained empty since May and was sterilised and given new substrate/habitat, 14 more animals were put in there in September and 7 more in November 2022.
- In December 2022 four were missing and 2 found dead. This time ***Enterococcus* was confirmed.** The remaining animals are currently in quarantine.
- **TOTAL LOST TO DISEASE: 40 (+14 currently in quarantine)**

Taronga Population

- Gout has been observed in the Taronga population since arrival in 2011.
- Gout was confirmed through post-mortems in BTS at Taronga Zoo since 2011 and in LG since 2013. Overall, the prevalence of gout is low based on post-mortems (BTS: average 1.2%; LG: average 3.3%)
- Lizards from as young as 8 months have been affected.
- Common causes of gout in other lizard species are dietary and lack of water or humidity. Over the years, the husbandry has been adjusted to attempt eliminating gout in the population.
- The signs and symptoms present differently in both species, early onset can be detected in LG as they present with white nodules on joints and the face. BTS often have joint swelling but usually isn't detected until paralysis of limbs.

Issues

- Free-ranging invasive geckos currently enter BTS exclosures and co-habit with BTS. Biting is understood to be the primary mechanism of *Enterococcus* transfer which occurs through both territorial/social hierarchal aggression and breeding. The exclosure facility is not designed to prevent ingress of invasive geckos (Figure 1).
- Due to male BTS aggression, a ratio of ~70% female to 30% male is maintained for all adult/breeding age exclosures and enclosures of BTS. This leads to an excess of males that are required to be housed in a 'bachelor' exclosure of a maximum of ~70 individuals. These animals tend to be more prone to biting and appear more likely to acquire and pass on *Enterococcus*. Multiple outbreak events have occurred in BTS bachelor exclosures resulting in mass euthanasia of exposed animals.
- Enclosure design prevents ingress of invasive geckos into enclosures however a recent *Enterococcus* infection within an enclosure raises questions about other forms of transfer. The Lizard Lodge is not a secured facility and invasive geckos are able to access equipment, stored penpals, water bowls and bark (Figure 2).
- After the completion of a 120-day quarantine period, some reservations still exist as to the safety of reintroduction to the captive core breeding population as the period between exposure

to the bacterium and appearance of symptoms often varies and can be a long time before symptoms show.

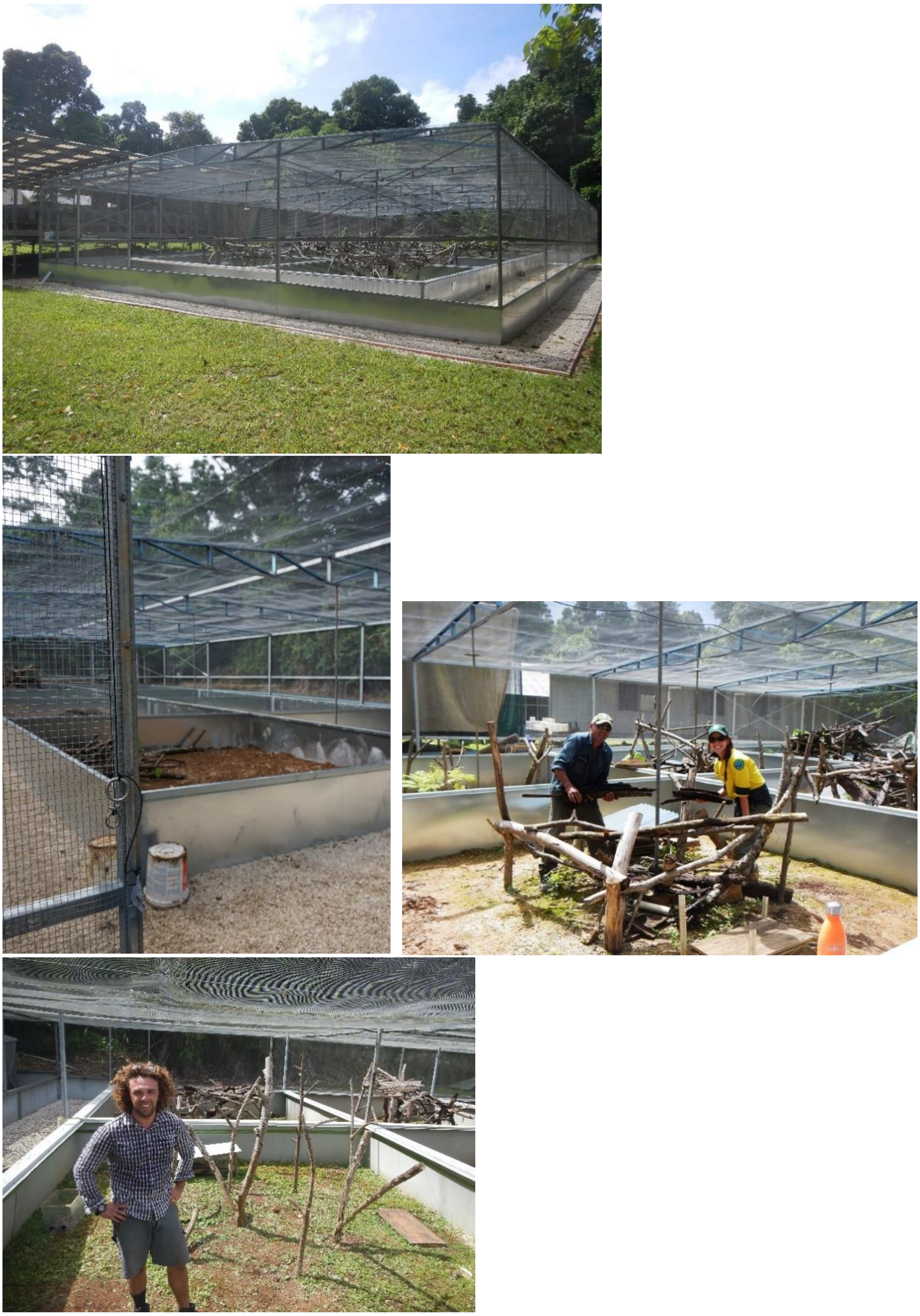
- 

Figure 1. Blue-tailed skink exclosure design

Figure 2. Lizard Lodge: enclosures and penpals housing captive core population of LG and BTS

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CPSG Christmas Island Lizards Conservation Planning Workshop Briefing Paper: Predator Controlled Sites (Soft-Release Sites)

Background

Two soft release sites (SRS) have been established on Christmas Island for the reintroduction of the Christmas Island Blue-tailed skink (*Cryptoblepharus egeriae*; BTS) and Lister's gecko (*Lepidodactylus listeri;* LG); Circuits SRS and East-West Baseline SRS. Both sites are in rehabilitated forest habitat and are surrounded by predator-exclusion fencing.

Since the establishment of the first site in 2017, captive bred BTS were translocated into these sites in four separate reintroduction trials, which met varying degrees of short-term success. Ultimately, the first three released BTS populations eventually failed due to invasive predators entering the sites. LGs have been translocated into SRS in three reintroduction trials, with differing challenges and results to BTS, but have also failed to achieve long-term success in the first two translocations (see Appendix A for timeline of significant events).

The fourth BTS and third LG reintroduction trials commenced on their release in February 2023 after the establishment of a new fence design experimentally tested to prevent incursion of wolf snakes and centipedes.

<u>Soft-release sites</u>

Circuits SRS (Since 2017)

- Constructed in 2017 within a mine site to forest rehabilitation area to keep centipedes and wolf snakes from the site, and LGs & BTS within the site.
- Fence design included galvanised sheet metal fence (same material as used for BTS exclosures), with overhanging vegetation removed and a 1m barrier between the edge of the vegetation and fence. There is also a road bordering the outside of the fence (Figure 1). Electric stripping was placed on the outside of the fence in the second BTS trial, and internally part way through the first LG trial. The electric stripping voltage was low on the internal fence, serving as a deterrent for LG escape.
- Between April 2021 and November 2022, a second predator-proof fence was constructed outside the first. Two poisoned 'no-mans land' barriers were added (one in between the two fences and one outside) to prevent ingress of wolf snakes and giant centipedes. The fence is made of flat HDPE with smoothed welded joins an upgraded, stronger outer electrical barrier for predators and a lower voltage inner electrical barrier for containing LGs (Figure 1).
- Between BTS trial 1 and 2 (2018) and BTS trial 2 and 3 (2022) significant efforts were undertaken to remove habitat, eradicate centipedes and wolf snakes, replace habitat, and re-seed site with invertebrates.

Figure 1. Photos of Circuits SRS: predator proof fence in 2018 (top left, right), and in 2022 after construction of second fence (bottom left, right)

<u>East-west Baseline SRS (since 2020)</u>

- Established in 2020, this was the second SRS constructed off East-west Baseline road, within a minesite to forest rehabilitation area. The site has greater natural habitat availability and vegetation diversity. Fence design included hexagonal plastic panels, crab fencing, electrical barriers for predator exclusion, rat prevention and gecko escape (Figure 2).

