

ASIAN TOAD ERADICATION FEASIBILITY
REPORT FOR MADAGASCAR



Fig. 1a. *Duttaphrynus melanostictus*, Asian toad. Female, Tamatave Madagascar. Photo J. Reardon.

Pete McClelland, James T. Reardon, Fred Kraus, Christopher J. Raxworthy and
Christian Randrianantoandro

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Corresponding author: *jreardon@doc.govt.nz*

FOREWORD

It is important to recall that Madagascar is a country of exceptional biodiversity worldwide. For example, among the 300 species of amphibians reported, the rate of endemism is nearly 100%. The recent incursion of the invasive Asian toad constitutes a direct threat to this unique biodiversity but also to human health and the country's economy. We suspect the toads impact may be comparable to the Cane toad in Australia; we must act swiftly to prevent a similar disaster unfolding in Madagascar.

The publication of this report is being enthusiastically awaited by the scientific community and conservation, organizations as well as government authorities in Madagascar. In order to ensure the success of this eradication feasibility report, recommendations require the support and commitment of all stakeholders; any delay in decision might lessen our capacity to resolve this urgent issue.

The present report are results of work carried out by eradication, invasive species and herpetology experts: Pete McClelland, James T. Reardon, Fred Kraus and Christopher J. Raxworthy. National and local authorities, Malagasy scientists and non-governmental organizations have contributed immeasurably to the eradication plan.

The plan includes current knowledge of the Asian toad situation in Madagascar, next steps and discussion of available options. Critically, the eradication feasibility criterion of possible corrective measures is given careful consideration against the facts. It is important to emphasize capacity-building activities and testing of eradication methods (which has never before been attempted) before a large programme of this sort can effectively commence and be successful.

Dissemination of this report is essential for all stakeholders working in the fields of conservation, resource management, human health, import and export trade and economic policy. The Malagasy government authorities and various entities should be well recognized for helping make possible its completion.

CHRISTIAN RANDRIANANTOANDRO
NATIONAL COORDINATOR
EMERGENCY CELL AGAINST THE ASIAN TOAD INVASION
MADAGASCAR

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EXECUTIVE SUMMARY

An eradication of an amphibian species has never been achieved on the scale being considered here and the Asian toad incursion in Madagascar presents a plethora of logistical challenges.

However, there has been no systematic testing or development of eradication tools for this species in this environment and so technical feasibility cannot be properly judged until methods are tested. Human health, ecological and economic impacts of disregarding eradication as an option are simply too great for the authors to recommend abandoning eradication under our current state of knowledge. We therefore recommend development of eradication methods proceed in a two-stage process thus evaluating the viability of methodologies before advancing to employing those practices at the landscape scale.

Should the evaluation of eradication methods demonstrate serious failure of multiple methods, seriously threatening the likelihood of success of an eradication attempt, we recommend eradication efforts be abandoned to avoid wasting resources that could be better used toward mitigation measures, species and habitat focused conservation efforts and public health education programmes to ameliorate the damage and impacts of Asian toads in Madagascar. It is important to note that mitigation in the long-term is likely to carry a far higher total cost than eradication in the short term.



Fig. 1b. Asian toad emerging after rain in Kandy, Sri Lanka. *Photo: J. Reardon.*

This report considers the logistics and feasibility of eradicating a population of Asian toads, *Duttaphrynus melanostictus* (Fig. 1.), a non-native invasive species recently established in Madagascar. These considerations are for governance/leadership bodies that must make rapid and decisive decisions which are practical and appropriate given the current state and situation.

Eradication feasibility reports usually state clearly whether an eradication operation should proceed or not. Unfortunately in this case, the issues are complex and so follows the recommendations.

The Current situation as we understand it

Based on the current size of the incursion and observations by locals, Asian toads arrived in Madagascar by at least 2010 and have now spread over an area of approximately 98 km². Given an average approximated density of 400 toads per hectare (based on replicated sampling across stratified habitat types in areas where no previous disturbance of toads is known) it is estimated the current population is estimated at around four million toads. The invasion front of toads appears to be expanding approximately two km per year. Toads currently occupy lowland habitats (both rural and urban) and there are no likely known barriers to their population expansion in Madagascar. These toads are rapid breeders producing up to 40,000 eggs per year, long lived, poisonous to other animals and opportunistic predators devouring anything they can swallow.

What we predict will happen if nothing is done

If these invasive toads are not eradicated, or at least controlled and contained, they will continue to spread over the majority of Madagascar. The presence of these invasive toads is likely to cause major ecological and economic negative impacts with the potential for the major reduction or even total loss of toad prey species, both endemic and unique invertebrate and vertebrate species in Madagascar and thus exacerbating species extinctions. Predatory species that feed on toads will also be impacted and threatened through toad poisoning upon ingestion. Economic impacts include an increase in Black rat (*Rattus rattus*) numbers once predator populations are reduced by toad poisoning, leading to increased loss of stored food supplies and damage to commercial goods and equipment. An increase in rat numbers will have human health ramifications through rat borne diseases elevating the incidence of plague already present in the incursion area. Economic costs will be incurred through impacts to the export industry where biosecurity concerns increase freight handling times and costs or becoming barriers to export.

The toads undermine Madagascar's environmental tourism sector—an industry which has huge value to the nation, now and in the future. Critically the Asian toad is a risk to human health of Malagasy citizens where frogs are a common part of the diet. Asian toads have proved to be lethally toxic to human in South East Asia (Chi et al. 1998).

There are four basic strategic options for dealing with the issue:

1. Do nothing and accept these toads will become a permanent part of Madagascar's biodiversity with the consequential environmental, economic and human health impacts.
2. Undertake sustained control of toad populations in priority sites which may protect high priority species, or sites, but (this will have an ongoing financial cost in perpetuity) and

accept any environmental, economic and human health impacts across most of the country.

3. Contain the spread of toads to their current distribution, if this is possible given the range of habitats they presently inhabit and the uncertainty of detecting and removing toads at low numbers.
4. Completely eradicate these toads from Madagascar. This would eliminate all possible ecological, economic and social impacts the toads may have on Madagascar; with no long-term cost implications other than on-going biodiversity improvements—which are presumed a prerequisite for all options.

Pros and cons of options

While eradication is the most financially expensive option in the short term, benefits of permanently removing all toads and thus their impact and associated risk far outweigh the benefits of sustained control. Control programmes require commitment in perpetuity since any benefit(s) would be lost shortly after the programme was discontinued. Control programmes quickly become more expensive than eradication, thus complete elimination out-ranks opposing control methods.

Eradication, along with high intensity control, requires the development/confirmation of techniques to detect toads at low density and efficiently remove toads at all densities.

Recommended strategic option (eradication)

We recommend an attempt be made to completely eradicate toads from Madagascar. This strategic option offers the best solution in the long-term but will have the disadvantage of high short-term cost. An eradication plan should be implemented under consistent review as new methodologies are tested and logistical methods of elimination are further established.

What is required to achieve eradication?

To eradicate these toads from Madagascar will require detection methods which will be sensitive to every individual animal, across the entire incursion area. Toad capture/removal methods must remove toads from the population faster than they breed and recruit. Finally, a critical factor for success is to ensure no further Asian toads are brought into the country.

There are a number of potential removal methods which will require further testing and trials to determine what combination of eradication techniques work best under Madagascar conditions. Trials will be required to determine what level of effort will be prescribed to deploy the determined methods across the landscape predicted to be infested by the time the project becomes operational.

With so many unknowns at this stage, particularly the choice of detection and removal techniques to be successfully used in eradication, it is difficult to estimate the final cost and that eradication is possible. Our best cost estimate produces a cost of between US\$2 million and US\$10 million, but this figure can be further refined through the process recommended below.

To undertake eradication requires:

- Establishment of a governance and leadership body.

- Installation of a suitable management and administration structure.
- Confirmation of finances—initially for trials followed by developed eradication operations should trials offer feasible eradication options.
- Establishment of adequate biosecurity measures to prevent human assisted spread of toads into, out of and within Madagascar; to prevent the introduction of additional invasive species, and if the eradication is successful, to prevent the reintroduction of toads back into Madagascar.
- Educational programmes established to inform residents of the impacts and risks posed by toads, the techniques to be used for eradication, how to assist with the eradication and helping identify the scale of the incursion and determining any possible satellite populations which could exist outside the incursion area.
- Map habitats, the extent of the incursion, and any potential barriers to toad movement.
- Develop a density estimation for toads across various habitats to inform the strategic deployment of toad elimination methods.
- Develop/confirm humane euthanasia techniques.
- Develop/confirm sensitivity of detection techniques including acoustic detection, tracking tunnels and environmental DNA.
- Confirmation of detection and removal techniques including hand removal; barrier fencing and pitfall traps; citric acid/sucrose spray; acoustic location; tadpole traps; herbicide; egg collection; refuse management; toad detector dogs; capping or treatment of water bodies and toad traps. These potential methods of detection and eradication will require initial trials to confirm their efficacy for use in an Asian toad eradication programme.

Regardless of whether the eradication proceeds or not, it is recommended that biosecurity measures are put in place to prevent further incursions and a public awareness programme established to educate Madagascan residents about the toads, their negative environmental influence and associated health risks to humans (toad poisoning is known to be fatal but nevertheless associated sicknesses are extremely unpleasant and costly if hospitalized).

How to proceed:

Decide on strategic option(s) – if eradication is decided:

1. Identify participating agencies and institute project.
2. Secure phase one funding: test eradication methods and evaluate operation.
3. Initiate required biosecurity and education programs.
4. Carry out the prescribed experimental trials for evaluation of eradication methods.
5. Reassess feasibility and costs.
6. Secure phase two funding to execute approved eradication programme.
7. Create a comprehensive plan covering all aspects of proposal and approved working plan: project governance and decision making; methods and priorities for removal; public engagement; research and adaptive management; procurement and recruitment; training and development.

1 INTRODUCTION

This document considers the feasibility of eradicating a recently established population of Asian toads (*Duttaphrynus melanostictus*) from Madagascar.

To be successful an eradication program must meet seven essential criteria:

- **Technical feasibility:** Technique(s) to be used at the project site are able to remove all individuals of the target population(s).
- **Sustainability:** Preventing re-invasion by target species can be achieved.
- **Socially acceptable:** The project has full support from the community and other key stakeholders.
- **Politically and legally acceptable:** All required permits and consents secured.
- **Environmentally acceptable:** Environmental impacts of the eradication are manageable and acceptable.
- **Capacity:** All determined skills, resources and equipment can be acquired.
- **Affordability:** The required funding is available and secured.

To achieve eradication you need to be able kill the target species faster than it can breed at all densities. To be able to achieve this requires the ability to detect them at low densities in all habitats.

This report considers the current invasive Asian toad situation in Madagascar, as of June 2015, against these stated criteria listed. Its aim is to state what is needed in order to achieve eradication, what limitations stand in the way of that objective, and what needs to be done to surmount those limitations.

The concepts and practice of species eradication can be complex. It is critical that readers of this report are familiar with the basic conceptual differences between “pest control” and “pest eradication,” as these two objectives have very different goals requiring equally different strategic approaches (Table 1.). There is growing data supporting the present thinking in this report but many of the fundamentals of eradication have been well understood for more than two decades (Bomford and O’Brian 1995).

Table 1. Comparison of eradication versus ongoing control.

	<i>CONTROL</i>	<i>ERADICATION</i>
<i>Project target</i>	<i>To maintain target species population to an agreed level where impacts are tolerable.</i>	<i>To eliminate the target species entirely, therefore requiring no ongoing management except for external biosecurity at the border.</i>
<i>Strategy & tactics</i>	<i>Focus on sites of highest value or where benefits of control exceed costs of control. Focus on sustainability of action—socially, financially and technically. Monitor benefits, costs and impacts.</i>	<i>Prevent spread, target every individual, and prevent reinvasion. Focus on meeting eradication criteria through skilled deployment and adaptation of methods and appropriate scale of effort.</i>
<i>Ongoing impacts</i>	<i>Impacts on non-target species and humans will be ongoing relative to the agreed level of control. A very high level of control is required to gain a meaningful level of benefit.</i>	<i>Nonexistent – once toads are removed there are no ongoing impacts.</i>
<i>Biosecurity</i>	<i>Internal biosecurity still required to prevent the expansion of the incursion area.</i>	<i>External biosecurity required; (which would cover many species) to prevent reinvasion.</i>
<i>Risks</i>	<i>Control for the Asian toad is unlikely to be possible on a large scale meaning limited high value site or species lead protection is likely. If for any reason funding or support ceases control will stop and benefits rapidly lost. Ongoing risk of expansion of incursion area increasing the costs of a control programme or making it unfeasible.</i>	<i>There is an inherent risk of failure in any eradication. Hence it is important to adequately test the proposed techniques before committing to any eradication programme. Inadequate funding means that the project could not be fully implemented and therefore is very likely to fail. Failure to adequately improve border biosecurity might mean risk of reinvasion.</i>
<i>Financial Cost</i> <i>Note: actual costs for both control and eradication can only be calculated once techniques and scale of control are agreed upon.</i>	<i>Initially lower than eradication but ongoing in perpetuity so total cost likely to soon exceed eradication costs. This strategy makes on-going, albeit reduced economic and social impacts inevitable.</i>	<i>Initially, large one-time cost but if eradication successful, no continued large costs except biosecurity; long-term economic and social costs of pest species are ameliorated.</i>
<i>Benefits</i>	<i>Reduced initial costs (but vary greatly over time).</i>	<i>Target species removed, no ongoing costs except biosecurity; no ongoing impacts.</i>

Further, differences between pest control and pest eradication it is important to acknowledge the different cost models. Pest control focuses on identifying cost effective control methods capable of

targeting the largest proportion of the pest population(s). In contrast, eradication begins with tools that target the majority of the population in the most cost effective manner not compromising the efficacy of subsequent methods and usually reserves the most sensitive tools for targeting hard to capture individuals that remain. **As such, the cost profile of multi-method eradications are one where the cost of removing the initial majority is equal to or less than the cost of removing the final few individuals.**

The Asian toad, *Duttaphrynus melanostictus* (also known as the Asian common toad, Black-spectacled toad, Asian black-spotted toad, Common sunda toad, and Javanese toad, Fig. 1a, 1b and 1c) is widespread throughout Asia, occurring from Pakistan through central Asia and across southern China, including Taiwan, extending across South Asia, covering Sri Lanka, the Malay Archipelago and Indonesia incorporating the island of Borneo and associated island groups. Across this range the species is known to occur from sea level to 1,800 m and is generally associated with disturbed and agricultural habitats (van Dijk et al. 2004). Asian toads do occur in undisturbed habitats, including rainforest (southern Sri Lanka, eastern central Thailand, Sabah, Northern Borneo, Reardon, pers. obs.), but apparently at low densities. The species is listed as “Least Concern” under the IUCN Red List of Threatened Species. The Queensland State Government (Australia) lists the Asian toad as a significant pest in their pest risk assessment (Pest animal risk assessment 2010).

Asian toads are an introduced species in a number of countries, including western regions of New Guinea and the Indonesian islands of Bali, Sulawesi, Timor and Ambon but no investment has been made to measure their impacts. Across its range the species appears to be regarded as benign, although it has been noted as a nuisance in Sri Lanka because of its abundance in water tanks used for laundry and cooking water in villages.

The Asian toad females can reach 200 mm in snout-to-vent length with typical dry warty skin and is a crepuscular predator of invertebrates and small vertebrates captured largely by ambush predation.