Figure 2. Photos of EW Baseline SRS: predator proof fence, habitat structures and crab fencing

Table 1. A summary of BTS SRS trials at Circuits and East-west Baseline (EWB) sites

Date	Site	# BTS	Reintroduction Details
Trial 1			
2017	Circuits	137	First reintroduction of BTS into the site. This trial failed within six months, as the population of 137 animals rapidly declined until no animals could be detected. Despite attempts at trapping and physical removal, the invasive giant centipede (*S. subspinipes*) was abundant in the site and was found to be a threat to the survival of the skinks (Emery *et al*. 2021a). Emery and CINP staff also concluded that suitable habitat and connectivity was lacking. Based on what was learnt from the first release, major works were undertaken at the site, including; • Centipede eradication with insecticide • Improvement of habitat quality and complexity in the site, • Addition of a crab fenced and poison treated 'no-man's' barrier • Addition of external electric barrier • Addition of artificial habitat • Addition of bird netting over habitat • Increased vegetation-free buffer surrounding the site
Trial 2			
2018	Circuits	170	In a second release trial 170 BTS were released to the site. Reproduction was evident within the first six-months post-release, after an initial decline of 25-55% [95% C.I.]. The BTS population grew to an estimated >1000 individuals before a significant decline were detected in the population in 2021. While re-incursion of centipedes at high densities was initially thought to be the cause, wolf snakes were later found in the site. The remaining reptiles and habitat were removed; 173 BTSs and 2 LGs (all that was found) were returned to captivity as the reintroduction was declared failed.

Trial 3			
May 2022	EWB	200	200 BTS were released in the first trial for the EWB site. Unlike the LG release at the same time, the population of BTSs never appeared to increase above the number of lizards released, however gravid females and recruitment was regularly observed (population estimates were not obtained, and trend data was extrapolated through transect counts). In addition, transect count monitoring suggested the BTS population was declining at a slow and gradual rate since 18-months post-release. 2023: Transect count monitoring could no longer detect BTSs within the site in January 2023, and the third trial of BTS reintroduction was deemed failed.
Trial 4			
Feb 2023	Circuits	168	The release of 168 BTSs to the site occurred one week after the LG tents were opened

Table 2. A summary of LG SRS trials at Circuits and East-west Baseline (EWB) sites

Date	Site	# LG	Reintroduction Details
Trial 1			
Feb 2019	Circuits	160	As the second BTS trial at circuits SRS was meeting short-term metrics of success (population growth and no signs of threat occurring) and following the installation of an internal electrical barrier to prevent gecko escape, 160 LGs were released into the site in the first reintroduction trial for the species. The LG population decreased by 59-76% [95% C.I.] in the first month post-release and decreased a further ~10% in December 2019 at 10-months post-release. Monitoring was undertaken by PhD Jon-Paul Emery who concluded that the decline of LGs in SRS was likely due to their dispersal out of the site due to the electrical barrier being ineffective, lack of quality habitat and harassment from large numbers of *Camponotus* sp. ants. Dec 2019 estimate of 30 individuals remaining in the site [C.I. 95% 25,45] (Emery et al. 2021a). In 2022 observations suggested LGs were persisting in similarly low numbers to Dec 2019 however throughout the remainder of 2020 the population continued to decrease, until only 3-4 individuals were observed during nocturnal searches.
Trial 2			
May 2022	EWB	200	In May 2020, 200 LGs were released in a second reintroduction trial for the species (first trial for the site) in a penned release (tent) to reduce stress and dispersal. LGs persisted and appeared to maintain relatively stable numbers for the first-year post-release. Counts of individuals through

			monitoring hide usage were relatively consistent and recruitment was observed (Figure 3).
Trial 3			
Dec 2022	Circuits	150	150 LGs were released in closed, penned tents in the reconstructed and refurbished site. Before monitoring commenced, Lister's were found to be escaping the tent through a gap in the bottom. In Feb 2023 the remaining LG's in the tents were counted before they were permanently opened and 76 of the 150 translocated were found. Issues with the internal electrical barrier were occurring at the time so it is unknown whether they escaped or are persisting in the site (detections within the site have been challenging and low).

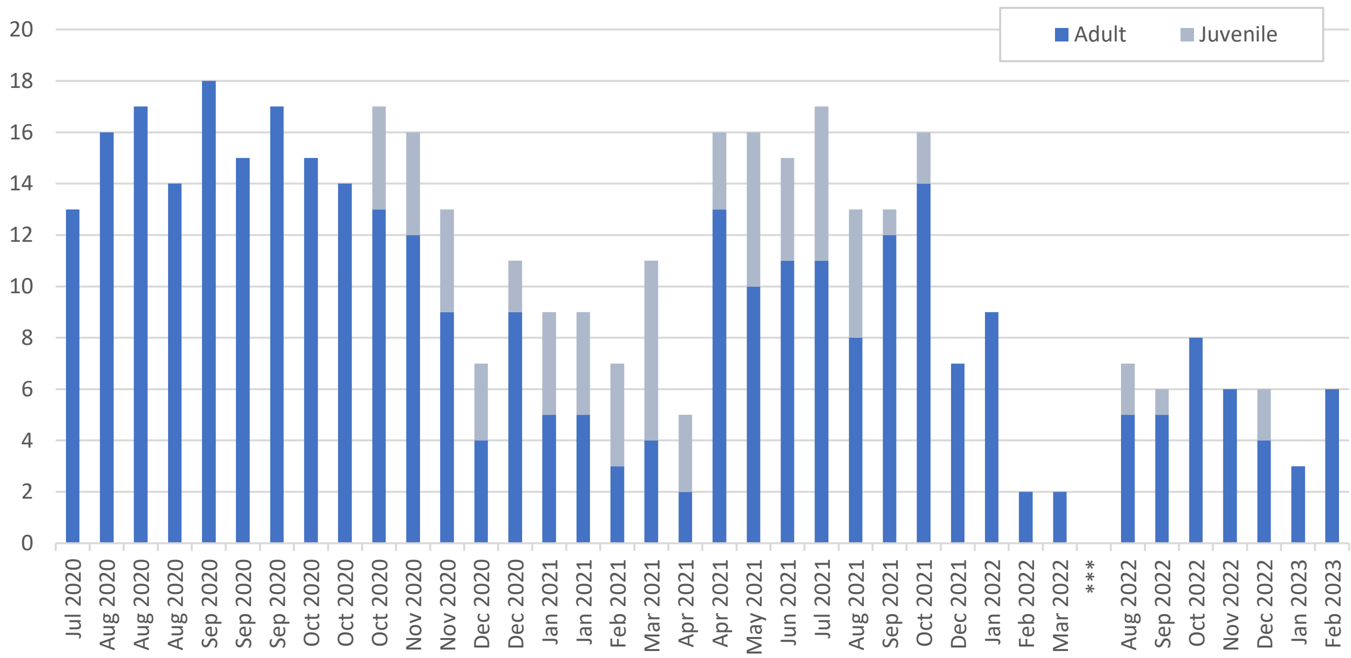


Figure 3. Counts of LGs observed in EW baseline SRS via monitoring hides. Monitoring initiated two-months post-release (July 2020). Between April and July 2022 monitoring was ceased while new waterproof hides were constructed.

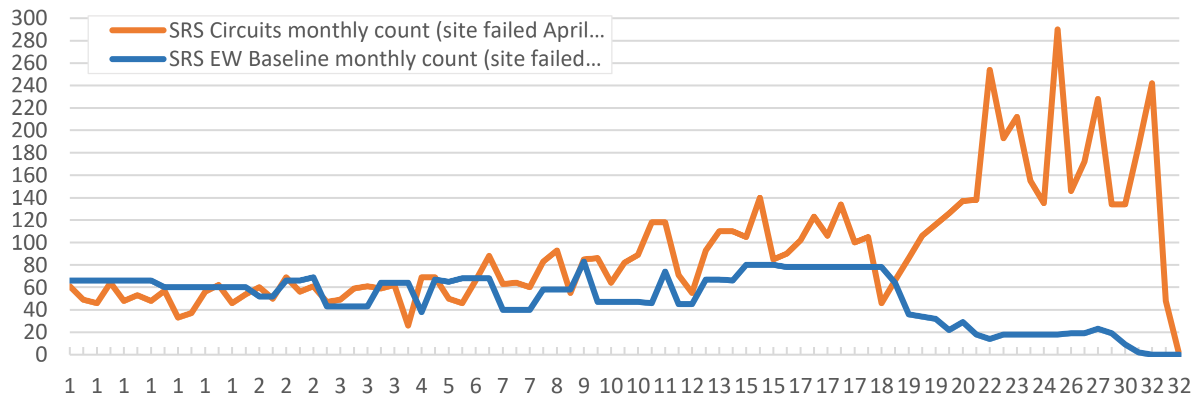


Figure 4: Comparison of population trends between the Circuits SRS (BTS trial 2) and the EW Baseline SRS (BTS trial 3) using count data of BTS (transect monitoring) at each month post release.

Current Status

As of February 2023:

- EW Baseline SRS currently contains a small population of LGs, and no BTS. The decline of BTS in this site is suspected to be the result of wolf snake ingress. A wolf snake was discovered in the site and removed in October 2021 (16-months post release), however the BTS population continued to decline, suggesting that additional undetected snakes were likely to remain in the site. No further reintroductions are planned for EW Baseline SRS.
- Circuits SRS currently contains 168 BTSs and 150 LGs (likely to be less as internal escape-prevention electrical barrier was non-operational for more than four months). No data on the success of the recent release is available due to short timeframe since release.

SRS Monitoring Strategy

A variety of post-release monitoring methods have been tested and used to evaluate how effective reintroductions have been. Monitoring limitations exist (see Issues section).