Asian toad reproduction begin by males calling to attract females from in or around breeding pools where toads later engage in amplexus and end in production of strings of eggs layed by the female. Females are able to produce many thousands of eggs per season, which hatch into tadpoles metamorphosing into toadlets the same season.

The Asian Toad in Madagascar

The Asian toad was anecdotally noted in Madagascar as early as 2010 (Moore et al. 2015) but not reported until 2014 (Arnaud 2014). How the original founder animals got to Madagascar has not yet been confirmed, however their pathway was almost certainly via freight and/or containers brought to the site of the incursion from South East Asia. The Malagasy population of *D. melanostictus* was studied from a fragment of mitochondrial ND3 gene, based on 11 specimens provided by R.D. Randrianiaina, two specimens provided by R. Dolch and F. Glaw and one specimen provided by A.P. Raselimanana. All specimens had an identical haplotype, suggesting an origin from the same source population (M. Vences, unpub. data). Phylogenetically, compared to a range-wide data set, this haplotype belongs to a lineage occurring in China, Vietnam, Thailand and Cambodia, and the haplotype is identical to one found in Cambodia likely to be representative of Asian toad populations from Thailand, Cambodia and Vietnam (G. Wogan and B. Stuart, pers. comm.)—this strongly suggests an introduction originating from this geographical region. Research is on-going into the flow of materials via freight from South East Asia into the area of the Madagascan incursion of Asian toads. Multiply companies import shipping containers into the region making it difficult to pinpoint the exact origin of introduction. It is noteworthy that the incursion does not appear to extend to the Tamatave port though not having direct access to this port has not allowed us to verify this information.

From our visit it appears there are negligible biosecurity measures in place at either the port of Tamatave or at the Ambatovy mine. While we did not inspect any other major businesses in the region it is likely lack of biosecurity measures is widespread among the business community. Future invasions are possible without improved biosecurity measures in place.

We have been able to identify a number of importer facilities within the incursion area, all of which have, in theory, the potential to have brought the toads to Madagascar from South East Asia. Towards the core of the incursion area are:

1. Malgapro – Importer of products such as rice, sugar and oil from China, Dubai, India and Pakistan.
2. Ambatovy – The Ambatovy plant site was constructed with considerable assistance from the Sriracha Construction Public Company, based in Thailand and working with the Ambatovy project since 2008. It is likely that during plant construction, considerable quantities of materials, supplies and equipment were shipped from Thailand by Sriracha Construction (http://www.sricha.com/eng/current_projects.html).
3. COLAS – Construction, involved in Importation of unspecified goods/materials.

Towards the periphery of the incursion is located:

4. SolCiment Callidu – Importers of unspecified goods/materials.

Further research is necessary to investigate the timing and quantities of freight imported by these companies and the geographic origins of freight shipments. With these data, it may be possible to identify the most likely pathway of invasion. Identifying this pathway is a vital element of learning and ensuring biosecurity measures are appropriately improved to prevent reinvasion.

There is little information available on the specific likely impacts of the toads on the ecology of Madagascar. However, there is a significant literature describing the effects of the Cane toad, *Rhinella marina*, (Fig. 2.) as it has spread across Australia (Burnett 1997). Due to the general ecological similarity between the two toads, both having cosmopolitan diets and habitat requirements, it is reasonable to anticipate similar ecological impacts from the Asian toad invasion in Madagascar. Like the Cane toad, the Asian toad is potentially poisonous to naive predators and is likely to negatively impact many native and endemic predators, including snakes and mammals. Madagascar has no native toads but does have a globally significant, rich and vulnerable endemic herpetofauna. Research and climate modelling has investigated the potential ecological reach of the Asian toad in Madagascar and a recent publication illustrates that the Asian toad has the potential to establish across the majority of the country (Pearson 2015).

A high profile concern for the Asian toad incursion in Madagascar is the potential for lethal poisoning from the consumption of toads and toad tissue by humans. This along with other details of the toads potential impacts are given a more detailed description in section 3.3 but it should be clearly noted that multiple cases of poisoning, including deaths in children are reported from Laos, which is within the Asian toads natural range, and within communities with a high level of awareness of the toxicity of Asian toads (Keomany et al. 2007).

It is too early to predict what form the economic consequences of the Asian toad in Madagascar will take but they may include negative impacts on agriculture, tourism (through loss of biodiversity) and World Trade Organisation restrictions on exports from Madagascar due to the risk of transporting toads to new locations. Such sanctions are a possibility if the Asian toad is deemed to be an ecological and economic threat to trade partners as a result of its impacts in Madagascar.

Soon after the identification of the toads in Tamatave their potential ecological impact was recognised by scientists and the desirability of eradicating them promoted by the Malagasy government, non governmental agencies (NGO) and individuals. International experts worked with NGO's, including the Madagascar Fauna and Flora Group and Association Mitsinjo and the Madagascar Government to gather support for an Asian toad eradication programme and seek funding for a formal study of its feasibility.

The Asian toad incursion has raised serious concerns among the conservation community. Not only are direct impacts on native biodiversity feared but there is concern the toad might vector amphibian diseases such as *Ranavirus*. However, the science community actively engaged with amphibian issues in Madagascar lack experience and skills in pest eradication. As such, three of the authors, who have research and applied experience in pest-animal eradication were contacted and requested to lead the study. Mr. Peter McClelland has extensive expertise and experience in eradications globally, including New Zealand, Australia, the USA and the Pacific. Although primarily having worked on rodents, the operational parameters and processes for eradication programs apply across taxa. Doctor James Reardon is a herpetologist with operational experience in eradication programmes targeting reptiles and amphibians. He is currently working on two invasive herpetofaunal eradication programmes in New Zealand. It was decided that in combination they provided the required expertise on amphibian specific approaches to eradication and its requirements. The feasibility study is also supported by Dr. Fred Kraus, who is a global authority on invasive herpetofauna, and was the instigator of the eradication feasibility study. Our team includes Dr. Christopher Raxworthy, who first identified this species of invasive toad in Madagascar, and who has 30 years of herpetological experience working in Madagascar, and Christian Randrianantoandro, who is an experienced herpetologist in Madagascar, and has been designated the interim national coordinator for toad eradication efforts.

Local population perspectives

During the feasibility report field visit the authors made an effort to gather opinions and information on the Asian toad from members of local communities within the incursion area. Little additional knowledge was gathered beyond that of Moore et al. (2015). There was a common opinion in Tamatave/Toamasina among local communities surveyed that the toads arrived with the establishment of nickel-mining and processing facilities. In this area the toads were referred to as the 'Dynatec' toad, Ambatovy's predecessor. No evidence was presented for this belief other than apparent timing of the toads first detection, which occurred at the same time the plant site was being constructed.

The authors are aware of recent reports of a "spiny toad" likened to the Asian toad known in Toamasina, being reported from Mahanoro, less than 200 km to the south of the current incursion. The report by Michella Raharisoa is difficult to verify without local inspection and includes implausible claims of cow death caused by the toads. However, given the direct road connection to this site with the Asian toad incursion a satellite incursion is entirely plausible and verifying this report is now among the priorities of the programme (<http://www.lexpressmada.com/blog/information-live/biodiversite-le-crapaud-epineux-debarque-a-mahanoro-12315/>).

Eradication perspectives

There has been limited investment in amphibian eradications globally, with only three successful toad eradications recorded: 1) a small-scale operation in Europe which utilised techniques that are not suitable for the Asian toad incursion in Madagascar (shooting); 2) the removal of a small incursion on an American military base in Okinawa, Japan; and 3) the eradication of Cane toads from a very small (6.5 ha) island in Bermuda (Wingate 2011). The difficulties with even controlling the spread of Cane toads in Australia and reducing their rate of spread highlight the likely problems to be faced in undertaking a toad eradication in Madagascar.

Options for the management of toads on Madagascar are:

1. Do nothing. This would have implications for Madagascar's biodiversity and economy as well as the health and well-being of Malagasy citizens.
2. Develop and put in place a control programme to prevent or limit the spread of the species either indefinitely or until eradication techniques can be developed. This is a high-risk strategy due to the difficulty in maintaining a non-physical boundary i.e., not fenced. Containment costs will quickly grow to surpass eradication costs. Identify species at high risk of extinction from toad impacts and undertake protection either *in situ* or in captivity (species-led program). The resources to achieve this are large and the management outcomes likely to be financially and logistically unsustainable. Further, not all impacted species are likely to be identified *a priori*, meaning that some will be left unprotected until too late.
3. Identify high-value sites containing a range of species of concern, and undertake work to protect those sites (site-led program). Again, it is questionable such long-term programmes, even if practicable, could be financially sustained in the long-term.
4. Undertake an eradication and put in place an associated biosecurity program to prevent re-invasion. Although this would be expensive in the short-term, it would be far cheaper in the medium to long-term than any serious ongoing control programme, which would need to exist in perpetuity.

Unless physical barriers are possible 2, 3 and 4 all require the development of techniques for the detection and removal of toads at low density, which are also crucial for the eradication option.

Eradication is the preferred solution to any invasive organism incursion, but not always feasible. As such, eradicating the Asian toad from the Tamatave region has been a default position of local authorities, environmental NGOs and the Ambatovy Mining Company, although the author's encountered serious confusion over the technical difference between "eradication" and "control." Unfortunately, it seems that while toads were apparently observed by locals at least as early as 2011 and possibly earlier, the issue only became recognised by both the mine and NGOs and reported to government in 2014—by which point preliminary searches have shown the extent of the toad incursion to be at least 98 km².

Given the technical and logistical challenges involved in undertaking a toad eradication in Madagascar, it was agreed the first step was to undertake an eradication feasibility study. This is internationally recognised as a best practice for eradications allowing a decision to be made with confidence and with good knowledge of the costs, benefits and risks involved.

It is important to note that this feasibility study is designed to consider all the requirements for undertaking an eradication and then advise on the overall feasibility of Asian toad species eradication from Madagascar. It covers the known constraints and requirements of undertaking an eradication programme and highlights where additional information needs to be compiled. It is NOT an eradication plan, which would require significant additional work on confirming eradication techniques, application strategies, project governance and management structures, costs and a timeline.

This report is designed to be used to decide whether eradication is feasible and practical to pursue by the relevant Malagasy government agencies and NGOs holding responsibility. If it is deemed worthwhile to proceed with eradication, this document can be used to help develop an appropriate strategy, raise support and funding through a discussion of potential tools as briefly described in Appendix III.

It is important to recognise the difference between “control,” where the aim is simply to reduce the population to a desired level, and “eradication,” where every individual of the target species has to be removed. It is also recognised reducing the population by even 99% is the easy part of any eradication project. The difficult part is to eradicate the remaining 1% and then confirm none are left. Indeed, it should be expected the cost model of eradications usually demonstrate a far greater proportion of an eradication budget is spent detecting and removing the final 1% than spent removing the initial 99%—this cannot be stressed enough, especially for those without experience in pest eradications.

1. GOAL, OBJECTIVES and OUTCOMES

2.1 Goal

To examine the feasibility of complete eradication of Asian toads from Madagascar—including identifying techniques suitable for locating and removing toads and what is required to determine their efficacy. If it is decided to attempt the eradication, the project (Asian Toad Eradication from Madagascar) will aim to eradicate the target species *D. melanostictus* from the island country of Madagascar, thus eliminating existing and future impact of this species on the islands ecology and economy.

Successful eradication will require several separate but interlinked tasks:

- Confirm and maintain required political and public support for the project for the duration of the operation.
- Set up appropriate operational and financial management systems and governance.
- Delineate current extent of invasion, including identifying the location and size of any possible satellite populations; this will need to be continually confirmed and updated during the project.
- Prevent establishment of satellite populations through transport of goods from the current incursion area.
- Establish suitable biosecurity systems at likely ports of entry and highlight the need for such mechanisms to be future industrial investments in Madagascar; to prevent toads (and other biosecurity threats) reinvading—this will have additional benefits in keeping out other potential invasives.
- Confirm methods to be used for the eradication. As there is no current “one hit” technique comparable to a single aerial bait drop for rodents, eradication would likely require use of multiple techniques. It is crucial that not only the techniques to be used but also the order in which they are used be considered.
- Confirm suitability and accuracy of detection methods to both establish the extent of the incursion and to give the required level of confidence in knowing there are no toads left in the treated area.
- Confirm funding for the project. The two stage approach involving a testing of methodologies, ahead of full-scale eradication, enables some funding flexibility.
- Begin eradication as early as possible so as to minimise the area to be treated and the costs involved.

A secondary issue not dealt with in this report, but will need consideration, is what response could/should be undertaken if eradication is deemed infeasible.

Eradication is the only objective that has a definitive end point. All other responses would need to be carried out in perpetuity.

The authors' believe/meaningful control to contain the toad to its current range cannot be achieved considering trade and infrastructure within Madagascar. It would be easy to kill thousands of toads, but at best this will only slow the rate of spread, as most killed animals would come from high-density areas due to the difficulty in locating toads at low densities.

2.2 Objectives and Outcomes

This document represents a preliminary feasibility study for toad eradication. The objectives of an eradication project and the outcomes that would result are:

Objectives	Outcomes
<i>Objective 1. Prime objective</i> <ul style="list-style-type: none"> Removal of all invasive toads from Madagascar – PHASE 2. 	<i>Outcome 1.1.</i> Toads removed from Madagascar.
	<i>Outcome 1.2.</i> Native species protected.
	<i>Outcome 1.3.</i> Associated social/human/economic impacts removed, and benefits achieved.
<i>Objective 2.</i> <ul style="list-style-type: none"> Develop and test methodologies required to eradicate toads. – PHASE 1. 	<i>Outcome 2.1.</i> Options for methodologies investigated.
	<i>Outcome 2.2.</i> Methods tested.
<i>Objective 3.</i> <ul style="list-style-type: none"> Feasibility study updated as new information becomes available. 	<i>Outcome 3.1.</i> Field trials (large-scale) undertaken to confirm efficacy of selected techniques.
	<i>Outcome 3.2.</i> Feasibility agreed upon or discounted.
<i>Objective 4.</i> <ul style="list-style-type: none"> Biosecurity implemented to prevent reinvasion. 	<i>Outcome 4.1.</i> Biosecurity plan developed and implemented.
	<i>Outcome 4.2.</i> Reinvasion of toads prevented (if eradication is successful).
	<i>Outcome 4.3.</i> Prevention of establishment of additional invasive species.

As there are no confirmed techniques for eradicating toads on the scale required in Madagascar, it will be important to consider the feasibility of all possible techniques and then test the efficacy of the most promising methods; costs would then need to be determined. It is probable that no one technique will be suitable and multiple tools will be required, e.g., manual captures, chemical control and ability to target different life history stages.

It is easy to remove large numbers of toads, but those numbers must exceed replacement rates for eradication to be successful. Given the high fecundity of toads, this will be difficult to achieve. Further, it is the last few individual toads the most difficult to detect and remove, but without their capture all previous effort would be wasted if they survive and reproduce. The last remaining individuals in eradication programmes often exhibit aberrant behaviours, sometimes the result of conditioning by previous eradication methods. While toads are less likely to exhibit learned behaviours than mammals (rodents and ungulates have been known to adopt very unusual behaviours following eradication efforts) those last toads may survive because of unusual behaviours such as extremely conservative movement patterns, or use of novel refugia or choices of breeding sites, non-calling breeding males. Hence, techniques adopted for a toad eradication on the scale required will need to be applied strategically.

A crucial component of any eradication is being able to ensure the risk of reinvasion is manageable. To do this will require the development and implementation of suitable border biosecurity systems. Appropriate biosecurity would ideally be in place prior to commencing the eradication in order for testing but due to the urgency to commence the eradication quickly they would need to be implemented in conjunction with the eradication. Because of the multi-agency nature of biosecurity, working through multiple government agencies, national and regional governments, port companies, transport companies and major industries, this may be unrealistic. Implementing suitable biosecurity measures will not only minimise chances of reinvasion by toads but also by other unwanted species. Even if toads are not eradicated, there are major benefits to implementing biosecurity to prevent other invasives having major ecological, economic and/or human health impacts. This objective can be completed regardless of whether toad eradication proceeds or not and is likely to have significant environmental and economic benefits to the country.

A separate but related issue is outgoing biosecurity. While the current incursion persists, there is a risk to trade partners of toads being transported in goods and materials (mechanical machinery and materials). The toads have shown how they can be successfully transported long distances (this incursion), and there is a real risk of transferring toads to any port that is serviced from Madagascar, and especially from Tamatave. This includes Reunion and Mauritius, but also most other ports regularly receiving cargo from or via Madagascar.

In addition to testing eradication techniques, it will be important to confirm a suitable technique for detecting toads at low densities with a very high level of confidence. This is for both delineating the area to be treated and to confirm the success of eradication. A significant portion of the cost of the project is likely to go into the latter, as if even two toads are left together, the population is likely to return to previous densities within a few years.

Suitable techniques will need to be tested at a scale that truly reflects the field situation i.e., covering the diverse range of habitats, land ownership, etc. found in the incursion area.



Fig. 1c. Asian toad female, Sabah, Malaysian Borneo. *Photo: J. Reardon.*



NFig. 2. Cane toad, *Rhinella marina*, Papua New Guinea. *Photo: J. Reardon.*

3 THE SITE

The treatment site for any eradication effort can be considered in three ways:

- The confirmed incursion site. This includes the port city of Toamasian/Tamatave and the adjacent Ambatovy nickel processing operations and extensive urban and agricultural areas including a number of waterways, and is at least 98 km².
- The probable incursion area. This is almost certain to be significantly larger than the confirmed 98 km² site. Toad populations will constantly increase while an eradication is being considered and planned. It will require further survey effort to delimit the extent of population(s), including search for additional satellite populations.
- The potential incursion area. This covers most of Madagascar (587,041 km²), based on the transport of goods from Tamatave around the country with no biosecurity in place and minimal ecological barriers to spread.

The confirmed site of the Asian toad incursion covers a broad range of habitats found throughout the probable and possible incursion sites including:

1. Urban areas, including lower socio-economic urban and rural communities, i.e., close living and limited facilities. Included are areas of higher socio-economic communities having large enclosed houses.



Fig. 3. Drainage channel in central Tamatave. *Photo: J. Reardon.*



Fig. 4. Drainage sump filled with refuse and occupied by Asian toads in central Tamatave. *Photo: J. Reardon.*



Fig. 5. Potential toad refugia in well maintained urban central Tamatave. *Photo: J. Reardon.*



Fig. 6. Even well maintained properties such as this have many possible refugia, such as under houses (Central Tamatave). *Photo: J. Reardon.*

2. Industrial areas, including the extensive heavy industrial compounds of the Ambatovy mine.



Fig. 7. Ambatovy Mine nickel refinery is the largest industrial area within the current distribution range of the Asian toad incursion. *Photo: Ambatovy.com.*

3. Agricultural areas. The city of Tamatave is surrounded by extensive agricultural areas including rice paddies and market gardens.



Fig. 8. A drainage “sump” in an area of extensive rice paddy. *Photo: J. Reardon.*



Fig. 9. Flooded rice paddies adjoining village. *Photo: J. Reardon.*



Fig. 10. Extensive rice paddies adjoining regenerating exotic forest. *Photo: J. Reardon.*



Fig. 11. Asian toad male in human refuse at rural fringes of Tamatave. *Photo J. Reardon.*

4. Secondary and regenerating vegetation. Areas out of urban and agricultural development in the incursion area appear to be dominated by seral woody communities predominate with exotic species such as *Eucalyptus*, *Mimosa* and *Tamarix*. No significant natural habitat areas appear to exist within the incursion area.



Fig. 12. Mixed largely exotic regenerating forest within incursion area. *Photo: J Reardon.*

All of these habitat types appear to contain Asian toads. Nationally, it is difficult to identify ecological barriers to dispersal and colonisation. The dry areas of the west and south may be less suited to the Asian toads, but the presence of Asian toads in the dry central northern regions of Sri Lanka certainly highlights the fact that these toads are highly adaptable. The potential role of altitude in limiting toad survival is also unclear as toads are known to occur up to 1,800 m above sea level (van Dijk et al. 2004). Species distribution modelling results, based on the native distribution, indicate that Asian toads will occupy almost all of Madagascar (Pearson, 2014).

The proportional representation of these habitats has not been accurately characterised for the incursion area beyond recognising all are well represented. Among the tasks for advancing this project is the need for GIS skills to be applied to accurately describe habitat and land-use mosaics. Survey effort has to date focused on delimiting the incursion area rather than closely examining occupancy or density across that area (Fig. 13.)

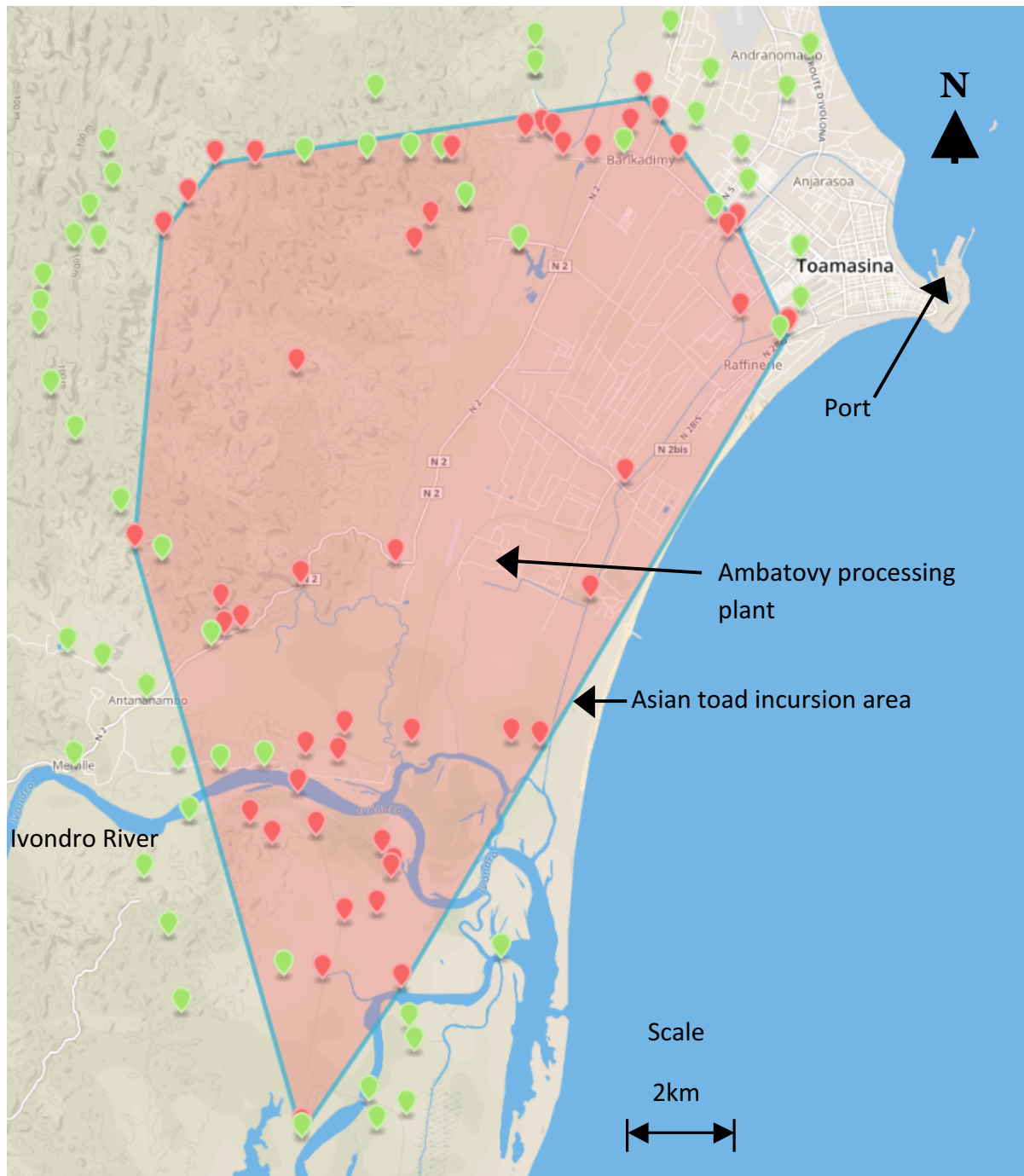


Fig. 13. A map of the known incursion area as of February 2015 with green markers indicating sites surveyed where toads were not detected and red markers indicating toads detected; red polygon—the minimum presumed incursion area (98 km²). Note, an additional 12 negative survey locations sit outside of map (*adapted from Moore et al. 2015*).

Civil society in the incursion area

Madagascar has centralised government based in the capital of Anatanarivo (Tana), approximately 320 km from the confirmed incursion area. Atsinana Regional government is based in Tamatave, and villages are overseen by an elected Village President.

The current incursion area includes a large portion of Tamatave city and is likely to incorporate in excess of half a million people in urban and rural areas. Land ownership covers the full spectrum from private residential, corporate and government-owned lands.

Most land is utilised for agriculture and food gathering. There is little forest remaining in the incursion area, although many of the hill areas are in early stages of regenerating forest, often with introduced species (e.g., *Eucalyptus*) dominating but appear to be heavily disturbed by fire (Fig. 11)—these are often used for charcoal production. Flat lowland areas are predominately used for rice production. Most waterways are commercially harvested for fish.

Access to Tamatave is good, with a major port, airport and a high-quality roads linking it to the capital and the rest of the country. Access within the incursion site is highly variable, ranging from a comprehensive road and alley network in the urban areas to limited road access in rural zones. As the toads have moved south and crossed the Ivondro River they have entered an area where the primary human access is along a railway line having no adjacent roads or villages.

Physical access for an intensive eradication project, or even for the delineation survey, is likely to be difficult because of the lack of road access to some areas.

There is a defined wet season, November to April, which is likely to be the predominant breeding period for toads, but there are suitable water bodies present throughout the incursion area which could permit breeding all year long. The Asian toad's reproductive patterns are yet to be described in Madagascar but based on observations to date, and studies elsewhere, males congregate around water sources and call to attract females who then lay eggs in the water. Most water sources can be utilised including brackish water and ephemeral pools provided they last long enough for the eggs to hatch and tadpoles to metamorphose into toadlets.

3.2 Target Species

3.2.1 GENERAL DESCRIPTION

The Asian toad is a large and robust member of the Bufonidae reportedly reaching 200 mm snout to vent length in females with an average size of 85 mm reported by Mercy (1999); males are usually smaller (van Dijk et al. 2004; Mercy 1999). Adult colouration is variable (see Figs. 1a, b and c) and can range from plain brick red, cream to almost black. The most common colour pattern is pale yellow-brown marked boldly with dark or reddish brown streaks and spots. Their dorsal surface and limbs are covered with warts varying in size, usually with a spinous protrusion and often pigmented black. Males have a subgular vocal sac coloured yellow-orange in breeding males which also exhibit the inner side of the first and second fingers and having nuptial pads. Juveniles apparently possess a black band around the throat running between the chin and breast and have no warts, having a very small Tympanum according to Mercy (1999). The toads have many attributes making them an ideal

invasive species – they are physically robust, can live in a wide range of habitats and ecotypes, highly fecund (may lay up to 40,000 eggs per season) and have cosmopolitan breeding tolerance. They do require water for breeding, but it can be standing or slow flowing, of which there is no shortage in the incursion area.

3.2.2 REPRODUCTION AND DEVELOPMENTAL BIOLOGY

Breeding depends on access to water. Where water is available breeding will persist year round but in more seasonally dry habitats a distinct breeding season is observed with maximum reproductive effort at the beginning of the wet season (Mercy 1999). The lunar cycle influences ovulation, which occurs in association with a full moon. The ovaries can make up 30% of the total body weight of the toad at this time. Females lay a long string of black eggs, externally fertilized by the male. Eggs are enclosed in a thick mucus membrane and deposited usually on submerged vegetation. Breeding is most commonly noted in ephemeral or vernal pool(s). Male Asian common toads have a continuous spermatogenic cycle however a study in Taiwan showed there was a larger concentration of spermatophores in the male toad during a specific time of the year (Huang et al. 1997; Kahn 2000; Mercy 1999; Saidapur and Girish 2001). Males congregate at breeding sites and call females. Their call can be noted as sounding like “creo-o,o; cro-ro-ro-ro-ro-ro-ro” and intense competition among males for females means many males are often found clinging to a single female (Kahn 2000; Mercy 1999). This behaviour clearly offers an excellent opportunity to target toads when they are highly detectable, aggregated and breeding—an obvious advantage to an eradication effort.

Female Asian toads can produce up to 40,000 eggs per season and this potential has been confirmed in Madagascar (R. Danielle, pers. comm.) and eggs hatch within 24 to 28 hours. Tadpoles are small and black usually around 15 mm in length and associate in groups (Khan 2000). Research has shown that Asian common toad tadpoles reared with sibling groups grow at a higher rate and develop faster compared to larvae reared in mixed groups (Saidapur and Girish 2001). A study done by Mogali et al (2011) illustrates that tadpoles of Asian toads emerge at different times and sizes in the presence of predators and under such circumstances tadpoles will decrease in body mass up to 46% and metamorphosis will also occur earlier.

These data are largely drawn from work with the Asian toad in its native range and there is currently very limited information available on the biology and ecology of the Asian toad in Madagascar.

The current area of incursion in Madagascar suggests they are very able dispersers, at least in disturbed and urban habitats. Like all toads, the Asian toad has parotoid glands behind the eyes and above the tympanum on either side of the neck. These glands produce bufotoxins, which are steroid lactone alkaloids, synthesised to act as a repellent to predators. It is these toxins that lead to much of the concern that invasive toads will impact native predator species evolutionarily naive to toads as prey items.

Longevity has been estimated as an average of four years in the wild and records exist of Asian toads reaching 10 years of age in captivity (Mercy 1999; Khan 2000).



Fig. 14. *Duttaphrynus melanostictus*, Asian toad female in suburban drainage, Tamatave. Note the melanic canthal, pre-orbital, supra-orbital, post-orbital, mandibular, maxilla and orbito-tympanic ridges that the specific name *melanostictus*, describes. *Photo: J. Reardon.*



Fig. 15. Research student with male and female Asian toad captured during day in the dry, open vegetation pictured in background. *Photo: J. Reardon.*

3.2.3 INCURSION ORIGINS, RANGE, DENSITY AND ABUNDANCE

The presence/absence surveys carried out to date give a minimum incursion area of 98 km² (Fig. 13.). However this is very much a minimum estimate as the survey techniques were conservative (visual observation of toads along transects), and it would be easy to overlook toads if not in high density. During the initial surveys only one survey was undertaken at each site; it was not possible to check for satellite populations either along waterways or transported by humans in rubbish or produce.

Genetic work to confirm the original source location for the invasion is currently being undertaken. These samples could be used as voucher specimens for any future incursions. If toads are detected after an eradication was deemed successful, genetics can determine if it was a new incursion or whether the eradication attempt had failed.