LG Monitoring

- Capture-mark-recapture (CMR) surveys were used by PhD JP Emery in LG trial 1 to gain survival and population estimates and identify reproductive events. CMR monitoring is currently planned for the third trial for LGs in the Circuits SRS site.
- Diurnal hide occupancy monitoring is used to detect persistence of LGs in SRS and aimed to be able to detect changes in population trend.
- External monitoring to detect whether Listers geckos were emigrating from the site was briefly tested in trial 3, which involved ink cards and hides in trees and habitat outside the SRS, however ants quickly monopolised hides, and ink cards were thought to be more effective at detecting LG emigration in the areas between the fences.
- Nocturnal quadrat monitoring using eye shine to detect LGs.

BTS Monitoring

- Capture-mark-recapture (CMR). In the first SRS trial and the beginning of the second trial at Circuits SRS, CMR methods were used by PhD Jon-Paul Emery to determine survivorship and population estimates of BTS.
- Transect monitoring to detect changes in population trend.
- Body condition surveys to monitor for changes in body condition (indicating a lack of resources or stressor present) and changes in population demographics.

Invasive Species Monitoring

- Ink card monitoring to detect the presence of rats within the site, and for trial 3 in the dead man's zone between fences.
- Nocturnal search to detect the presence of wolf snakes, introduced geckos, rats, and huntsman or orb weaver spiders.
- Pitfall traps have been used in the past and have captured some centipedes, however, have also resulted in mortality of giant geckos and blue-tailed skinks who have inadvertently been trapped with the centipedes.

- Trap cameras have been put in the SRS and on the top of the fence surrounding the SRS in the EW baseline trial. New reptile automated cameras will be trialled supplied by Deakin University (Don Driscoll's team) better suited for capturing ectotherms.
- Rat trapping (cage and snap traps) are have been used both to detect and remove rats in SRS
- Ink card monitoring was used to detect presence of LGs in various micro-habitats in LG trial 2 (EW baseline) and the method doubled as a detector for rat presence.

Issues

- Predator Incursion
    - Constructing a fence in a forested environment that can withstand UV, heat, heavy rain, falling trees etc and prevent ingress of rats, giant centipedes and wolf snakes is extremely challenging and yet to be proven successful.
    - Wolf snakes have been observed to climb smooth flat surfaces up to 1m tall, and may be able to climb higher (Figure 4). Centipedes can also climb relatively smooth and flat surfaces (they have been detected dead on the perimeter electric barrier 1m high) and can enter on earth works equipment, habitat or falling branches. Rats can jump over 1m from a standing start.
    - Electrical barriers have become a critical safeguard, however they are not an absolute deterrence and invasive geckos and spiders are easily able to breach this defence. Literature suggests persistent animals will bypass the barrier. Additionally, electric barriers are not always reliable; they can arc in rain or, or if an animal (i.e. invertebrate) is stuck across the barrier this causes batter drain and a loss of power to the fence. Latest design of electrical fence at Circuits SRS has a lethal or near-lethal shock to small animals (~5 kV), as previous electrical fence designs did not deter incursion.
    - Once centipedes and wolf snakes have entered the site, no technique has been found to remove them other than full site destruction, application of insecticide, and re-build of the site. Additionally, no proven techniques to detect or lure/trap wolf snakes have been developed that are effective in SRS's.

Figure 4: Wolf snake recorded climbing welded join in HDPE fence (left) and climbing smooth, vertical surface of HDPE fence without the aid of join or water tension (right).

- LG egress from site

Electrical barriers to prevent LG's escaping have been limited in their success. Other options for prevention of escape such as an application of lithium grease or aluminium sheeting have so far not been found to work in Christmas Island conditions (climate and challenging rehabilitation site conditions).

- Habitat not ideal for LG
  - Both SRS sites have been established on rehabilitation fields. Vegetation in both sites is low, open canopy regrowth favouring generalist BTSs rather than closed-canopy, dense vegetation likely to be preferred by LG.
  - Less is known about the habitat preferences of the LG than the BTS.

Limitations of past monitoring, and designing a monitoring program that addresses success criteria

- For monitoring to be effective, it must be able to be evaluated against clearly defined objectives that are linked to management plans.
- The criteria for success outlined in CINP's reintroduction plan for soft-release of the blue-tailed skink and Lister's gecko (2018) into EW SRS has included measures of survivorship and population growth that could not be determined through the monitoring plan developed.
- When the aim of monitoring is to detect a change in abundance or occupancy then monitoring should be designed to have sufficient statistical power, otherwise managers may be misinformed about the ability for a monitoring program to detect such changes (Strayer 1999, Wintle 2018).
- Monitoring undertaken by JP Emery in LG trial 1 and BTS trial 1 and the beginning of trial 2 used statistically testable monitoring methods to determine population sizes (CMR surveys for LGs and transect monitoring for BTSs which provided trend data closely comparable to the results statistically tested distance sampling methods). While CINP continues to use transect monitoring methodology for BTS for population trend, we have not used CMR in other LG trials or statistically tested other LG monitoring methods.
- CMR methods are highly resource intensive and highly disturbing to a LG population that are capable of leaving the boundaries of the SRS.
- CINP monitoring methodology has been inadequate to determine survivorship or population estimates of LGs.
- While recruitment can be observed through detecting gravid females and juveniles post-release, we cannot ascertain their survival to adult reproductive age without identifying individuals throughout their lifecycle. This is of particular importance in populations where growth does not appear to be occurring (for LGs we cannot determine if population is not growing due to impacts on survival or egress from the site). Hide occupancy monitoring used to extrapolate growth or decline of the population has its limitations (no statistical analysis of results, limited ability to detect change). In addition, the results can't reliably be extrapolated under influencing factors such as limited number of available hides or disuse of hides during heavy and prolonged rain events.

References:

Emery, J. P., Valentine, L. E., Hitchen, Y., & Mitchell, N. (2021a). Survival of an Extinct in the Wild skink from Christmas Island is reduced by an invasive centipede: implications for future reintroductions. Biological Invasions, 23(2), 581-592.

Internal: Reintroduction Plan for soft-release of the Christmas Island blue-tailed skink, Cryptoblepharus egeriae, and Lister's gecko, Lepidodactylus listeri. (December 2022) K Schubert

Internal: SRS 21C Monitoring Trials (January 2022) K Schubert

Internal: SRS Evacuation Report (April 2021) K Schubert

CIRAP 2021, Attachment 4 SRS Update

Appendix A

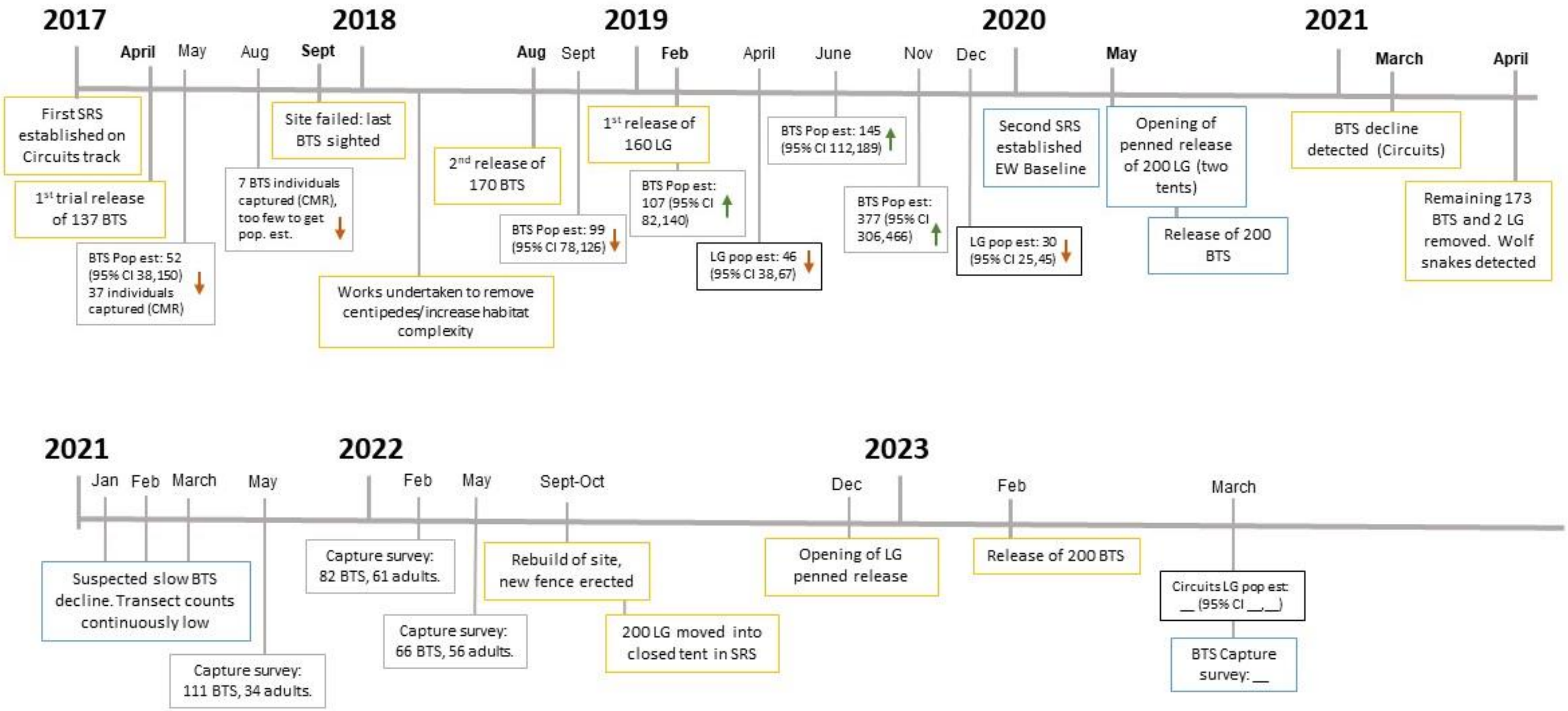
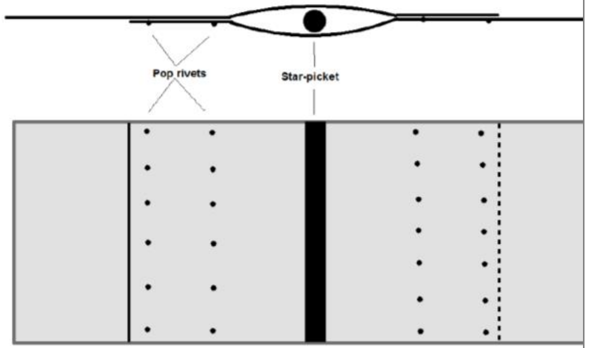
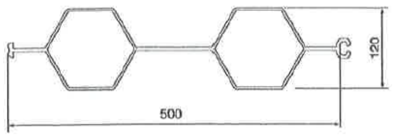


Figure 3: Timeline of significant events in Circuits SRS (yellow border) and EW Baseline SRS (blue border)

Table 3. Specifications of current and previous SRS exclusion fences

Specifications	SRS 22C (OLD fence, Circuits)	SRS 21C (EW Baseline)	SRS 22C (NEW fence, Circuits)
Area (m^2)	2648	3345	2648
Perimeter (m)	200	225	200
Fence depth under-ground (mm)	200 (backfilled, erosion occurred over time)	200 (trench-dug)	300 (300mm deep and 200mm wide trench dug and concreted in, 30-100cm from outside of existing perimeter fence)
'No-mans' width (mm)	300	300	200 (dead man's width varies 70-100cm)
Fence height above ground (cm)	100	100	100 (both fences)
'No-mans' gravel depth (mm)	30	30	30
'No-mans' gravel size (mm)	10-20	10-20	10-20
Fence design	 *(pictured in image 3 too)*	 	
Fence material	Galvanised metal	Recycled PVC "Prolock"	Recycled flat panel PVC
Fence join	40cm overlap around star-picket fence dropper secured with wire and pop rivets on inside of the fence.	Interlocking design allowing movement of 10-110 degrees	Plastic weld
Fence panel length (cm)	550	50	500
Fence panel height total (m)	1.2	1.2	1.3
Conduciveness	Requires grounding to earth	Non-conductive material	Non-conductive material

CPSG Christmas Island Lizards Conservation Planning Workshop Briefing Paper: Assisted Colonisation of Blue-tailed skinks on Cocos (Keeling) Islands

Background

- Captive bred populations of Blue-tailed skinks (BTS) were first translocated to Pulu Blan in September 2019 and to Pulu Blan Madar in March 2020 (296 successfully released on each), as a trial to establish self-sustaining wild populations as part of the species' recovery and security.
- Pulu Blan (2.08 ha) and Pulu Blan Madar (1.86 ha) are two neighbouring islands in the Cocos (Keeling) archipelago, approximately 200m apart. At extremely low tides, the islands are connected via a sand bar.

Figure 1a. Photo from the edge of the NE side of Madar at a regular tide, facing Blan.

Figure 1b. Photo from Blan at an extremely low tide, facing Madar.

- While the population from the first release on Blan met initial success metrics, the population from the release on Madar underwent a large decline within the first 6-weeks post release. The cause of the decline was attributed to a yellow crazy ant (YCA) super colony.
- A supplementary release of an additional 250 BTS took place on Madar in June 2021.

Current Status

Pulu Blan Madar:

In October 2022, at 31 months post-release (16 months since top-up release), results from a capture-mark-recapture (CMR) survey on Madar did not give the result expected, as we expected the population should have grown since the last survey 7-months prior.

- A total of **216** captures were made over the 8 survey days, of which **182** were individuals, (this was similar to the 233 captures made during CMR seven months prior of which 194 were individuals).
- The population was estimated to be **544 [95% C.I. 403,735]**, which is less than the estimate obtained seven months prior of 733 [95% C.I. 532,1009]. Apparent survival between March 2022 and October 2022**,** (24–31 months post-release) was **42**% **[95% C.I. 30,54],** which had greatly reduced from survival estimates of 80% [95% C.I. 61,91] between 13-24 months post-release.
- Body condition had decreased in the seven months between CMR surveys, however it was not deemed statistically significant when tested using a linear regression model.

Pulu Blan:

The last CMR survey was undertaken on Pulu Blan at two-years post-release in September 2021, where the BTS population had continued to grow since the previous survey 12-months prior, no threatening processes were identified, and the skinks were in good health. Body condition had increased from earlier post-release measurements. The estimated annual growth rate between 1-year and 2-years post release was 87.3%.

Due to the results of the CMR survey on Madar in October 2022, CINP management decided that an additional CMR survey before the CPSG workshop would help to ascertain whether the population on Madar is indeed under threat, and further investigate any threatening processes that may be occurring. Though CMR monitoring of the population on Blan isn't due next until September 2024 at 5-years post release, management decided it would be a good opportunity to investigate the stability of the population on Blan at the same time to ensure the potential threat on Madar isn't impacting both islands simultaneously. This CMR work will be conducted in March 2023 two weeks before the workshop and will be presented in a separate document.

Table 1. Population and survival estimate for BTS populations on Pulu Blan and Pulu Blan Madar at each CMR session. *It should be noted that the confidence intervals can be broad, therefore estimates should not be considered as an absolute value. Survival estimates between initial translocation and 6-weeks post release were calculated based on population estimates at 6-weeks. Individuals in the top up translocation on Madar were not included in survival estimate of 80% for period of April 2021 – March 2022.

Pulu Blan					
	Date	**Time post release**	**Estimate**	**SE**	**95% C.I.**
Population estimates	September 2019	*Initial translocation*	296		
	October 2019	6-weeks	218	31.33	165, 289
	March 2020	6-months	307	31.56	251, 376
	September 2020	12-months	591	98.4	426, 819
	September 2021	24-months	1271	191.6	946, 1708
Survival estimate	September – October 2019	0-6 weeks	72%		55, 97
	October 2019 – March 2020	6-weeks to 6-months	77%	7.2	60, 88
	March – September 2020	6-12 months	69%	6.6	55, 80
	Sept 20 – September 21	12-24 months	70%	5.3	59, 80
Pulu Blan Madar					
Population estimates	March 2020	*Initial translocation*	296		
	April 2020	6-weeks	82	16	56, 121
	June 2020 – Island-wide YCA baiting				
	August 2020	6-months	119	43	58, 242
	April 2021	12-months	200	61	109, 367
	June 2021	*Top up translocation*	250		
	March 2022	24-months/9-months post top-up release	733	119	532,1009
	October 2022	**31-months/16-months post top-up release**	**544**	**83**	**403,735**
Survival estimate	March – April 2020	0-6 weeks	27%		
	April – August 2020	6-weeks to 6-months	62%	19	**24, 89**
	August 2020 – April 2021	6-12 months	60%	11	**37, 79**
	April 2021 – March 2022	12-24 months/0-9 months top-up release	80%	7	61, 91
	March 2022 – October 2022	**24-31 months/9-16 months top-up release**	**42%**	**6.1**	**30, 54**

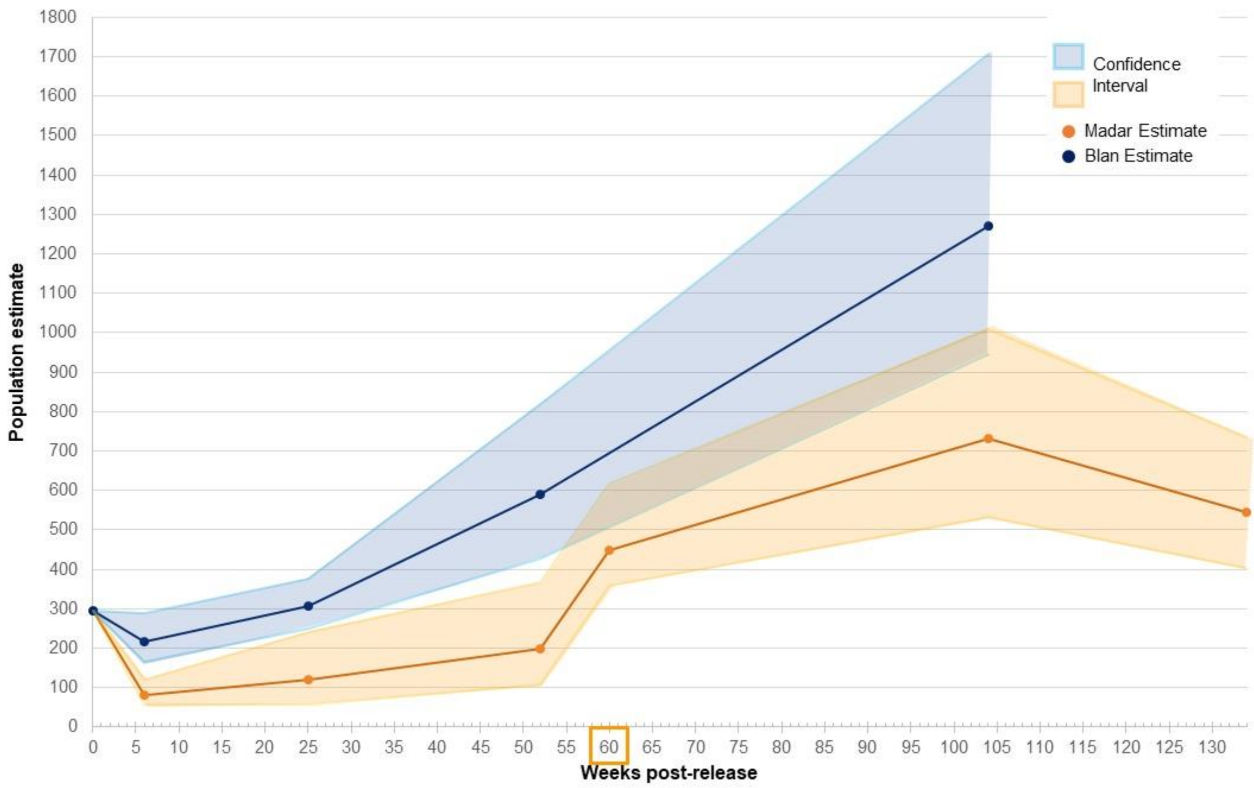


Figure 1. Population estimates of Pulu Blan (blue) and Pulu Blan Madar (orange) shown on a timescale over number of weeks post-release. At 60 weeks post-release on Pulu Blan Madar, the top up translocation of 250 additional animals occurred – for this period, confidence intervals were estimated from the previous LC/UC +250.