Preliminary surveys have attempted to measure toad density in three different ecotypes: urban, rural/agricultural and non-production forest habitat, which largely consists of regenerating exotic woody species appearing to be dominated by *Eucalyptus*. At each ecotype three sites were selected (non-randomly) so nine sites were searched in total. On average, across these sites there are 5.8 toads per 100 m² or 580 per hectare with a maximum density of 18 toads per 100 m² or 1,800 toads per hectare. This estimate contrasts with a quoted figure of 65 toads per hectare quoted by Ambatovy (Mark Sitter, pers. comm. to IUCN ASG) for the area under their management. However it is unclear if this density estimate was generated pre or post of the on-going efforts to remove toads, as such actions will have density dependent effects influencing any estimate of density.

A third of the sites (3 of 9), did not appear to have toads present and these sites were all rural, non-production habitat. It is very encouraging to know toad abundance is superficially lower in this ecotype although we must remain cautious as the increased structural complexity will reduce toad detection probabilities. Equally, the ecotype with the greatest apparent density of toads was urban with an average of 51 toad per 100 m². This figure may be influenced by the more searchable nature of urban habitat and we should be mindful of the heterogeneity of habitat suitability in all ecotypes. These figures are of course only loosely indicative being derived from a small, non-random sampling effort but did not allow us to understand the numerical magnitude of this incursion. These figures allow us to extrapolate an estimate of toad numbers within the known incursion area. If we assume that only 2/3 of the 98 km² area is occupied by toads then there is 65 km² or 6,500 ha of occupied habitat. At an average of 580 toads per ha that is a population of 3.77 million toads, not considering tadpoles.

The usefulness of this extrapolation is to emphasise that even if eradication methods miss only 0.01 of the toad population, we are left with 37,700 toads remaining. Such a number would breed and recruit at a rate that would neutralise any eradication effort within two or three seasons.



Fig. 16. The Asian toad team developing techniques to conduct a brief evaluation of toad densities across all possible ecotypes ranges. *Photo: J. Reardon.*



Fig. 17. *Leioheterodon madagascariensis*, the Madagascan giant hognose snake, potentially poisoned by Asian toads. *Photo: Andrew Routh.*

3.3 Impacts

3.3.1 THREATS TO HUMAN HEALTH AND WELLBEING

The Asian toad poses a real and lethal risk to human health in Madagascar. It is with some surprise the authors discovered this species, ubiquitous within its native range is implicated as the cause of poisoning multiple humans and has been documented as the cause of death and cardiac arrest in children who have consumed toad tissue (Keomany et al. 2007). It is also surprising in these studies is the common knowledge among those communities suffering these cases of poisoning, that the toads are poisonous. We feel that this health risk is elevated when considering the toad's establishment in an environment such as Madagascar where there is an extensive rural population that partly rely on hunting and gathering for their sources of protein and who are entirely naïve to the poisonous nature of the Asian toad. Further, a study (Keomany 2007) points that a number of other records in the literature consider cases of poisoning after consuming toads or their eggs (Chern et al. 1991; Kuo et al. 2007; Chi et al. 1998; Yei and Deng 1993; Cheng et al. 2006; Jan et al. 1997). Together, this body of literature suggests the health impacts of Asian toads in Madagascar may be significant and lethal to humans especially in communities familiar with the consumption of frogs as a regular part of the diet.

Any reduction in the number of larger snakes, refer 3.3.2 could also lead to a surge in Black rat (*Rattus rattus*) populations, leading to serious economic consequences such as loss of stored rice and other food supplies, and damage to commercial goods and equipment as electrical wiring. In the 1990's, the over-collecting of *Acrantophis* snakes for the boa skin trade in the Ambato-Boeny region of Madagascar reportedly led to a dramatic increase in black rat populations, with serious economic consequences. This was the subject of a study funded by GTZ (C.J. Raxworthy, pers. comm.).

3.3.2 THREATS TO MADAGASCARS FAUNA AND FLORA

The impacts that Asian toads will have on the Madagascar fauna and flora are currently unknown. Full impacts from the toads cannot be known without detailed studies which will take years to complete. Although this work should be done, the time taken to obtain the data would allow the invasion to expand beyond any hope of eradication. Consequently, management decisions for the toads must necessarily be based on impacts seen from what is known about ecologically similar species. In this instance, we can derive reasonable estimates of likely impacts from what is known about impacts derived from the ecologically similar Cane toad, *Rhinella marina*, in Australia. In both Madagascar and Australia, large generalist toads adaptable to human-degraded environments were introduced to isolated landscapes whose native fauna were historically unexposed to toads and, hence, highly susceptible to their novel toxins. Based on impacts seen in Australia, the high toad densities already reported in Madagascar, and the predicted massive spread of toads into most regions of the island (see Pearson 2015), we can expect that negative impacts will be substantial and occur in many habitats and communities.

The most obvious direct threat concerns poisoning of naïve predators. This too has been the greatest impact from Cane toads in Australia. Large frog-eating endemic snakes are likely to be especially vulnerable (e.g., *Leioheterodon*, *Ithyphus* and *Dromicodryas* spp.). There have already been reported observations of snakes dying after eating toads in the Tamatave area (M. Moore, pers.

comm.) now confirmed as *Leioheterodon madagascariensis* (Fig. 17). In the remaining native habitats, many other locally endemic smaller species of snakes will also be vulnerable if they feed on toadlets or tadpoles—the reduction of snake populations would disrupt the food supply to other predators (such as hawks).

Other endemic groups that feed on frogs are likely to be vulnerable, including Tenrecs (*Tenrec*, *Microgale* spp.), carnivorous mammals such as the Fosa (*Cryptoprocta ferox*), and the endemic mongooses (*Mungotictis* spp.), Mouse lemurs (*Microcebus* spp.) and birds such as the spectacular endemic radiations of Madagascar ground rollers (*Brachypteracias* sp., *Geobiastes* sp., *Uratelornis* sp. and *Atelornis* spp.) and Vangas (Family: Vangidae). Many of these species represent an important part of Madagascar's charismatic biodiversity, helping drive the ecotourism industry. In addition, toads are voracious feeders. Their high density is likely to reduce populations of ground-dwelling invertebrates and small vertebrates, such as endemic frogs (*Stumpffia* spp. *Gephyromantis* spp., *Mantidactylus* spp.), skinks (*Amphiglossus* spp.) and chameleons (*Brookesia* spp.) due to predation (Figs. 18, 19, 20). Direct competition for food may also affect other large ground dwelling endemic amphibians such as *Dyscophus*, *Scaphiophryne* and *Plethodontohyla* genera, although this is of less certain. All of these impacts are expected to be greatest in the most diverse and sensitive communities, which are located in the 10% area of surviving natural habitat in Madagascar. These negative impacts are thus likely to affect most of the protected reserves and national parks in Madagascar below 1,800 m elevation.

Toads could also have more indirect, but potentially serious, impacts on invaded communities. In particular, they may alter animal communities through serving as nutrient sinks, storing nutrients in their bodies that would normally be passed up the food chain by predator consumption. Because native predators will either quickly die from toad consumption or learn to avoid eating them, toads will quickly be avoided as a food source and end up as a dead-end store of nutrients in local communities. This will short-circuit native food chains, thereby depriving higher trophic levels of necessary nutrients. In Australia, the invasive Cane toad has been documented to have this effect, forming four times the mass of the pre-invasion native frog communities, nutrients now unavailable to support native predator communities.

Lastly, toads may serve to introduce or spread foreign diseases to native amphibian communities. The greatest concern in this respect is the dual threat from *Ranavirus* and chytrid, *Batrachochytrium dendrobatides*, which has been spread globally by trade in alien frog species and has caused massive declines and extinctions in amphibian faunas worldwide. To date, chytrid has not affected Madagascar's large and unique frog fauna but concerns are elevated due to its recent discovery among numerous Anuran taxa (Bletz et al. 2015). However, should toads carry this disease, it would be expected to produce widespread extinctions in Madagascar, as it has elsewhere.

In summary, despite its heavily degraded state Madagascar still has a large number of endemic species likely to be impacted by the toad. Toads will impact food chains from both the top (consuming prey and serving as an energy sink) and the bottom (poisoning predators), either of which could eventually affect the ecology across much of the country.



Fig. 18. *Dyscophus antongilii* (Tomato frog), a potentially vulnerable species to the advance of Asian toads into remnant native ecosystems. Photo: C.J. Raxworthy.



Fig. 19. *Mantidactylus melanoplura*, a potentially vulnerable species to the advance of Asian toads into remnant native ecosystems (Mantadia N.P. Madagascar). Photo: J. Reardon.



Fig. 20. *Brookesia supraciliaris* (Leaf chameleon) a potentially vulnerable species to the advance of Asian toads into remnant native ecosystems (Andasibe, Madagascar). *Photo: J. Reardon.*

3.4 Benefits of Eradication

The benefits of eradication will largely be ecological through removing the risk of poisoning of naive predators naive to the Asian toad. Toad eradication would also eliminate any impacts of toad predation on many smaller species which in turn reduces an unnatural level of competition with native species. Many species in Madagascar are already under significant human-induced stress through habitat destruction, hunting and collecting and the impacts of other introduced species. The toad will increase that pressure and may drive some species to extinction or at least reduce them to the point where specific site-led or species-led management is required to save them.

Economic impacts, such as major changes to the islands ecology or agriculture are unknown but may include an increase in rat numbers affected by reduction of larger snakes—most likely to be poisoned by the toads. This is a concern as rats (*Rattus rattus*) are already a major economic problem in Madagascar.

The benefits to human health of an eradication of the Asian toad is clear—removing the risk of lethal poisoning to humans and animal species. At the very least, failure to eradicate the Asian toad necessitates the Madagascan government engage in an effective education programme to promote the message that these toads are poisonous to people and some livestock. There is also a risk that the

toads, by reducing predators like snakes through poisoning, will increase the prevalence of plague infections which are already present within the toad incursion area.

Putting in place comprehensive biosecurity systems will have benefits far wider than just the reducing toad populations and/or expansions. Incoming biosecurity, if put in place, will significantly reduce the chance of toads, as well as other future invasive species, establishing thus preventing any negative impacts they may have.

Outgoing biosecurity also requires attention, especially if the toads are not eradicated. Consideration will need to be given to possible actions which may stop them establishing at other locations which receive goods from or are serviced by ships which had visited Madagascar. Failure to do this could lead to World Trade Organisation sanctions being put in place on goods originating from Madagascar according to the legislation supporting the WTOs Trade Liberalisation agenda.

4 Requirements for Successful Eradication

4.1 Technical approach

As there are no examples of amphibian eradications over such a large area, it is important that methodologies are tested and evaluated for their efficacy for eradicating toads from Madagascar. There is a range of techniques available that target various life stages as detailed in Appendix III and summarised here:

- Tadpoles via removal with tadpole traps or chemical treatment of water bodies.
- Breeding adults via physical removal, including using audio stimuli to elicit calling from hidden males.
- Juveniles via spot-spraying with citric acid or sugar solutions, physical removal.
- Eggs via removal of strings from ponds.
- Breeding adults through fencing or draining some water bodies.
- Non-breeding terrestrial adults and juveniles through physical capture.

It is therefore crucial to develop by trial an array of options to measure their efficacy. The information from the trials will then be used to determine the technical approach to be considered, along with the scale of the treatment site to see if eradication can be technically feasible across the entire incursion landscape. If suitable techniques are identified they would be implemented using an adaptive-management process, constantly reviewing their efficacy and adapting them as required. If insufficient suitable methods are validated during trials—eradication will not be feasible.

It may be helpful to note here that recent work on the control of Cane toads in Australia has provided some hope for the containment of toads where eradication is deemed impossible (Letnic et al. 2015). In this case it needs to be stressed that the Asian toad incursion area in Madagascar is signifi-

cantly more humid with far greater access to water sources than the arid area of Australia considered in the Letnic et al. (2015) study.

It is estimated there are currently approximately four million toads in Madagascar based on an extrapolated calculation. This is certainly not exactly accurate but an essential preliminary calculation to provide some numerical perspective for the issue. In the calculation we expect a 1:1 sex ratio and that 75% of the population are of breeding age. While each female can lay up to 40,000 eggs there is only an average of 20,000 laid per female per year, and only 1% of eggs survive from hatching to join the breeding population. Under these plausible assumptions a control programme requires us to kill 1,500,000 toads per year just to maintain numbers at their current level. In order to eradicate them within four years it will be necessary to kill over 2,500,000 per year. Failure to remove toads at a greater rate than this will result in the failure of an eradication effort.

4.2 Sustainability

For an eradication to be successful it is crucial that once toads are removed, they are not allowed to re-establish by renewed importation. The current incursion shows that unless changes in biosecurity are made, there is a clear pathway for toads to be transported again to Madagascar from Southeast Asia.

Although undertaking a comprehensive biosecurity programme can be complicated and expensive, there are basic actions that can be implemented cheaply and quickly, which can significantly reduce the risk of new populations establishing. This can include educating staff especially at the port and at businesses or facilities engaged in import/export activities; to note and report any new species they observe; inspecting high-risk goods; and having a rapid-response plan in place to facilitate immediate removal action if and when a new incursion occurs. Enforcing standards of cleanliness and order can also increase the ability to detect invasive organisms while also raising the general standards of operation. Expert assistance should be sought to develop a biosecurity plan that is appropriate for the local conditions.

Particular thought will need to be given to biosecurity in and around Tamatave whether an eradication proceeds or not. If an eradication proceeds it will be important to minimise the risk of toads being moved outside the infested area where they could establish satellite populations elsewhere in the country, potentially putting the whole eradication project at risk of failure, or at least, significantly increasing the operational risk and cost of the project.

If an eradication project is not to proceed, thought will need to be given to whether it is feasible to try to reduce the rate of expansion of the toads. It is possible that some of the techniques that are put forward for consideration for an eradication are effective at significantly reducing toad numbers but won't reach the level required for eradication; these could be used for an ongoing control programme if the required ongoing resources were available. This would potentially buy time while additional work on toad control, and eradication options are invested. That is, it is possible that given adequate resources, a methodology could be developed which is not currently available, and it

should be noted the greater the area the toads inhabit the harder and more expensive it will be to implement such a method. It is not considered likely that a control programme will do anything other than reduce toad numbers and possibly decrease their rate of expansion.

Although all evidence currently indicates that Asian toads have not yet reached the port facility of Tamatave, given the current rate of spread estimated to currently be approximately two km per year (see Fig. 13 and consider an incursion timeframe of 4–7years), it will not be long before they do. This will pose a great risk of introducing toads to new sites across Madagascar and internationally.

4.3 Social acceptability

While further work will be required to confirm the level of support within the community, from our site visit there appears to be a very high level of support within the community to remove the toads. There is a keen desire for eradication and, in some quarters, an expectation; although there is not a good understanding of what is required to do this (as opposed to control). Some localised control is already being undertaken, and many people believe that eradication is simply intensive control, i.e., that it is simply a numbers game and the last toad will be as easy to remove as the first if you simply keep at it—this is not true!

Concerns over human health risks are likely to be a major reason for the community support shown for the eradication to date, and the concern is likely to remain. Similarly there are concerns about the impact of toads on chickens, which are common through the inhabited area and of economic importance, especially to lower economic groups. There are stories of chickens being killed by toads reported to Reardon and McClelland during the site visit but no carcasses were observed. Once again this concern has led to significant support for eradication.

Community support may depend on control techniques to be used; hence, it will not be able to confirm final community support until the preferred techniques are identified. For example, people may be very happy with physical removal but not happy with the use of chemicals, even though some level of removal via safe chemicals such as citric acid and sugar solution may be feasible.

Required aspects of public support needed for successful eradication:

- Access to all properties in the possible incursion area both for removal and monitoring across multiple visits.
- Acceptance of the techniques to be used.
- Avoiding the use by the public of any techniques that may be required for follow up monitoring so as to avoid educating individual toads (behavioural modification).
- An impression that a bounty system will not be an element of an eradication plan to prevent the stock-piling and manipulation of toad populations. The eradication effort will still yield extensive employment opportunities.
- Ongoing support for biosecurity, initially to prevent the establishment of satellite populations and to detect any that may already be present and then to detect any further incursions.

There will inevitably be significant pressure to introduce a bounty system as a quick, easy and socially desirable (it puts money into the community) way of reducing toad numbers that will be seen as

doing something. Bounties have been used for animal-control projects globally for centuries and although they do reduce animal numbers, very few have succeeded in eradicating invasive animals. It is more common for them to lead to “farming” of the animals to provide a sustainable income. One additional problem with bounties is they place the same value on all individuals, whereas removing animals at the periphery of an incursion is more valuable than removing those towards the core of the range, as doing so reduces the rate of spread, whereas those towards the core are generally much easier to catch. Also, animals surviving towards the conclusion of the project, when there are very few and hard to catch, are more important than eliminating those at the start, when they are plentiful. In short, the negative aspects of attempting a bounty outweigh any possible benefits, and the idea should be clearly avoided publicly.

Table of Key Contributors

Key stakeholders identified so far:*

Name	Organization/function	Contact details
Madame Sahondra Rabesihanaka	Malagasy Government – MEEMF: Head of Service, Biodiversity Conservation	Sgff.dvrn@mef.gov.mg
Mr. Eric Robsomanitrandsana	Malagasy Government – MEEMF: Responsible for native fauna.	Eric.dvrn@mef.gov.mg
Ms. Maya Moore	Madagascar Fauna and Flora Group	Maya@savethelemur.org
Mr. Devin Edmonds	Mitsinjo Association	devin@amphibiancare.com
Dr. James Reardon	New Zealand Department of Conservation	jreardon@doc.govt.nz
Dr. Fred Kraus	Invasive reptile and amphibian expert	fkraus@umich.edu
Dr. Christopher Raxworthy	American Museum of Natural History	rax@amnh.org
Mr. Pete McClelland	Independent eradication consultant	pmcclelland@xtra.co.nz
Dr. James Lewis	Amphibian Survival Alliance	jplewis@amphibians.org

*We acknowledge that there will be numerous in country stakeholders playing a critical role in any programme of work to address the Asian toad incursion but the feasibility study did not enable us to discuss the situation with sufficient potential stakeholders to make listing them here appropriate.

4.4 Political & legal acceptability

From the limited discussions had with MEEF Represented by Madame Sahondra, it appears that there is a high level of governmental support for the eradication of the toads. It needs to be confirmed that this is reflected at a political level and will result in ongoing support. The future political situation in Madagascar is unknown, but if there is strong support initially, the primary risk would be withdrawal of support by the Government.

NGOs, National, Regional and Local government would need to work closely together with clear lines of command and control so that once the operation started there are no unexpected delays.

Whether eradication is legally acceptable will depend to a large part on the techniques used, as some of these may require governmental permits or consents, although environmental legislation seems minimal in Madagascar. An example could be registration of a possible ranicide, which will not be able to be confirmed until the required trials are completed. Alternatively, if a technique is not able to be legally implemented there is no use in carrying out the trials. Issues may include animal welfare and human health concerns.

A major concern is obtaining access to ALL properties within the known incursion area as well as any potential outliers, both current and future. The review team were informed that access would not

be a problem, but when dealing with thousands of land owners, as would be the case for this project, not having access to even one property could lead to failure if it harboured toads. Although there is little doubt that most land owners are supportive, there are concerns about some industrial/business sites that have a high level of security and also some of the gated houses in the city. It would be important to have a legal mechanism to allow access to such areas if required. It is not known if this currently exists. If not, it needs to be provided by either local or national government.

The biosecurity required for the eradication will also need political and legal support to enforce the standards required to prevent reinvasion—there are many examples of island biosecurity systems available worldwide to base this on.

4.5 Environmental acceptability

The environmental impact of the eradication on non-target species or habitats will largely be dependent upon the techniques used. For example, the impacts of a stand-alone physical removal programme could be quite different to a programme which involves the use of chemicals.

A physical removal programme would have a high level of disturbance, i.e., an intensive grid search, but probably only short-term impact. This compares to the use of some chemicals, which may either destroy vegetation or harm other wildlife e.g., any chemical which kills toads or in any way affects their biology may have an equal or greater effect on native amphibians depending upon how they are applied. It is believed that the area so far inhabited by the toads has only a few, common, widely distributed natives. Their collateral loss is unlikely to be significant. Any impact has to be considered against the likely long-term impact across the whole country of not eradicating toads.

Once trials have been undertaken to confirm preferred control techniques, the acceptability of likely or potential impacts of those methods would need to be considered.

4.6 Capacity

This relates to the systems that would need to be put in place to give the required administrative support for the project and the capacity of the relevant organisations to provide that support.

Project Administration

Eradication of toads from Madagascar would be a multiyear (estimated to be at least seven years, including planning and result monitoring), logistically challenging and very expensive (millions of dollars) project. The scale of the project would require extensive governance and financial-management systems to be in place.

Project Governance

Any eradication attempt would require clear governance and management structures with agreed roles, responsibilities and accountabilities. This not only reduces the risk of potential disagreement among involved parties, which can be highly disruptive to an eradication programme, but allows for fast decisions to be made on operational and funding activities.

Fortunately the Madagascar Fauna and Flora Group (MFG) under the local direction of Ms. Maya Moore have agreed to function as the lead organisation. Critical skills provided by MFG include that it is already working on the island, in the area of the incursion and with a staff and contact network at the local and national level and excellent links to the international conservation community. It would be infeasible for a new organisation to be established solely to run the project, as it would need to set up all the required infrastructure as well as processes, e.g., labor management without any existing local knowledge, taking too long considering the toad's range would have increased in the interim, increasing cost and duration of the project. As with many such developing nations, the most important skill a governing organization will need to have to be successful is familiarity with the local society, government and ability to facilitate skills transfer to locally sourced labour, while being skilled in navigating political and process weaknesses.

Although it may be theoretically possible to run the administration from a location remote from Tamatave, it is considered important to have the major base in Tamatave so that there is a close link with the field programme. This, combined with the requirement for local knowledge for the operation itself, means that the NGO would need to be based in or close to Tamatave. The only organization which appears suitable for this is the Madagascar Fauna and Flora Group (MFG), based in Tamatave. Although it has a staff of approximately 30, they are already fully committed to their other work, and taking the role on would mean significantly expanding their staff and systems. This would obviously need to be cost determined into any eradication budget.

There would be a range of organisations and individuals that either have to be or are interested in being involved in a project such as this. Many of these would have minimal understanding of what is required for undertaking a successful eradication, as opposed to control i.e., they are focused on killing large numbers of toads and not on killing the last toad. How these groups interact will need to be carefully managed to avoid conflict or diversion of resources from the eradication itself.

A structure which has been shown to work well for engaging key players through the planning and implementation of a major eradication is the model used in Australia for the Macquarie and Lord Howe Island eradications where a steering committee was established. This included representation from the government, who have overall responsibility for the environment, major funders and the implementation organisation(s), as well as eradication expertise. It is important that this group be kept small (no more than six people) to facilitate functionality because large groups invariably spend a lot of time discussing tangential issues and are, consequently, inefficient at reaching decisions. This group can then act as the conduit for information both into and out of the steering group to the relative agencies and individuals.

The roles and responsibilities of the steering group need to be laid out clearly in a "Terms of Reference" for the group. This will include which groups or departments each group member is responsible for keeping informed. A crucial component of a successful working group is that all members have as their goal a successful eradication so the debate is over on what can be done to facilitate that goal rather than representing the interests of their parent organizations. While ultimately a political decision on whether the project should continue, needs to be informed by eradication experts.

It is further recommended that a scientific and technical advisory group (TAG) be established as soon as possible, both to oversee the trials and any eradication itself. This group can provide advice to the

project manager and the steering committee on technical issues relating to eradication. This is likely to include eradication expertise, non-target expertise and social/local expertise. Once again, this group should be kept to a manageable size (no more than eight people), with additional personnel with specific skills and expertise able to help on specific issues as required. It is recognized that a large number of individuals and groups may want to be involved with this group (e.g., people working on potentially affected non-target species), so managing the social dynamic of this group will be important, as is recognizing the group is advisory only, and the steering committee and operational team will make decisions based on all information available.

As with any eradication, the quality of the work and hence the skills and motivation of the work force, is paramount. Although there is a plentiful and relatively cheap labour force available, careful consideration would need to be given to ensure that all field staff are focused on doing the work to the required standard so that once an area has been cleared the team can move on to new areas with a high level of confidence—field leadership skills will be important.

Whether partner organisations or businesses become a functioning part of an eradication programme it is critical that they work collegially with the coordinators of the eradication effort and show commitment to apply agreed operational standards and professionalism.

Table 1. Key skills needed to complete the project. Note: this only relates to Stage One Eradication and detection technique development and an incursion delineation survey.

KEY SKILL	PURPOSE	METHOD TO OBTAIN SKILLS
PROJECT MANAGEMENT	Oversight and administration: eradication experience.	Target personnel with the required skills and experience.
FIELD OVERSIGHT	Oversight of the field trials and distribution survey.	Source local labour.
FIELD WORKERS	Undertake the trials and survey.	Use local labour, to be selected using local contract, ideally skilled personnel.
APPLIED SCIENCE	Design and coordinate the required trials and produce relevant reports.	Joint role for internal and external personnel, probably provided by the TAG.
ADMINISTRATION	Coordinate budget and project reporting.	Local NGO.

4.7 Affordability

It is not possible to develop a detailed budget for an eradication itself until:

- Techniques for both the eradication and surveying for toads at low density have been developed.
- Size of the incursion is confirmed, including any satellite populations.
- Administration of the project is established.

It is apparent that any eradication will cost probably between US\$2 million and US\$10 million and as insufficient funding will inevitably lead to failure. It is important that adequate funding is identified before the project is started as otherwise, it is a waste of time, money and goodwill. The need to confirm the funding must be balanced against the need to commence the eradication as soon as possible as the incursion area and hence, costs are likely to increase exponentially with time.

Costs for Phase 1—selection of detection and eradication techniques and confirmation of the extent of the incursion need to be undertaken by personnel who know the cost of operating in Madagascar. We estimate the costs for year one to be approximately \$US385,000 (see Appendix III).

Delays in implementing the eradication will increase the cost as the incursion will continue to expand, including an increased risk of satellite population establishing through human assisted movement.

6 CONCLUSION

We believe that the eradication of Asian toads from Madagascar is not currently feasible because:

1. No proven methods of removal are known which will eliminate toads faster than they reproduce and recruit.
2. No tested detection methods are sufficiently sensitive to ensure all animals are detected with a probability enabling removal greater than reproduction and recruitment.
3. No sufficient confidence of the current toad distribution and how rapidly the incursion is expanding, including human assisted movements.

However if these issues can all be answered, and there is sufficient funding available, it is possible that eradication is possible.

Appendix III of this report briefly details the technical investigations needed to undertake in order to confirm whether toads can be eradicated. If techniques are suitable, an operational plan can be developed and cost determined to confirm the financial feasibility of the project.

KEY ISSUES. Required to enable eradication programme:

Issue	Action
Detection techniques.	Refine possible options and undertake trials.
Eradication techniques.	Refine possible options and undertake trials.
Delineating the extent incursion.	Use selected technique to undertake survey.
Develop a complete operational plan.	Based on a technique(s) being available.
Cost of eradication.	To be cost determined once the operational plan is developed.

6 Acknowledgements:

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We especially thank Jean François (Parc Ivoloïna/MFG) for undertaking many of the distribution surveys and for coordinating the site visits including liaison with local residents. We are very grateful to MFG and Association Mitsinjo for providing staff for the distribution surveys.

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APPENDICES

Appendix I: Site Visits

Two of the authors (McClelland and Reardon) visited the incursion site from 23–29th November 2014. The first task was to develop a “terms of reference” for the visit and subsequent report. This was promoted by the apparent misconception by some people the output from the trip was to be the provision of an eradication plan telling them how to eradicate the toads and how much it would cost. The terms of reference were signed off by the relevant parties and disseminated to everyone currently involved in the project.

During the stay they visited a range of distribution survey sites as well as looked at the full range of urban and rural habitats, including major waterways, potential breeding areas, both in the city and in rural areas, and a range of terrestrial habitats. Visited were sites within the Ambatovy nickel processing plant and associated staff accommodation, including a meeting with Samuel, the environmental manager for the company. Guided by: Jean Francois, second in charge at the MFG, who had undertaken most of the distribution surveys; accompanied by Devin Edmonds of the Mitsinjo Association, who had been involved in many of the surveys along with Maya Moore of MFG; and Dr. Roget Danielle of the University of Anatanarivo, who has been undertaking some preliminary research on the possible impacts of the toad.

Through Jean François’ local knowledge and connections the group talked to several of the Village Presidents (the elected village leader) to find out the local view on the toads and try to identify any potential issues with undertaking an eradication of their area.

On the 24th the group met with Aro Ratvomonehary and Lydia Randrianasoloo of the Ambatovy mining company to discuss the situation and Ambatovy’s role in any eradication. They stated that Ambatovy were currently undertaking survey work within their site and they would follow the requirements of any eradication plan, i.e., they would undertake the work on Ambatovy land rather than have any external personnel working on their property. This approach was confirmed during all discussions with Ambatovy personnel.

On the 27th the group was joined by Christian Randrianantoandro, national coordinator for the Asian toad project and Eric Robsomanitrdrasana of MEEF (Ministry of Environment, Ecology and Forests) to discuss the issues and thoughts to that point. The following day, McClelland, Reardon, Danielle and Randrianantoandro met with the Regional Office of Environment, Ecology and Forests to update them on the project’s progress.

McClelland and Reardon, along with Danielle and Randrianantoandro, met the Secretary for MEEF, as well as other government officials and NGO representatives in Anatanarivo. On the 5th of December. McClelland and Reardon updated the group on their thoughts to date and stressed the difference between a control operation and an eradication, in which every last individual had to be removed, as it appeared there was some confusion between the two methods. They also stressed they were there to look at the “feasibility of undertaking an eradication” and the report would cover feasibility only, and not be an eradication operational plan. There was a real desire to start a response

straight away so it was necessary to state that an eradication requires planning and coordination and while it would be easy to go out and kill thousands of toads immediately these would be in the high density areas and, given the animal's rapid breeding rate and other factors, would make very little difference to the overall extermination of the species. There was discussion on putting a bounty on toads but it was agreed that this would have the same effect as just killing toads—killing the easy ones, with the added risk of farming toads.

Appendix II: Terms of Reference

This report has been requested by the Amphibian Survival Alliance and the IUCN SSC Amphibian Specialist Group Madagascar on behalf of the Government of Madagascar. The feasibility study is being developed by Mr. Peter McClelland, an expert in eradication of pest animals, Dr. James Reardon, a scientist for the New Zealand Government Department of Conservation who specializes in eradication of invasive reptiles and amphibians, Dr. Fred Kraus, the head of the eradication feasibility study group and expert in global invasive reptile and amphibian issues and Randrianatoandro Christian, national coordinator for the eradication project. Our contribution of expert opinion to the government of Madagascar and other stakeholders is intended for the inclusive benefit of securing security for Malagasy social, economic and biodiversity values.