Issues/Challenges

CHALLENGE 1: Survival on Madar

- The estimates obtained from the October 2022 CMR survey suggests the BTS population on Pulu Blan Madar could be under threat. Population estimates have decreased from the last CMR in March 2022, and we expect the population should have substantially increased over this period following trends previously observed (Blan supports a larger population, SRS estimates of carrying capacity was ~600 animals (JP Emery), and Madar is 7x the size of the SRS). Carrying capacity for Pulu Blan Madar is unknown, and it is acknowledged that it may differ from neighbouring island Pulu Blan which currently supports a population estimated to be more than double the size of Madar. However, several factors provide support that the skink population could be under threat and further growth has not been restricted by carrying capacity or resource availability, which are listed below:

(1) Surveyors frequently observed skinks foraging and consuming a range of invertebrates, and an abundance of small ants, crickets, flies, beetles, and termites were readily seen. In addition, most skinks defecated while being handled in the morphological assessment (scats were kept for research purposes) showing they had recently eaten. Therefore, appears unlikely that food resource availability is restricting population growth.

(2) While there have been some concerns in the past that the denser vegetation on Pulu Blan Madar reduces the availability of suitable basking habitat for the skinks, assessment of occupancy mapping from each CMR session shows the skinks are widespread, utilising a range of habitats, and do not appear to be restricted to certain locations on the island. CMR surveys began in the mornings and skinks were commonly observed (and more visible to surveyors) basking in sunny patches, which shifted as the sun rose over the island. Skinks were also observed in shaded habitat, particularly later in the heat of the day. Some habitat enhancement (coconut tree felling) had been undertaken by PKNP Rangers prior to this survey on September 13, 2022, to create more areas of open canopy, which appeared to have no significant influence on skink occupancy density overall but was used by skinks. Occupancy data from March 2022 closely resembles the locations where skinks were found during this CMR survey period. As such, it also appears unlikely that habitat availability is restricting population growth.

(3) The proportion of females that were gravid when captured is relatively consistent with the last CMR survey in March (March: 63, 49% gravid; October: 33, 57% gravid) showing frequency of breeding would not be negatively impacting population size. In addition, a higher proportion of individuals captured in this survey were of juvenile and sub-adult age (March: 44%; October 67%), indicating previous breeding events resulted in successful recruitment.
Known threats that have rapidly resulted in a skink population decline such as YCA impacts (Madar) or the invasion of a wolf snake (SRS), have not appeared to negatively impact the proportion of gravid females (proportion of females that were gravid was 64% in April at 6-weeks post release on Madar when population had undergone significant decline due to YCA). Thus, you may expect with a consistent proportion of breeding adults and successful recruitment of juveniles that the population would be increasing.

Pike et. al. (2008)[3] found through encompassing data from 57 species of reptile (in 109 populations) that a stable population consists of high juvenile survival rates that are highly correlated with adult survival. The proportion of juveniles on Pulu Blan supports this result, as each CMR session after 6 months post-release has remained between 42-49%. Also, prior to the recent CMR session, the proportion of juveniles on Madar after 6 months post-release had also remained between 42-48%. The 67% of juveniles seen in the October 2022 CMR survey is variable and unlike any demographic extrapolated from CMR in the Cocos populations to date, therefore could be suggestive that the population is currently unstable. However, continuing to monitor the demographics of the population long term in conjunction with population estimates will help us to better understand what may be causing a change in proportion of juveniles and whether it is indicating threat to the population.

(4) Survivorship on Pulu Blan, where the population estimates have continuously increased at each CMR interval, has consistently been close to 70% (all confidence intervals ± 10-15%). On Pulu Blan Madar, the population was negatively impacted by YCA in the first six-months post-release, thus early estimates of survivorship were low with widened confidence intervals (C.I. ± 25-30%). However, in the CMR survey in March 9-months after the top-up release, survival was estimated to be 80% (C.I. ± 19%). The current survival estimate of 42% (C.I. ± 12%) seven-months on provides direct support that a threat is impacting the survival of the skink population on Madar. The results of the March 2023 survey (which will only be available days before the workshop) will provide updated information allowing us to interpret the current level of threat.

CHALLENGE 2: Understanding threats and how to manage them

- *YCA and rats – Control, eradicate or leave be? Cost/benefit of each option*
- *What level of threat do rats pose to BTS population?*
- *What level of threat do invertebrates (YCA, huntsman spiders, and wasps) pose to BTS population?*

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[3] Pike, D. A., Pizzatto, L., Pike, B. A., & Shine, R. (2008). Estimating survival rates of uncatchable animals: the myth of high juvenile mortality in reptiles. *Ecology*, *89*(3), 607-611.

- Introduced huntsman spiders have been observed consuming adult blue-tailed skinks on CKI. This species of huntsman has also been observed on multiple occasions consuming blue-tailed skinks and Lister's geckos in the SRS on CI.
- During the CMR survey on Madar where a recent threat to the survival of the population was detected (October 2022), YCA were found on habitat utilised by skinks and interactions with BTS were observed. Fewer YCA were observed by the end of the CMR survey due to Vanquish Pro spot baiting efforts the day before CMR commenced. The most recent YCA activity monitoring was conducted in September 2022 and had increased in activity since June 2022, suggesting the YCA population was growing. Some injuries such as tail scarring and bruising were observed on the skinks during morphological and health assessments, though for most injuries it is difficult to ascertain the cause. Two skinks displayed a small patch of blue marks on their skin which look much like the markings left on the skink that was attacked and killed by YCA in its container on the day of the release (necropsy later identified necrotic cells at the location of the blue marks). A skink was also photographed by a community member in September 2022 (before CMR took place) with head and tail scarring and bruising.

- PKNP Rangers trapped rats within the CMR survey period (14-20 October 2022) using both cage and snap traps with different lures. Rats were trapped (rather than lethal baited) so stomach contents of the rats could be extracted and examined for traces of reptiles.
  - Rat trapping Madar 5 nights @24 sites (6 sites set for 6 nights) <u>TOTAL 18 rats trapped</u>. 6 rats on the first night, most on the eastern side of the island. 2 rats on the last night around the Pondok.
  - Rat trapping Blan (5 nights) @33 sites <u>TOTAL 1 rat trapped</u>. Only trapped one rat on the first night.
  - The stomach contents of the rats that were captured are currently being investigated for evidence of reptiles using DNA sampling, results should be returned in time for workshop.

CHALLENGE 3: Designing a monitoring plan and success criteria that are aligned.

- Outlining measures of success through re-evaluating current success criteria (i.e., what does success look like and at what timeframe post-release?)
- Setting realistic and measurable objectives for identifying a healthy population, and a population under threat.
- Creating trigger points for appropriate management intervention
- Monitoring techniques – i.e.:
  - how frequent monitoring needs to be to detect changes in population/adequately detect triggers for intervention,
  - what monitoring methods are best to provide reliable data to guide management decisions, that have the least cost on resource allocation yet still addresses the aims and objectives and is measurable against success criteria (cost/benefit).

CHALLENGE 4: Setting future directions and goals.