1. The document is not an eradication operational plan but a “feasibility study.”
2. This document is designed to explore and discuss feasibility of an eradication project based on current incursion status including environmental, social and technical parameters to minimize risk of failure and waste resources.
3. Control and eradication are very different concepts: the control of a pest animal aims to diminish their abundance to a prescribed level. Eradication is the total removal of all individuals in an incursion, and as such specific operational parameters must be met. These are:
 - a. **Technical feasibility:** Technique(s) be used at the project site must be capable of removing all individuals of the target population.
 - b. **Sustainable:** Re-invasion of the target species can be prevented.
 - c. **Socially acceptable:** The project has full support from the community and other key stakeholders.
 - d. **Politically and legally acceptable:** It is possible to secure all required permits and consents to conduct an eradication project.
 - e. **Environmentally acceptable:** Any negative impact of the eradication are acceptable for the environment due to the benefits of eradication.
 - f. **Capacity:** It is possible to assemble or develop the necessary skilled individuals, resources and equipment for the eradication project.
 - g. **Affordability:** The eradication project must be achievable with the resources available (being conscious of the overall long-term costs of control).
 - h. **Detection and interception:** It must be possible to detect all individuals in the incursion area and place them all at risk of capture. This is likely to require the use of multiple techniques in carefully prescribed order to reserve the most sensitive techniques for the last remaining and therefore most difficult to target individuals (This is why we must be cautious about rushing into employing toad removal techniques).
4. Any planning and development of an eradication plan must be considerate of Malagasy social and political conditions.
5. Any development of an eradication project following this feasibility study must be acknowledged as an “eradication-by-research” project as no tools or processes are currently proven for the eradication of toads from large areas.

6. It is critical that prior to the receipt of the feasibility study report that accountability and leadership structures be accepted by a suitable organization or partnership of organizations lead by a Malagasy organisation.
7. This feasibility study report was intended for delivered to Malagasy partners by January 30th 2015. During the writing of the feasibility report it became clear that the document needed to function as much more than the traditional feasibility report for a broader audience including NGOs, Government and stakeholders. Because of this the report had been delayed in it's release until November 2015 to allow for further research and discussion with partners on its content. Following the submission of this report and its recommendations it is important that partners understand the time-bounded nature of progressing any eradication planning. Testing and evaluation of tools and techniques for detecting and removing toads must precede their wide-scale employment.
8. Given the risks of extending the delay to operationalizing eradication due to fund raising delays, it is important to immediately begin canvassing for financial support on the provision that if the eradication does not proceed then funds will be returned.

A number of assumptions will need to be made in the development of the feasibility report and these will be stated in the report.

Appendix III: Preliminary Technical Strategy

This document is not an eradication operational plan, however it is acknowledged there is urgent need to consider the potential operational methodologies and parameters to be able to make a quantitatively informed decision on whether to progress the programme of work. This requires us to consider cost and, in some cases, test prospective methodologies to inform that decision. Also, some urgent issues need to be rapidly addressed to maintain options for advancing an eradication operation and providing a framework and accountabilities for the decisions that need to be made.

We must acknowledge that an eradication of an amphibian has never been achieved on the scale we are considering here, or in such a complex environment. Thus, we cannot confirm whether eradication is feasible until we have evaluated potential eradication tools. Each potential tool must be tested promptly to evaluate its relative efficacy, bearing in mind factors such as life-history stage (eggs, tadpoles, metamorphs, juveniles, adults, breeding adults), season and ecotype, when relevant. It is probable that any one method will be inadequate to achieve eradication within a given area. Therefore, we have to consider a strategy that uses multiple tools (Methods will need to be used concurrently too.), based on efficacy at a particular population density. This order of application of those tools is also a strategically critical element of successful eradication to avoid creating a difficult-to-target residual population.

1 URGENT ISSUES

1.1 Governing/leadership body – It is extremely important a small body be identified to lead all efforts related to the toad incursion issue. No eradication programme is possible until accountability is clearly identified and the remit to lead the programme of work is defined.

Recommendation: Discuss with current lead organisations and key in-country partners to date (Malagasy government, MFG, Association Mitsinjo, ASA) how this body should be made up and how they will be supported. It is vitally important that a governance/leadership body be designated as soon as possible as it is necessary for evaluating and acting on the recommendations of this report. This body needs to be responsible for immediately raising funds to achieve the goals discussed below. Once funding is available and administrative structure in place (see next item), secondary administrative structure can be responsible for raising subsequent funding, as needed.

1.2 Management and administration structure – Beyond the leadership and accountability necessary to steer such a programme of work it is essential there is accountability for administering the resources and infrastructure required. This ideally would be undertaken by a single organisation so that there are clear lines of accountability and responsibility and preferably, by an organisation that has an existing structure in place in Madagascar—facilitating faster implementation of any work. Considering the limitations on capacity in Madagascar, this function may need to be sourced elsewhere.

Recommendation: During discussions in Madagascar, it was suggested adequate resourcing were available to support the full costs; MFG may be able to consider such a role. This possi-

ble option should be urgently explored further. The authors are not aware of alternative options.

1.3 Financing – Costs of development of eradication methods or the underpinning research to support such methods will require funding. It is extremely difficult to secure funding without a very clear, prescribed proposal, yet delays in securing funds will seriously undermine eradication potential.

Recommendation: Lead organisation should communicate with major possible donors, funders and partners (e.g., IUCN, UNEP, UNDP, ADB) to highlight the issue and potential requirement for rapid funding. Our proposal here is to seek US\$385,000 for the first twelve months of research, development and testing. Should eradication proceed beyond this point the project is likely to cost between US\$2 m – US\$10 m and take at least a further 5–6 years to complete.

1.4 Biosecurity & education – It is an immediate concern that the toad may be inadvertently spread beyond its current incursion area by accidental transportation in goods and equipment being moved out of the incursion area. It is clearly extremely challenging to achieve adequate biosecurity for all internal trade moving through the incursion area. However, minimum measures should include a nation-wide awareness campaign identifying the toads and recommending actions, including reporting any interceptions with the accountable governing body of any eradication effort as well as reporting any new incursion sites.

The second major concern regarding biosecurity is the seaport of Toamasina/Tamatave. During our evaluation we were not able to gain access to the inner port area, but examination of the area and its perimeter highlights the fact that there is no effective barrier to the spread of the toad into the port area. The presence of toads in the port facility would significantly increase the risk of toads being transported to other locations, especially those with significant trade from Tamatave.

Recommendation: Lead organisation should develop a communication and education programme to raise awareness of the invasive toad and provide channels for reporting new location sightings. Although international standards in biosecurity vary greatly, and we acknowledge the limited infrastructure in Madagascar, suggesting actions as simple as enforcing cleanliness and tidiness in port storage and handling areas, together with well-displayed and easily understood instructions to collect and report any organisms to staff made responsible for their removal, could significantly reduce risk of toads and other organisms being transported to and from the port.

1.5 Mapping/GIS – There is a need to accurately map and delimit habitat types and identify the extent of the incursion area as well as potential barriers to toad movements within and around the incursion area to assist in strategic planning of any eradication effort.

Recommendation: Look for GIS mapping experts within government and the private sector who can be contracted to work on the project. It is important they have a clear understanding of working with environmental data.

1.6 Delimitation – Although efforts have been made to describe the full extent of the toad incursion, the methods used are likely to be insensitive to toads in low-density populations. As we do not understand the population dynamics of the expanding incursion we must assume toads may occur over a wider area in densities low enough to avoid casual observation.

Recommendation: Specific efforts should be made through a communication plan to raise awareness of the toads in towns and destinations likely to have received significant freight from the incursion area. Survey teams able to efficiently question local communities about toad presence and conduct their own searches should be dispatched to the highest-risk sites. To achieve this, the communication plan will need to have a national reach and be appropriately designed to ensure the key messages reach rural, as well as urban communities.

2 METHOD TESTING AND EVALUATION

Although this report is not an eradication operational plan, it is essential any eradication plan will consist of the application of a suite of detection and eradication tools to give the programme hope of meeting the minimum criteria of eradication.

All eradication methods will require testing to evaluate their efficacy to remove the target animal. As eradication against this species has never been attempted before, nor any eradication conducted around Tamatave, nor any amphibian eradication conducted at such a large spatial scale, we are considering the use of methodologies untested against such a large incursion. Hence, it is critical that we evaluate efficacy of potential tools across the range of ecotypes over which we need to operate. The application of methods will rely on understanding the numbers of individuals being targeted, their life-history stages and the proportion of those individuals that can be intercepted and removed with each technique.

Due to the time constraints of this project the methodologies proposed are not exhaustive, but hopefully cover the majority of tools and methods likely to be relevant for an eradication effort. Should research and eradication be operationalised, then further investment should be made in consulting those in the field of vertebrate eradication.

2.1 BASELINE DATA, IMPORTANT ISSUES AND MONITORING METHODS

The following methodological proposals focus on baseline data gathering and detection tools. It is necessary for us to evaluate variables such as average density to assist in the evaluation of techniques as a component of an eradication plan. Estimates are acknowledged as indicative only but are necessary to provide the best information to inform response decisions needed to be made swiftly and pragmatically.

It may seem inefficient to consider methodologies only able to detect toads rather than methods that both detect and destroy toads. In an eradication scenario it is important to consider methods that have the greatest probability of detecting the target animal as well as methods that detect and kill. If there are monitoring methods significantly more sensitive to toad detection than those able to

also result in toad capture, then they will be important components of accurately delimiting the incursion area, as well as confirming successful eradication.

2.1.1 Density estimation

Purpose: From the data gathered to estimate average toad density within the incursion area it will be possible for us to evaluate the apparent demographics (age and sex) of the toad population and any anomalies that may provide opportunities to strategize eradication. Most importantly will be the ability to extrapolate the data to the full known extent of the current incursion and make more appropriate estimations of the effort required for eradication planning, and the relative risk of methodologies being inadequate to achieve eradication.

Method: An initial and moderately low-cost action should be to evaluate the apparent density in a range of ecotypes known to contain moderate to high toad densities: urban (suburban settlement), intensive agricultural, and unmanaged vegetated habitat. We recommend that toad densities be estimated at several sites, preferably, 2–3 sites in all major ecotypes. This can be done quickly and cost effectively by small-scale destructive habitat clearance. The scale on which such methods should be employed should be limited to only 2–3 sites per major ecotype as the information gathered is indicative only for the scaling of subsequent methods testing, for extrapolating approximate toad population size, and therefore for enabling an improved evaluation of risk of proposed eradication strategies. The proposed methodology is to demark an area being no less than 10 x 10 m and no greater than 20 x 20 m. If possible, construct a “toad-proof” temporary fence using standard drift-fence designs or, if this method is not possible, employ additional labour to clear the periphery of the area to be searched and ensure the area remains under observation so toads do not move in or out of the area. A team of searchers then work through the area from one side of the area to the other within 2–3 m of each other clearing vegetation and any materials in or under which toads may be hiding. It will be necessary to have machete and spades available for the clearance of vegetation that cannot be effectively searched without removal. As such it is important the areas selected for the searches meet certain criteria:

1. Landowner consent is achieved amicably.
2. The area to be searched does not contain crops or anything the owner is not comfortable to be moved or damaged during a search.

All toads observed must be collected and placed in an escape-proof bucket protected from excessive direct sunlight. Once the team have made one thorough sweep of the area they should repeat the process ensuring that no opportunity remains for toads to occupy the area being searched.

Once the search is completed the collected toads should be swiftly examined and each individual measured (SVL), sexed and humanely euthanised by pithing, or by other means deemed humane by veterinary experts. If skeletal chronology (further discussion of this method below) is to be pursued, then limb samples should be collected and stored in labelled appropriate media.

Logistics and costs: This proposed work will require a team of at least six individuals led by someone with complete oversight and understanding of the technique being pursued and the skills to accurately record the data gathered. Transport will be necessary, involving vehicle and driver. Teams should be able to examine three sites per day, and if we aim for 3x sites in urban/suburban, 3x sites in rural agricultural and 3x sites in unmanaged habitat we will need 21 man days for the survey, an additional seven man days to reconnoitre sites, and four man days to record data and synthesise into a brief report. Working on a budget of US\$20/person/day plus US\$120 for vehicle costs (both costs approximated from observed costs during feasibility study visit) then this work will cost a minimum of:

- Survey labour: US\$3,080.
- Vehicle costs: US\$600.
- Analysis and brief write up: US\$80.

Total: \$3,760

The logistics of such an effort will require local knowledge and community-relations skills that appear to be exclusively offered by MFG in the region of the incursion. Staff would then be a mix of those with skills (as previously provided by the Association Mitsinjo), local knowledge (MFG) and probably some technical oversight from someone with ecological skills (e.g., Devin Edmonds, Roger Daniel Randrianiana). It is our understanding that this work is in part already under way.

2.1.2 Humane euthanasia

Purpose: Methods of humane euthanasia are essential to the testing or employment of any toad eradication tools. Methods need to be approved by an appropriate animal ethics body. This is an important issue as the use of humane methods will be a prerequisite for any donor supporting an eradication or research programme. Failure to develop and adhere to ethical practices risk both funding and the reputation of the programme. This may seem like an unnecessary complication but it is an essential component of considering the eradication of any invasive vertebrate organism.

Method: The lead body accountable for the eradication should consult with veterinary experts and an appropriate animal ethics committee to identify appropriate methods currently accepted for the humane euthanasia of toads. This will need to be done in an informed manner with consideration of the need to have methods appropriate for use by unskilled workers within the context of the incursion environment in Madagascar. It is necessary different methods will be developed for different life-history stages. Eggs may have to be euthanized using desiccation methods ensuring all eggs are quickly rendered incapable of further development. There are established chemical methods for the euthanasia of tadpoles probably not suitable for the widespread use by unskilled labourers. Therefore, a method of trauma or rapid exposure to extreme heat may be appropriate, such as the decanting of tadpoles and toadlets into mesh baskets can be rapidly exposed to fire. Similarly, newly metamorphosed toadlets and small juvenile toads may require similar methods of euthanasia. Adult toads are likely to be quite robust animals and will require methods ensuring swift death, probably through trauma. Pithing and/or decapitation using specified tools are likely to be the solution. Due to the large numbers of toads that will need to be killed in this operation, the development of a

spring-loaded device than can release a bolt under pressure to cause lethal trauma to the brain may be a worthwhile investment. Obviously decapitation with a machete is a method well worth consideration, as unskilled workers are able to handle such tools, and the strategy avoids development and manufacturing costs of alternative devices. Personnel training will ensure proper execution of any chosen method(s) and ensure unnecessary suffering to animals euthanized as quick and painless as possible.

Costs and logistics: Very difficult to estimate without further investigation but we imagine the time cost of animal ethics groups, together with the development of tools is likely to cost in the region of **US\$10,000**. The production of any tools to support eradication would require the manufacture of hundreds of devices. The use of available technology such as machete decapitation and the use of fire for tadpoles/toadlets would significantly reduce this cost but must be approved by an animal ethics authorities.

2.1.3 Tracking tunnels

Purpose: Tracking tunnels are a low-tech method of passively detecting the presence of animals through the recording of their tracks. Although visual searches and local reports may be very effective as methods of determining presence or absence at moderate to high densities of toads, we need to focus on methods able to detect toads at much lower densities avoiding false negatives when assessing distribution. Such methods have been increasingly used for the passive monitoring of herpetofauna in New Zealand (NZ).