- Progressing beyond the experimental stage of the introductions
- Long term goals

Additional Information: Appendix

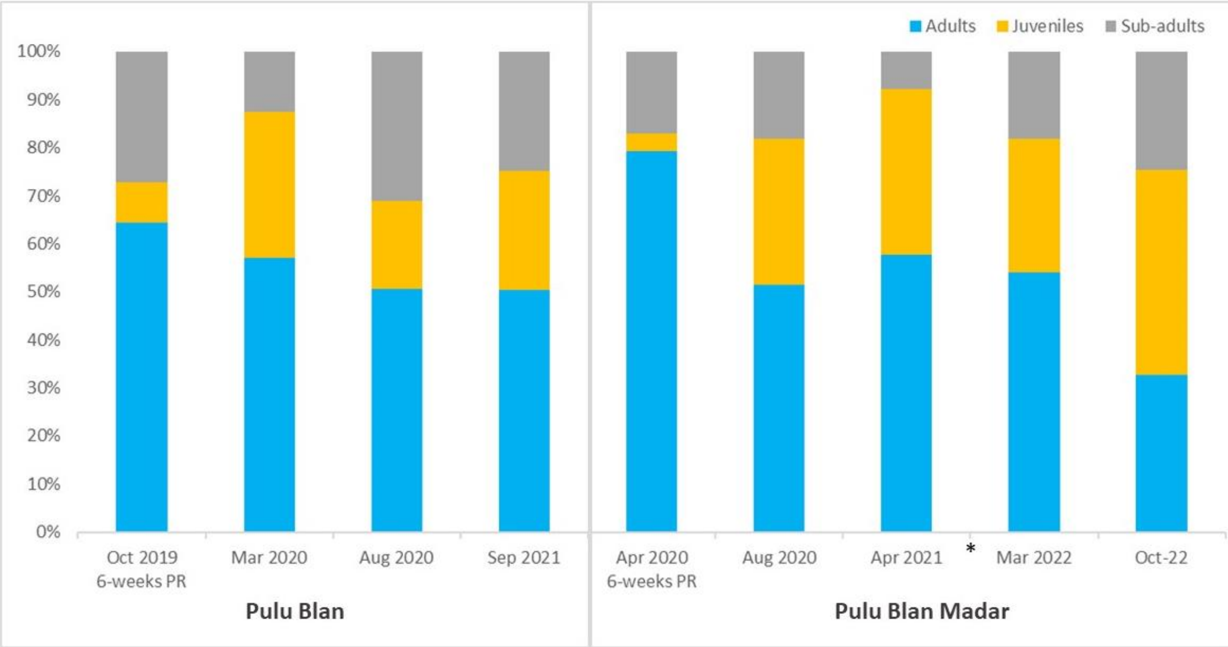


Figure A1. Proportion of adults (SVL >40mm), juveniles (SVL <34mm) and sub-adults (SVL between 34-40mm) captured during each CMR survey on Pulu Blan and Pulu Blan Madar.

**The top up translocation on Pulu Blan Madar between April 2021 and March 2022 (12-24 months post-release) was of all adults and even sex ratios*

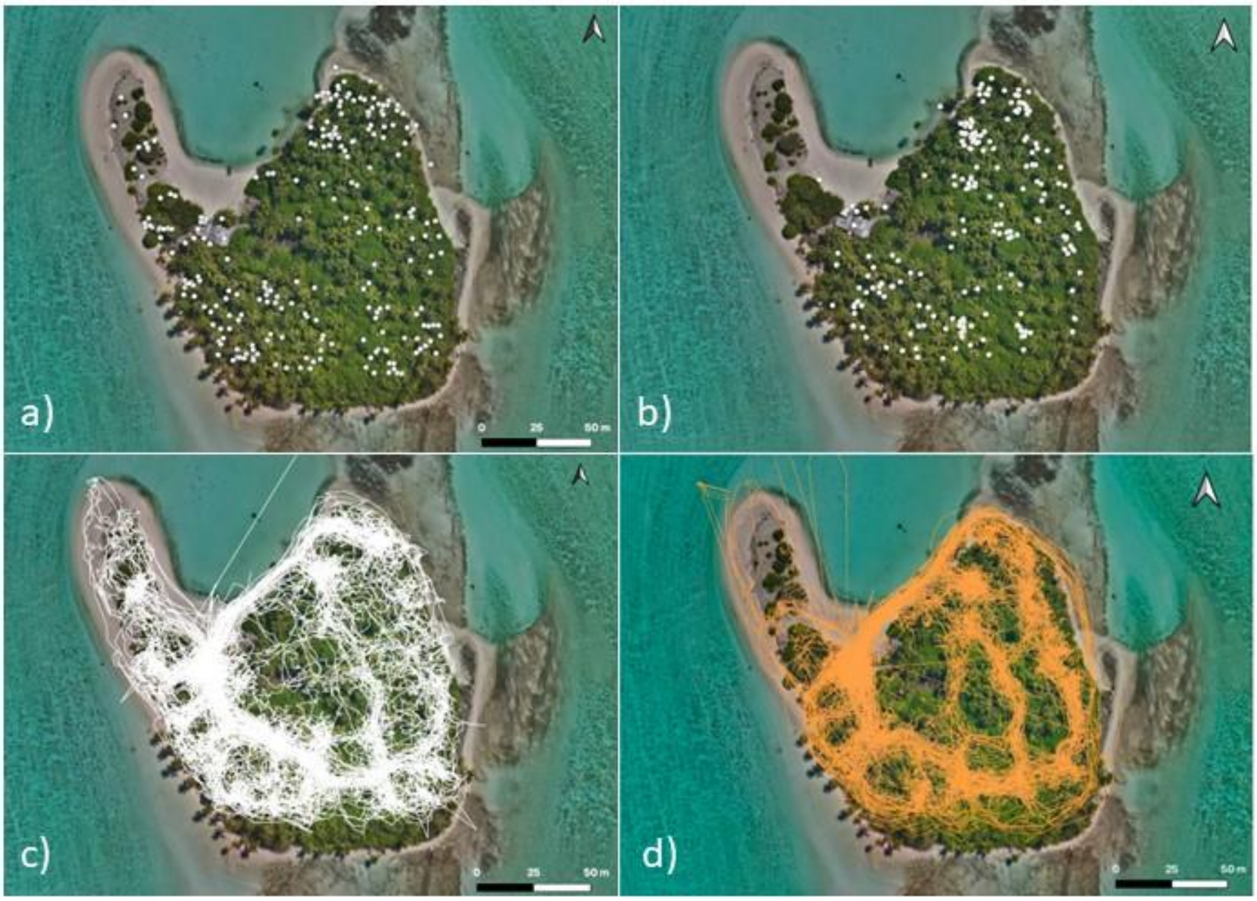


Figure A2. GPS locations of all skink captures during CMR surveying on Madar in March 2022 (a) and October 2022 (b). Tracks from surveyors showing search efforts on Madar in March (c) and October (d). Search efforts between 0800-1200 during CMR surveying over 8 days from two surveyors. Areas on the map that were not searched were impenetrable and are representative of dense habitat or old infrastructure.

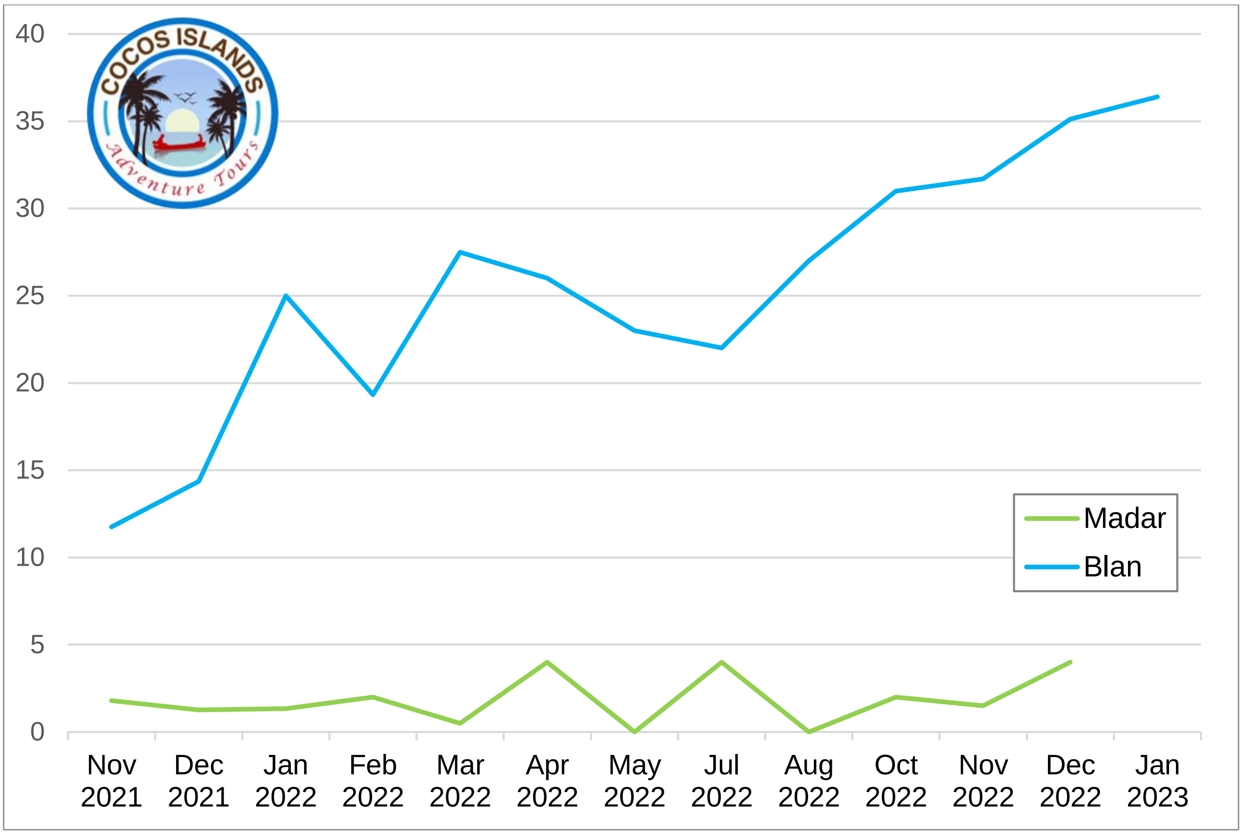


Figure A3. Cocos Adventure Tours Citizen Science Monitoring of islands, point count data.