Method: Tracking tunnels are mass-produced cards with a central portion covered in persistent ink. They work either passively, recording the tracks of whatever animal passes through them during their deployment, or can also include a lure to increase the likelihood of the target animal entering the tunnel. They are used extensively in New Zealand to monitor abundance of invasive rodents baited with peanut butter and deployed in lines of ten at specific spacings for a single night (Fig. 1). The tracking cards are placed within plastic or corflute tunnels that can either be purchased or constructed.



Fig. 1. A tracking tunnel showing rat tracks in New Zealand.

These devices could be tested to evaluate their usefulness by deploying lines of ten tunnels at prescribed spacings (e.g., no less than 20 m) focusing on likely locations, such as against walls, within vegetation, and adjacent to waterbodies. Ideally the tool would be tested in areas of known densities or at least high-density and low-density sites and within experimental enclosed areas where very low toad densities can be controlled, to determine their usefulness. As no tested anuran lure is currently available, it is recommended tunnels be tested unbaited. Again this avoids attracting rodents, whose tracks would potentially obscure toad tracks. The ink does dry out slowly and depending on weather, tunnels should be retrieved within 3–5 days and their ability to detect toads assessed (e.g., how dry the ink has become, the level of print coverage from non-target animals). The tracks of toads should also be collected by encouraging captive toads to travel through tunnels so observers have good reference prints of different-sized toads as well as likely local non-target species (rodent print patterns are readily available digitally, but other non-target native species, especially frogs, would need to be observed). If proven useful, this tool can be deployed relatively cheaply at multiple locations and is likely to provide greater sensitivity to at least moderate toad densities, compared to visual searches. It does not seem this method has been used to monitor the presence of amphibians elsewhere; hence, the need to test this method is of utmost importance in determining its usefulness for toad monitoring purposes.

Logistics and cost: The primary logistical concern is interference with the devices. In urban areas, the public may remove or disturb tunnels out of curiosity and if the construction materials are deemed useful, they may be collected for alternative uses. However, if they are deemed effective, staff are able to identify toad prints, the ink remains effective for a sufficient period and tracks are not regularly obscured by non-target animals, then they may be an appropriate detection tool. Their de-

ployment costs will depend on the number of sites deployed and the numbers used at each site. The costs of experimentally evaluating these tools are hard to estimate, but US\$5,000 is probably sufficient. If proven useful as a monitoring tool, a single worker should be able to deploy lines of ten tunnels per site at four locations/day, allowing time for careful placement. This would involve the following costs:

- 50 tracking cards and 40 tunnels: US\$470 (example costs: <http://www.gotchatraps.co.nz/> there may be more cost-effective local alternatives).
- Vehicle costs: US\$240.
- 4x full day labour (driver and worker, deployment and collection): US\$80.
- **Total per four sites: US\$790**

All field work will need to include a community-relations component seeking permission from local landowners and community leaders. This may add additional costs prior to tunnel deployment.

2.1.4 Acoustic monitoring

Purpose: Listening for toad calls may be an extremely effective way of detecting the presence of a population of Asian toads. The development of remote acoustic recorders and analysis software makes this technique even more effective but with significant added cost. The technique is only sensitive to calls of adult males and so will be best utilised during early wet weather periods when calling frequencies are highest among males (advertisement calling). This is a passive monitoring tool designed to be sensitive to low-density populations in which only a few individuals may be calling. While accompanying a recorder with a system broadcasting toad calls may illicit call responses in males we suspect that something like five days recording period would offer a similar probability of detection with less complexity and cost. The tool is expensive and logistically complex (see below) so is only suitable for the targeted analysis of incursion delimitation and potentially in the monitoring of eradicated areas in the final years of eradication. For a majority of sites it would probably be more appropriate to train local staff to listen for and record toad calls and locations to describe the range and extent of breeding habitat.

Method: For the use of electronic recorders, there is a number of commercially available acoustic recorders available, and whichever model is to be evaluated first needs to be tested for its effective range for detecting the call of toads under “average” conditions (ambient noise of wind/rain etc.). We then need to consider recording periods, as recorders can record continuously or only during programmed times. If toads are demonstrated to only be crepuscular/nocturnal callers then the recorders should be programmed accordingly. At the sites chosen in close proximity to potential breeding pools, it will be necessary to have fieldworkers manually record the frequency of calls in conjunction with the recorders to demonstrate their sensitivity as adequate. The recorders are unlikely to be as sensitive as the human ear (similar trials with kiwi call recordings in New Zealand demonstrated this) but we also need to know the recorders are sensitive at least to an area of 50 m radius to be a useful monitoring tool. The greater the sensitivity the more useful the tool will be. Some acoustic recorders have bespoke software for analysis, whereas other methods will require the use of sonogram analysis software such as Raven. If demonstrated as sufficiently sensitive to be

used as a monitoring tool, the devices will need a deployment strategy designed likely to focus on proximity to water bodies.

For the majority of easily accessed sites it will be more cost efficient to train and dispatch local workers to listen for and record the locations of toad breeding pools.

Logistics and cost: Acoustic recording devices range in price and sensitivity from the US\$849 Bioacoustics recorders (<http://www.wildlifeacoustics.com/store?slider2=song-meter-sm3#song-meter-sm3>) to much less expensive units, such as those developed by the Department of Conservation (New Zealand), that are available for US\$200 per unit. Software costs vary with use. As with other device-reliant methods, the primary logistical concern is interference with the devices. In urban areas, the public may remove or disturb recorders out of curiosity or to sell. This risk considered with the potential alternative of using field workers to listen and record toad calling means acoustic recorders are probably only useful for sites suspected to be low density toad areas and sufficiently inaccessible that costs of regular visitation and diminished risks of recorder loss or theft mean this method is preferable. A major cost of this technique would be the analysis of acoustic data gathered. It also offers logistical challenges of staff access to computers and necessary training, making this method expensive and for targeted use only at periphery sites where efforts are being made to delimit incursion area.

As mentioned, it will be more cost efficient to dispatch trained staff to survey for calling toads at potential breeding pools and this could be achieved at the usual cost of transport and train staff labour together with costs of data collation, analysis and reporting.

- Using a vehicle and driver with a trained field worker (calculated at **US\$320**) this would probably allow the surveying of 3–4 sites per day.

2.1.5 ENVIRONMENTAL DNA

Purpose: A major concern in the development of incursion responses to invasive species is the ability to ensure the area of incursion is fully delimited. Several methods are available for consideration as described here, and possibly the most efficient and sensitive is the use of environmental DNA (eDNA) sampling. Animals permanently shed tissue and cells into their environment, and those with aquatic lifestyles shed their tissue containing DNA into waterbodies they inhabit. Modern DNA amplification techniques are so powerful and cost effective it is possible to now identify the presence of a species from a series of water samples. The power of this technique is obviously not to confirm presence of, in our case, the Asian toad, in a waterbody in which they are abundant and easily observed. The power of the technique comes when evaluating waterbodies of any size that may be being used by only a very small number of toads intermittently. Even if toads have been absent for several days or even weeks, their DNA is likely to persist in the water column and is available for detection. Using this method it is possible to detect the presence of Asian toads in areas of low density or at the very periphery of their current range. Pools the toads are using for breeding will likely hold eggs and tadpoles at varying developmental stages, which promises to provide a strong molecular signal of Asian toad presence. Fortunately, Madagascar does not contain Bufonidae congeners so the probability of false positives are also reduced. The longevity of DNA in sediments means that the technique is of reduced value for follow up monitoring once an area has been cleared of toads alt-

though this issue has not been examined in tropical environments where degradation of DNA fragments may be accelerated.

Methods: Sampling of waterbodies is a very straightforward procedure of collecting multiple samples from the water column. Concerns exist that DNA may persist in sediment for extended periods and so in other instances care has been taken not to disturb sediment, as this can compromise results. This is less of a concern when delimiting species such as in our instance, unless we believe there may have been dynamic changes in the area toads are occupying over the period of the incursion. The main risk to the method is contamination between samples, and therefore a single site use kit would need to be developed so that collection equipment (dippers, etc.) and containers are only used once. Staff will need to be trained in collection protocols to ensure they are aware of the risks. Sample transport and storage requires samples are maintained in a chilled state (2–4 degrees) but not frozen.

We are not aware of the existing development of primers to sequence *D. melanostictus* samples. Once lab methods are available it is a fairly simple automated process of testing samples to determine presence or absence of toads. Laboratory analysis of samples is usually best done commercially, but this may be a situation where it is desirable to develop skills in country through collaboration with Malagasy universities.

Logistics and Cost: The major logistical challenge with this method will be ensuring all staff are trained in appropriate collection protocols and all samples are appropriately stored until analysis. The development of laboratory facilities in Madagascar, if none exist currently, may pose some large challenges but none insurmountable with good collaboration with an experienced lab. The recent use of eDNA techniques to delimit an invasive newt in New Zealand allowed us to accurately cost the methodology:

- Technical development of protocols to handle samples: US\$8,000.
- Sample analysis per 100 samples US\$1,000.
- Sampling equipment kits per 1,000 sites US\$5,000 23k.
- Labour and transport to collect samples (@ five sites per day) US\$320 per day.
- Sample storage and transport (guesstimate for fridges, etc.) US\$2,000.
- **Total for 1,000 sites US\$89,000**

2.2 DETECTION AND ELIMINATION METHODS

The following methodological proposals focus on tools necessary to remove toads from the environment. To reiterate, whereas one method may prove to be extremely effective, it is highly unlikely to be adequate to remove all individuals of a target animal such as the Asian toad that has such a range of life history stages requiring necessitating different methods of capture.

2.2.1 Detection and removal through delimited hand surveys

Purpose: The Asian toad is present in such numbers within much of the incursion area the size of the toad population and local economy mean hand collection is potentially a viable method of targeting the animals. While toads are mostly active by night, it is potentially possible to search the habitat during the day and achieve an acceptable rate of collection to justify this method inclusion in trials. This method would rely on local labour and probably act as an early stage tool for any eradication effort. With locally recruited teams of toad catchers, there will be a need to evaluate the proportion of toads collected in different ecotypes. Before the methodology can be considered as part of an eradication plan it will be necessary to measure its effectiveness. Thus, there are two parts to the discussion of this method:

Method: Testing methodology - To test this method it will be necessary to identify experimental areas that can be enclosed by toad-proof fencing. Such fences can be of the standard amphibian drift fence type but may need to cover an area of at least several hectares to provide the data required. Sites should be selected in areas of high toad density and preferably replicated in urban, rural-agricultural and rural-unmanaged ecotypes. Once fenced, the area is searched by a small team, and all toads located are recorded, removed and killed. Following this knock-down of the easily detected individuals the area is surveyed by experienced staff that collect as many toads of all age stages as possible putting in maximum effort to ensure as many individuals as possible are located. As the toads are detected, a second team implant PIT (Passive Integrated Transponder) tags into toads larger than 40 mm SVL. For toadlets smaller than this size we should consider implanting VIFETs (Visible Implant Fluorescent Elastomer Tags) into the toads. All toads are then released at the exact site of capture.

Once completed, the area and tagged toads are left for a minimum of five days to ensure they return to normal behaviour and refugia. A toad-collection team consisting of at least four workers per hectare then search the area using some destructive measures (e.g., vegetation removal) to remove as many toads as found. The day search should be repeated at dusk/night to try to intercept toads as they become active. The search effort should be repeated until a complete sweep of the area yields no further toad captures.

An alternative and possibly preferred strategy would be to find a habitat currently unpopulated by toads, build the experimental enclosures and then populate the enclosures with toads, all of which are tagged and conduct collection surveys as described above. The risk of this method is the need to populate experimental enclosures with toads but considering the extent of the current incursion, this small potential expansion is inconsequential to the investment in method development.

As toads are collected, they are scanned for PIT tags and a record made of each individual identified. The results will be scrutinised according to two issues: first, the proportion of the tagged toads that are detected, and second, the number of toads collected that were not pit tagged. The first analyses will inform us of the sensitivity of manual searching for toads with the effort invested. The number of untagged toads will help indicate the proportion of the population that should be expected to be difficult to detect with non-intensive methods.

Should the proportion of the tagged toads captured prove to be extremely high, by which, considering the 120 km² area of the incursion, should be greater than 99%, and no untagged toads are detected then we would propose that the methodology is appropriately successful to suggest declaring

eradication feasible within the ecotype in which the trials have been conducted. Ideally, we would recommend replicating the trial to at least three locations within each ecotype.

To operationalise this method there will need to be considerable investment in the strategic deployment of barrier fences to enable cleared areas to be delimited.

Logistics and cost: Costs of a trial are likely to be:

Cost per site: Labour (12x days 6x labourers at US\$20 per day, including overhead costs) – US\$1,440.

Transport (12 days @US\$120 per day plus driver at \$20 per day) – US\$1,680.

Fencing materials (@ US\$20 per linear meter NZ material costs est.) - US\$12,000.

Pit tagging equipment (US\$4,000 – including reader one-off cost) – US\$2,500.

Total – US\$17,620

One-off costs

Scientific & field management – US\$8,000.

Pit Tag reader – US\$1,500.

So for three locations the total trial cost would be: **US\$62,360**

The concept of manually searching a minimum of 120 km² using this technique over at least three seasons entails the employment of probably hundreds of workers and enormous management, communications, transport and administration structures. If we speculate that the delimitation is achievable, the labour available at US\$5 per day, and it will take four workers an average of two days to service each hectare, then, by extrapolation, the costs of this technique will be US\$240,000 per annum without consideration of infrastructure, transport, communications and administrative costs. We would guess the total cost of this method and administration would approach **US\$1m per year**. There are many logistical risks to this method, not least the complexity of coordinating such a huge labour force, negotiating access to all areas and ensuring a communication programme that prevents misinformation or the undermining of efforts.

For the trials, a technical risk here is the natural ejection of PIT tags, which ideally would require research on sub-cutaneous or intra-coelomic implantations to determine which method works better.

2.2.2 Barrier fencing and pitfall trapping

Purpose: It will be necessary to delimit areas that have been searched, from areas that have not, so as to prevent reinvasion of toads. It will also be necessary to delimit areas requiring different eradi-

cation methods, such as waterways. Delimitation will need to be maintained at a scale adapted to the areas being treated and maintained for the period of the eradication. The inclusion of pitfall traps along such fences would enable the capture of any toads attempting to disperse within the area. A specific focus of this method would obviously be breeding pools where it may be possible to intercept a very high proportion of the local adult toad population, if fences and pitfall traps are well maintained and serviced.

Method: Standard drift fence designs will be appropriate for these barriers but the use of durable materials will be necessary to ensure longevity. The fences will need to be dug into the substrate a short distance and their deployment should make use of natural barriers such as walls, or accessways such as roads/tracks. Pitfall traps can be simple buckets dug into the ground, but their humane use requires daily checks and the removal of toads for humane euthanasia and the release of non-target organisms. There is no need to test by trial this method, as its successes and design are well documented in the literature and by our personal experience.

Logistics and cost: The issue here is feasibility, scale and the issue of interference by people, vegetation and livestock if deployed for long periods. The costs of delimitation are likely to be large. If we assume that there is a small pool requiring fencing every five ha we would require approximately **US\$660,000** in material and construction costs.

The primary logistical concern is interference with the devices. In urban areas, the public may remove or disturb fences for alternative uses.