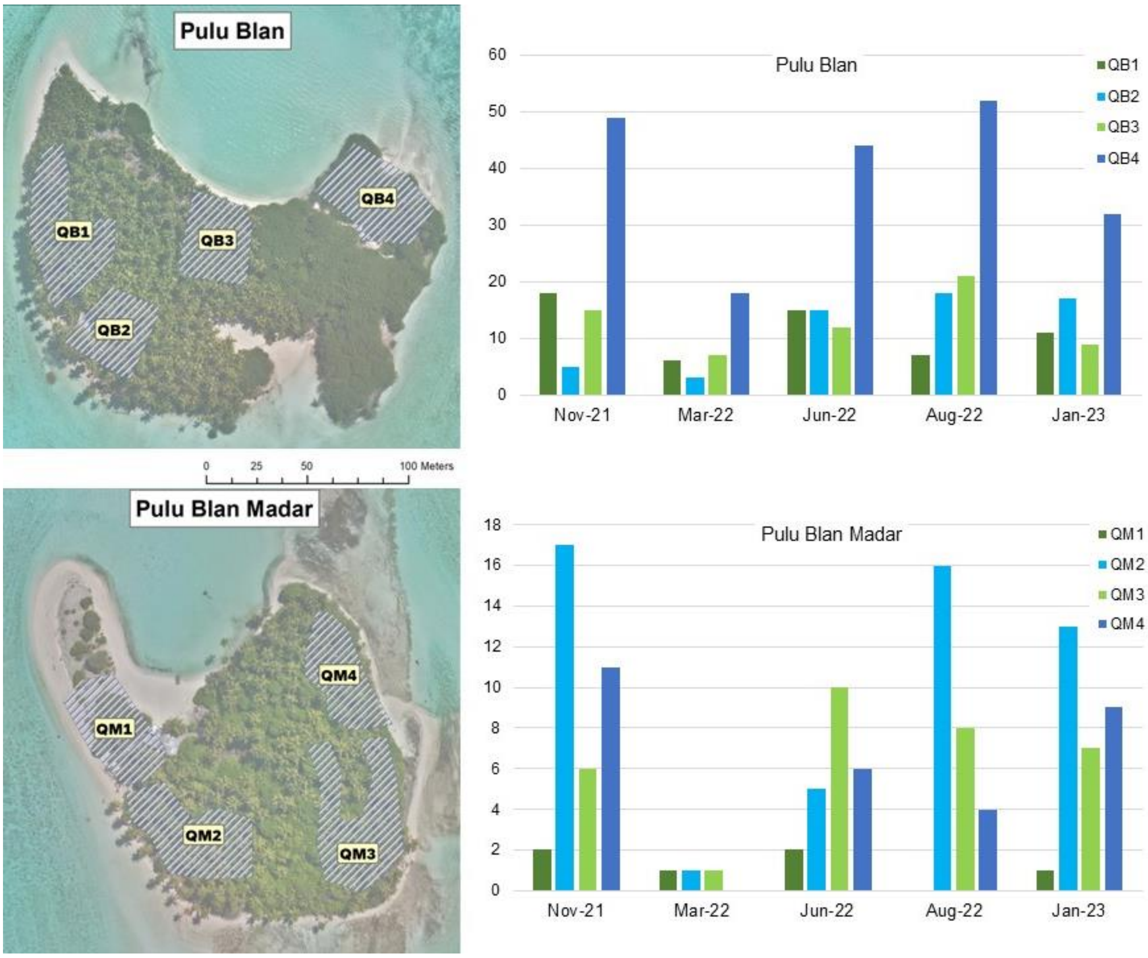
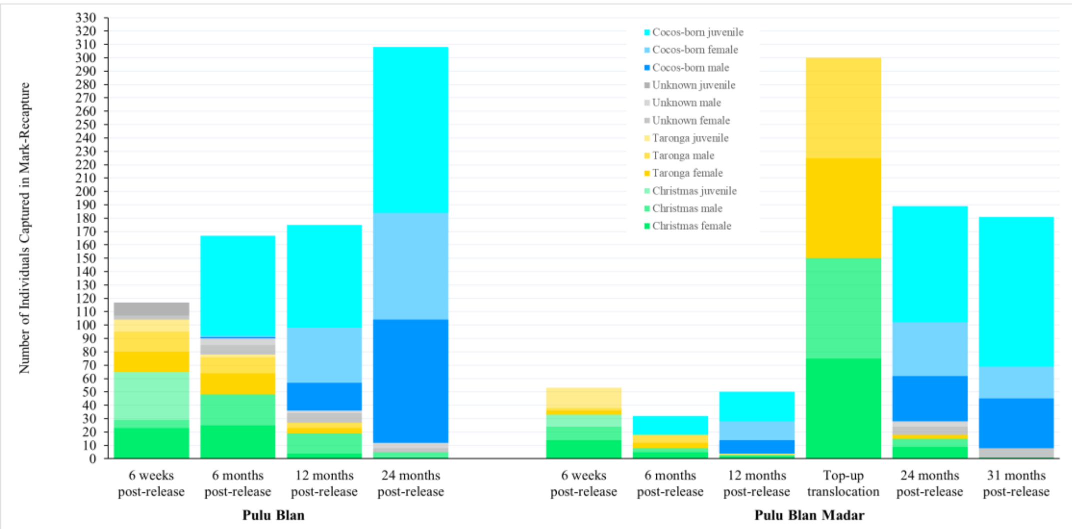


Figure A4. Quadrat monitoring data of BTS counts collected by PKNP.

Table A.1 Summary results of YCA Monitoring on Pulu Blan and Pulu Blan Madar. *March, April and May 2020 YCA counts were taken at 60 survey points per island, whereas the data from Dec 2021 to Jan 2023 were taken at 10 survey points per habitat type (total of 20 survey points on Blan and 30 survey points on Madar). Island-wide baiting was undertaken on Madar in June 2020 and spot baited in October 2022.

MADAR	*Mar-20**	*Apr-20**	*May-20**	Dec-21	Mar-22	Jun-22	Aug-22	Jan-23
Mean	*9.2*	*23.2*	*9.3*	0.1	0.63	0.8	0.56	0
Max	*75*	*126*	*33*	1	10	6	8	0
St err	*1.76*	*3.3*	*1.09*	0.05	0.36	0.29	0.27	0
Sum	*513*	*1311*	*559*	3	19	24	17	0
No. near	*NA*	*NA*	*NA*	14	8	11	17	3

BLAN	*Mar-20**	*Apr-20**	*May-20**	Nov-21	Mar-22	Jun-22	Aug-22	Jan-23
Mean	*0.6*	*1.6*	*0.6*	0	0.45	3.25	0.7	1.85
Max	*5*	*24*	*5*	0	5	**43**	4	11
St err	*0.13*	*0.5*	*0.13*	0	0.27	2.14	0.24	0.55
Sum	*39*	*111*	*38*	0	9	65	14	37
No. near	*NA*	*NA*	*NA*	0	4	5	15	19



CPSG Christmas Island Lizards Conservation Planning Workshop Briefing Paper: Overview of Program Timeline

2008

- Christmas Island Surveys – 18-day island wide survey to replicate BMP & Cogger /Sadlier as well as targeting unsurveyed areas with suitable habitat, North West Point, South Point and Egeria.

2009

- Christmas Island Surveys - Island-wide Survey continuation of qualitative diurnal studies at North-West Point, South Point and Egeria. Opportunistic surveys conducted at Egeria and North-west Point
- July/Sept – 44 Blue-tailed skinks *Cryptoblephars egeriae* (BTS) brought in from the wild into captivity.
- Sept – 2 Christmas Island Forest Skink *Emoia nativitatis* (FS) brought in from the wild into captivity.
- Nov – Lister's geckos *Lepidodactylus listeri* (LG*)* was rediscovered at the location of BTS collection after an absence of records for over 20 years
- Nov (to early 2010) – 8 *LG* brought in from the wild into captivity.

2010

- Christmas Island Surveys - intensive year-long survey at Egeria with opportunistic surveys elsewhere and capture efforts for BTS, FS and LG.
- Jan – 1 FS brought in from the wild into captivity.
- March – 1 FS brought in from the wild into captivity.
- May /June – 21 BTS brought in from the wild into captivity.
- June/July – 35 LG brought in from the wild into captivity.
- August – Last confirmed wild sighting of BTS.
- August - Last confirmed wild sighting of FS.

2011

- Christmas Island Survey – Island-wide opportunistic surveys conducted at Egeria, North West Point and sites with likely habitat/historical sightings
- Nov – 1 LG brought in from the wild into captivity.
- May - 8 BTS and 5 LG MAI groups established. Groups were formed based the on the capture location and known captive breeding history of individuals.

- May – The CI populations were split into two colonies with one colony remaining on Christmas Island and the other transported to Taronga Zoo, Sydney.
- 6 May - 45 BTS received at Taronga Zoo to form an insurance breeding population.
- 10 June - 27 BTS received at Taronga Zoo to become a part of the insurance breeding population.
- 10 June – 40 LG received at Taronga Zoo to form an insurance breeding population.
- Dec - the captive population size of both BTS and LG had almost doubled in size.
- June - Captive Husbandry and Genetic Management Plan by Peter S. Harlow, Michael McFadden & Paul Andrew produced.
- 5 Aug - Christmas Island Reptile Advisory Panel (CIRAP) established by Director of National Parks (DNP) and first meeting convened.
- 11 November - 11 BTS received at Taronga to become a part of the insurance breeding population.
- 11 November – 12 LG received at Taronga to become a part of the insurance breeding population.

2012

- Christmas Island Survey - Opportunistic surveys conducted at Egeria, North West Point and sites with likely habitat/historical sightings in May.
- Christmas Island Survey - 14-day Intensive dry season survey in October at sites with recent sighting history and likely habitat including camping efforts at Egeria and South Point
- April – Successful sexing of BTS by hemipenes inversion at Taronga Zoo.
- April - Collecting individual data ceased on Christmas Island for both species.
- June – Initial steps to assessment to determine feasibility for introducing BTS and LG to the islands of Cocos Keeling.
- Sept/Oct – Outdoor exclosures for BTS were trialled, starting with males only.
- Oct – Last confirmed wild sighting of LG at 2 sites Egeria Point & North West Point.

2013

- Christmas Island Survey - Intensive wet season survey at sites with recent sighting history and likely habitat. Island-wide Survey
- Jan – Taronga 8 BTS colonies were combined to 4.
- March – Christmas Island BTS and LG Census completed
- June - Christmas Island Blue-tailed Skink and Lister’s Gecko: captive program review and recommendations for 2013 by Peter Harlow, Paul Andrew and Caroline Lees produced.
- Aug – Cocos Island feasibility scope developed.
- Aug – Capacity was reached for BTS on Christmas Island, 4 populations were at capacity with 70 individuals each, so overflow enclosures were created.
- Aug – 5 exclosures ready on Christmas Island, to where excess BTS males and juveniles were released.

- Dec – Opening of the new Reptile House on Christmas Island.

2014

- March - Confirmation received that four of the five CI reptiles Commonwealth threatened species listings to be upgraded in March 2014 accepted. The Coastal skink (*E. atrocostata*) was not listed.
- March – Taronga Zoo BTS colonies 1, 2, 3 & 4 combined to form New A & New B colonies and males were no longer housed with females due to risk of female mortality, males were cycled through.
- April – Christmas Island LG and BTS Census completed
- April – Taronga Zoo BTS and LG eggs divided between 2 incubators one a Perspex made box maintained at room temperature and the other a Thermoline Incubator set to 26 degrees), to assess whether sex is temperature-determined during incubation. It was determined they are not.
- May – Gump the last FS dies in captivity.
- July – Media release for the FS
- Oct – First cases of bacteria found in 2 LG on Christmas Island.
- Oct– Christmas Island LG and BTS Census completed
- Oct - The Reptile Conservation Plan 2014-2024 was produced.

2015

- Oct – Christmas Island Census completed.
- Oct - the first two trial LG exclosure tents were initiated on Christmas Island. 127 LGs transferred to exclosure tents.

2016

- March - MAI population collapse occurred on Christmas Island for BTS collapsing four populations into two.
- June - First positive BTS infection of Enterococcus found.
- A Proposal for Predator Proof Reptile Containment Areas in Christmas Island National Park put together
- September MAI population collapse occurred on Christmas Island for LG was successfully completed during the biannual census. This involved collapsing four populations into two MAI groups.
- Sept – Christmas Island Census completed.
- Dec – Construction of new facility on Christmas Island to house BTS completed.
- Dec – Second quarantine room opened at Taronga Zoo, to allow for the increase in population numbers for both species.

2017

- April - 139 BTS were released into the soft-release site (SRS).
- July – it was identified that apparent population decline appeared to be occurring at the SRS site. In the weeks following this decline continued and the last BTS was seen at the SRS on the 7th of September. At least one animal persisted for up to two weeks after this based on prints found on ink cards at the site.
- Oct – Christmas Island BTS and LG Census completed.
- Dec- The new exclosure facility on Christmas Island was completed and officially handed over.

2018

- June – Egg management for both BTS and LG approved and commenced at both facilities.
- August 7th-9th - 170 blue-tailed skinks were released in the second trial reintroduction into the soft release site on Christmas Island
- September - 11th - 15th First Mark and Recapture of SRS.
- Oct – Results of nutritional analysis on feeder insects received, this looked at samples of species fed out on Christmas Island and Taronga Zoo to compare the nutritional data.
- Nov - DNP Executive Project Board approved the Blue-tailed skink conservation introduction project for the assisted introduction of Blue-tailed skinks to the Cocos (Keeling) Islands.

2019

- Jan - release of 160 LG into the SRS site at Circuits Track.
- Jan – Rats were eradicated from both Pulu Blan and Pulu Blan Madar.
- Feb - all approvals with the exception of the import permit were completed and confirmed that there were no other administrative requirements for Cocos (Keeling) Islands release of BTS onto Pulu Blan.
- Feb – Christmas Island BTS and LG Census completed.
- Feb - outbreak of the Enterococcus bacteria in a male-only exclosure.
- Ongoing – experiment to rule out parthenogenesis in LG at Taronga Zoo: 3 x 2-year old females housed together from hatchling stage, never being paired with males. They only laid infertile eggs. *Parthenogenesis doesn't appear to occur in this species.*
- Sept - Initial assisted colonisation trial of 300 blue-tailed skinks on to Pulu Blan, 150 from Taronga and 150 from Christmas Island of mixed age and sex.
- Oct - At six-weeks post-release on Pulu Blan, population estimates were obtained through mark-recapture.

2020

- Feb - The final Christmas Island MAI population collapse into a single population was completed for BTS.
- March - A second translocation of an additional 300 BTS took place on Pulu Blan Madar, 150 from Christmas Island and 150 from Taronga Zoo.
- April - At six-weeks post-release on Pulu Blan Madar and six-months post release on Pulu Blan, population estimates were obtained through mark-recapture.
- May - 200 LG from the captive population were placed in two tents for two weeks at the second SRS site EW base line and then tents opened and released Friday 8th.
- May - 200 BTS were harvested from the captive population and released at the second release site. E W Baseline site on Tuesday 12th.
- July - The final Christmas Island MAI population collapse into a single population was completed for *LG*.
- Sept - At six-months post-release on Pulu Blan Madar, and 12-months post-release on Pulu Blan, population estimates were obtained through mark-recapture.

2021

- March - FS (FS) EPBC listing changed from 'Critically Endangered' to 'Extinct'.
- April - Just after 12-months post-release on Pulu Blan Madar, population estimates were obtained through mark-recapture.
- April – 173 BTS were removed from the Circuits Track SRS site after noticing a sharp decline in population, also two LG were removed. Wolf snakes later found in site.
- June - Top-up translocation of 250 BTS (125 from each captive colony) to Pulu Blan Madar.
- June - 40 LG from Taronga Zoo were reincorporated to the captive colony on Christmas Island during the June 4 translocation to Cocos. (keeling) Islands, they are kept as four separate MAI Taronga Zoo populations.
- June – Taronga Zoo started to cross pair BTS within the A & B colonies.
- August – Christmas Island BTS and LG Census completed.
- September: at 2 years post-release on Pulu Blan, population estimates obtained through mark-recapture.

2022

- Jan - DNA and RNA extraction for genome sequencing of both BTS and LG, Taronga Zoo animals were used.
- March – 9 months after top up release on Pulu Blan Madar, population estimates obtained through mark-recapture
- May - Enterococcus outbreak confirmed in one of two BTS bachelor exclosures.
- August: Enterococcus outbreak confirmed in a mixed sex BTS exclosure.
- September: Enterococcus outbreak found in a further 3 mixed-sex BTS exclosures
- September – CPSG Christmas Island workshop planning is under way.
- Sept-Oct – Continued rebuild of the fence at the Circuits Track SRS site.

- Oct - Draft paper Reference genomes of two extinct-in-the-wild reptiles from Christmas Island reveal distinct evolutionary histories and conservation insights is submitted by Tristram Dodge.
- Oct - 150 LG introduced to Circuits SRS in penned release (closed tents)
- Oct - Pulu Blan Madar, population estimates obtained through mark-recapture (potential threat identified)

2023

- Jan – EW baseline SRS has declined, no more BTS were detected.
- Feb – 163 BTS are released into the Circuits Track SRS site and opening of LG tents.
- Feb – 52 BTS hard released onto Christmas Island.
- March - population estimates obtained through mark-recapture for both Pulu Blan and Pulu Blan Madar

CPSG Christmas Island Lizards Conservation Planning Workshop:
Glossary of Terms & Acronyms

		Acronym
Species	Blue-tailed skink *(Cryptoblepharus egeriae)*	BTS
	Lister's gecko (*Lepidodactylus listeri*)	LG
	Mourning gecko (*Lepidodactylus lugubris*)	MG
	Wolf snake (*Lycodon capucinus*)	WS
	Giant centipede… (*Scolopendra subspinipes*)	GC
	Yellow crazy ants (*Anoplolepis gracilipes*)	YCA
	Black rat (*Rattus rattus*)	Rat
Places	Christmas Island	CI
	Cocos Keeling Islands	CKI
	Pulu Blan Madar *(Cocos Keeling Islands)*	Madar
	Pulu Blan *(Cocos Keeling Islands)*	Blan
	Pulu Luar *(Cocos Keeling Islands)*	Horsburgh
	Soft-release site *Small, predator-proof, fenced area on Christmas Island containing BTS &/or LG*	SRS
	Christmas Island Minesite to Forest Rehabilitation Program	CIMFR
	1st SRS, located in CIMFR field 22C, near the circuit tracks	SRS Circuits/22C
	2nd SRS, located in CIMFR field 21C, near East-West baseline	SRS EWB/21C
	Taronga Zoo	TZ
Monitoring/ Management	CMR	Capture Mark Recapture
	MK	Mean kinship breeding strategy
	MAI	Maximum Avoidance of Inbreeding breeding strategy.
	WC	Wild Caught
	CB	Captive Born