2.2.3 Citric acid/Sucrose spray

Purpose: A 16% citric-acid spray is known to be effective in killing frogs with moist skin and has been used to eliminate populations of Coqui frogs (*Eleutherodactylus coqui*) in Hawaii for many years. The method works by inducing rapid dehydration of frogs due to osmotic imbalance between the spray and the internal tissues of the frog. Theoretically, this same osmotic effect can be had with any concentrated solute sprayed on frogs; hence, sucrose (sugar) may also be useful in this regard, although it remains untested for toads. Sucrose could be an attractive alternative, if effective, because it should be easier and cheaper to obtain in Madagascar. However, neither solution has yet been tested on toads, which, because of their dry skin, may not be as susceptible to osmotic water loss as most frogs. Hence, tests need to be done to assess whether either solution could be effective for this purpose against *D. melanostictus*.

If effective, this method is likely to be of greatest use for rapidly treating the high densities of newly metamorphosed toadlets as they leave and accumulate around pond margins. Treating the conspicuous adults with this method is liable to be no more effective than hand capture would be, so its utility is likely to be primarily for high-density concentrations of toadlets.

Method: Simple laboratory trials spraying a handful of toads (ca. ten each) with a 16% citric-acid solution or a 27% sucrose solution need to be tried. Toads would be housed in individual small containers, removed to spray enough to wet their backs, returned to the containers and observed for mortality/morbidity in 24 hrs. If toads do not die within that time period, the method will be ineffective for control. Tests of each compound should be done both on a sample of adults and a sample of

newly metamorphosed toadlets. Adults would be tested primarily to ascertain species susceptibility to the method, even though it is anticipated that the greatest need for the method would be against toadlets. If effective, spraying of toadlets would allow for rapid and effective killing of large numbers and avoid the need to capture each small animal when at high densities.

Logistics and cost: Both compounds are safe for human use and, indeed, are present in numerous foods hence, concerns about human poisoning are virtually non-existent. If effective, either compound would only be applied to terrestrial life stages of the toads. Experimental costs to test efficacy are expected to be low as all that is required are the materials and a sample of, for example 20 metamorphs and 20 adult toads and basic lab equipment such as holding tanks and spray bottles. Some cost would be incurred ensuring scientific oversight to quantify the concentrations and the level of subject exposure. We will also have to test effective application methods. Ideally this would be done using helicopter mounted agricultural spray equipment but it is doubtful that such equipment is available in Madagascar. Therefore, we need to evaluate the use of backpack spraying and the use of local labour. Costs are estimated to be **US\$8,000** to cover lab costs and advisor expertise.

An education programme will be required to ensure that locals are aware the use of the spray poses no risk to them or the environment so as to ensure that local support for the eradication is not threatened.

2.2.4 Acoustic location and physical capture

Purpose: Virtually all frogs reproduce by males attracting females to breed via acoustic calling. Calling among males is competitive; hence, males that hear another male call are frequently induced to call themselves in order to compete for the females' attention. This attribute can often be used to survey for frogs: if a recording of the species' advertisement call is played, nearby males can often be induced to call in response, thereby indicating their presence in the area. This method can potentially be used to illicit toad calls during the breeding season even when they occur at low densities. Hence, this provides a sensitive means of surveying the limits of the toad's distribution around Tamatave and also a possible method for intercepting male toads at extremely low densities.

Method: Visit potential breeding sites at night during the wet season, play the call of the species for ten minutes or so, and listen for responding males. If males are heard to respond, they should be tracked down, captured and killed. With two searchers and a little experience it is usually quite easy to triangulate the location of a calling toad and remove it.

Logistics and cost: Recordings of this species are already available on the internet. They merely need to be downloaded or obtained from the original poster with permissions to use. Equally, it would be very easy to record calls from within the current incursion area. Equipment needed would be a few digital recorders having powerful enough audio playback to broadcast the call around surveyed wetlands. Professional equipment is available for this purpose, such as the Foxpro (<http://www.gofopro.com/site/products/digital-calls/wf2>), which is robust to field use and cost **US\$200** each. Costs for the use of this technique would depend on the number of teams, amount of transport required and the number of call players requiring purchase (one/team, with a few backups in case of damage to original equipment). The method might be combined with remote acoustic monitoring for the detection of extremely low-density toad populations.

2.2.5 Tadpole traps

Purpose: Research on the related Cane toad in Australia has shown that tadpoles of that species are attracted to the chemicals secreted by the poison glands of the adult toad. Experiments have shown if these poison secretions are collected on microscope slides and placed inside a small aquatic trap, tadpoles of cane toads can be collected in large numbers, even removing most or all tadpoles from small ponds within a few days. Whether this method can work for the species of toad at Tamatave needs to be assessed.

Method: Construct a dozen or so tadpole traps (design given in Crossland et al. 2012), collect adult toads from which to obtain poison secretions, collect the secretions on microscope slides and place the slides in the traps and the traps in test ponds known to harbour tadpoles. Check the traps every day, remove and count trapped tadpoles and determine how long the traps remain effective in each pond. If small isolated ponds are tested by trial, once the traps are removed, visually check for tadpoles or use fine nets to check for efficacy (i.e., how many tadpoles remain).

Logistics and cost: This method should be able to be tested in fairly cost-effective manner in “lab” conditions potentially somewhere like the Parc Ivoloina by local researchers. Costs will be the materials to construct the traps, microscope slides, one box of latex surgical gloves, labour and vehicle to collect tadpoles/toads and deploy the traps. An estimate would suggest a budget of **US\$5,000** would cover field and lab costs for a methods trial that determined relative effectiveness under different environmental conditions.

2.2.6 Herbicide

Purpose: It may be appropriate to consider the use of certain herbicides to clear riparian vegetation surrounding waterbodies used by toads for breeding and also for the clearance of dense vegetation that otherwise restricts the ability of searchers to examine and capture toads.

Method: Standard application of glyphosate herbicides such as Roundup can be used. The use of such chemicals around waterbodies is contentious and so formulations with higher glyphosate concentrations and no surfactants have been developed.

Logistics and cost: Labour and chemical costs, together with some training of operators, would result in a per ha cost that will be influenced by the cost of locally acquiring glyphosate herbicide. Planning and transport would be additional costs and, due to the visual impacts and potential ecological impacts, both local ecological assessment and a consultation and communication plan would need to be components of this work. We imagine the total costs of this method, if applied broadly within the incursion area, would be in the region of **US\$100,000**, considering the opportunities for its use. We are not aware of the environmental legislation that may exist in Madagascar to describe the limits of use for such methods.

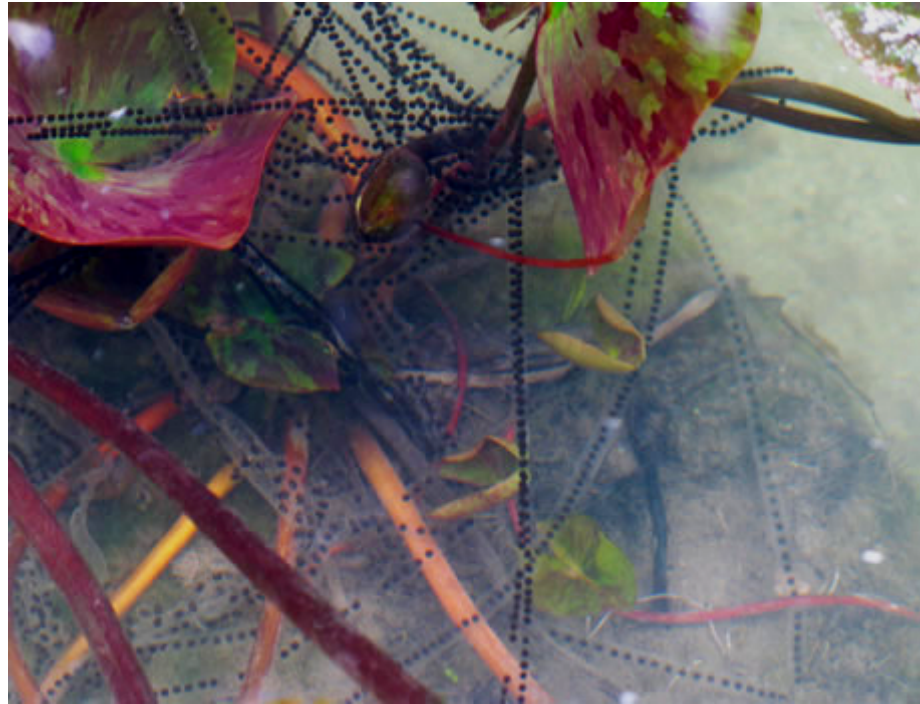


Fig. 2. Asian toad egg strings in small pond, Hong Kong. *Photo: Lung Fu Shan Environmental Education Centre.*

2.2.7 Egg collection

Purpose: Prior to hatching into tadpoles, Asian toad eggs may be able to be efficiently collected, thus reducing population productivity in areas where the toads breeding pools can be easily accessed and searched. This method has been used as a component of successful Bullfrog control programmes in North America but we acknowledge that the Asian toad is known to lay eggs at all depths within waterbodies (Fig. 2) and so the effectiveness of such collection might be restricted to smaller, shallow waterbodies.

Method: Workers would visually search waterbodies with bags or buckets into which the eggs are collected. A cost-effective method of destroying the eggs would be desiccation in the sun, burying or incineration.

Logistics and cost: Labour and transport to sites. It must be noted that this method will be questionable if Asian toads lay eggs at varying depths in waterbodies. Also, it would require the searching of all waterbodies in any area delimited as suitable. The proximity of any large unsearched waterbodies and even a modest number of smaller waterbodies would quickly nullify any efforts made due to the numbers of eggs produced by Asian toads.

2.2.8 Refuse management

Purpose: The incursion area in and around the port city of Tamatave has a serious urban refuse management problem. Although this issue is likely to be a human health issue, it is also a potential reservoir and vector for the Asian toad. Refuse appears to accumulate along roadways in the urban

areas and is communally dumped at sites around the periphery of the city. These piles of refuse provide habitat for toads to seek refuge and are extremely challenging to search for toads because of their complex and hazardous nature. The transportation of waste to these sites is also a potential vehicle for the spread of toads. Therefore, we recommend that refuse clearance and disposal protocols be developed for the incursion site that do not risk spreading the toads further and use methods to destroy toads concealed in the refuse.

Method: The details of this proposed method require civil engineer input, but we will tentatively suggest conventional land-fill type disposal of refuse accompanied by the rapid covering with soil could be a solution. Currently there is a programme of work that is taking refuse to the tailings disposal site of the Ambatovy nickel processing plant. This might be appropriate, but to prevent the spread of toads, this program should be evaluated in terms of the secure nature of the trucks used to transport the refuse and also the timeframe from refuse dumping to coverage. This should be done swiftly enough to prevent toads escaping. Data provided by the Ambatovy Mine suggests that the transport of refuse to the site has already spread Asian toads to the area.

Logistics and cost: Local civil authorities and municipal engineers would be necessary to properly design and comment on this suggestion.

2.2.9 Toad dogs

Purpose: To those with limited experience in vertebrate eradications, the suggestion of training a “toad dog” may at first appear expensive and inefficient. However, should an eradication effort be undertaken and prove to be making positive progress towards success, then the training of toad dogs may prove to be extremely useful for the location of the final individuals. Dogs are well recognised for their olfactory skills and ability to be trained to a specific target. Although there is no reason to believe toads pose a problem to this technique, it must be stated that it will be essential to use operators with experience to oversee a toad-dog programme.

Method: While trained dogs could be brought to Madagascar it is probably best to consider engaging the time of an experienced handler/trainer to work over a period of months with a prospective handler and candidate dogs in Madagascar. We can't determine whether Madagascar has an existing detector dog programme attached to either the military or other government agencies. A method that has provided quick results in NZ is the retraining retired security dogs that have demonstrated their ability in detecting explosives/narcotics. This has been achieved with retired bomb-locating dogs in NZ for locating the invasive alpine newt. It will take at least a year to successfully train a dog to be a reliable toad dog, and provision must be made to maintain the skills of any dog trained for the duration of the eradication programme. It is critical that the effectiveness of detector dogs be determined through controlled trials.

Logistics and cost: International expertise will be the largest cost involved in this method. We would estimate that training would require at least three extended visits by a trainer, which if obtained from a country such as NZ, would probably cost in the region of **US\$90,000** for three visits, each of an eight week duration (including flights).

2.2.10 Capping waterbodies

Purpose: The incursion area is unfortunately in an area with a great deal of standing natural water and drainages, which provide obvious obstacles to any amphibian eradication. However, in many areas, including urban areas, it may be possible to drain and fill small to medium-sized waterbodies that are of no municipal or significant ecological value. This may have the dual benefit of reducing potential breeding sites for disease vectoring mosquitoes.

Method: Civil engineer engagement will be essential for larger projects, but smaller waterbodies should be easily drained using conventional wajax pumps and earth-moving equipment to fill and cap the area with soil/substrate.

Logistics and cost: Costs will be as per civil engineering costs in Madagascar. No doubt there would be challenges of obtaining skills and access to a plant in a location like Tamatave. Communication and consultation with local communities will be essential for this method.

2.2.11 Chemical treatment of waterbodies

Purpose: As tadpole traps are as yet untested for Asian toads, it is important to consider additional means of targeting tadpoles. One method worth consideration is the use of rotenone or similar compounds to kill tadpoles. Rotenone is only effective on individuals with gills and so will not be equally effective for all developmental stages. However, the use of such a method has great application for waterbodies otherwise difficult to search or access. In New Zealand, we are currently conducting trials for the use of rotenone with newt larvae. We should also consider whether there are existing local methods using plant base compounds for fishing purposes.

Method: There is literature available to instruct on the use of rotenone for the control of fish that could be easily adapted for this purpose in tadpoles. It would be very useful to sequentially expose Asian toad tadpoles to known concentrations of rotenone at different developmental stages to determine efficacy. We also recommend investigating local methods of chemical fish capture. It may be that local plants or plant based substances are currently used and therefore are socially acceptable and appropriate for our purposes. Standard controlled methods involving the engagement of skilled individuals such as Devin Edmonds of the Association Mitsinjo would see this easily achieved.

Logistics and cost: Material costs for a lab trial should not be high in that all is required are small containers, basic husbandry skills and rotenone. If rotenone is not available in Madagascar, there may be some issue with its importation. The operationalisation of the method involve transport, planning and chemical costs that are difficult to estimate but probably are comparable to the described survey methods. A major risk could be community perceptions and consequences of this method, especially if local communities rely on fish from these waterbodies.

2.2.12 Toad traps

Purpose: While some of the methods proposed for testing here are designed to reduce or remove access to breeding pools we may use the toads natural ability and need to locate waterbodies for breeding as a trapping opportunity through the construction of temporary waterbodies. These may be specifically suitable for use in locations where other waterbodies have been capped and this strategy is currently being used in New Zealand to intercept alpine newts whose breeding pools have been drained and capped to some success.

Method: It may be possible to design and develop traps for breeding toads if waterbodies such as barrels are used as an attractive source of water, surrounded by easily searched refugia to retain toads near the inaccessible water source and accompanied by toad call recordings to attract breeding females and males. The trap sites would then be either surrounded by a helical fence to help contain toads (Fig. 3) or, if habitat allows a one-way “drop-wall” that prevents the toads from leaving. Refugia should be complex and solid enough to provide good cover and suitable microclimate for toads so they are not encouraged to try to leave the traps. The retaining wall structure of the drop wall design should be constructed of firm plastic or metal sheeting to ensure an unclimbable surface is maintained. The drop wall should be at least 40 cm deep and it would be worthwhile testing the toads preparedness to enter traps with different height walls to ensure we have an optimum height for capture and retention. If plastic mineral barrels are used as a waterbody by being cut vertically in half then the surface area of water would approach 2.5 m² which hopefully is sufficient water to act as an attractant. Such traps will work best when deployed with drift fences.

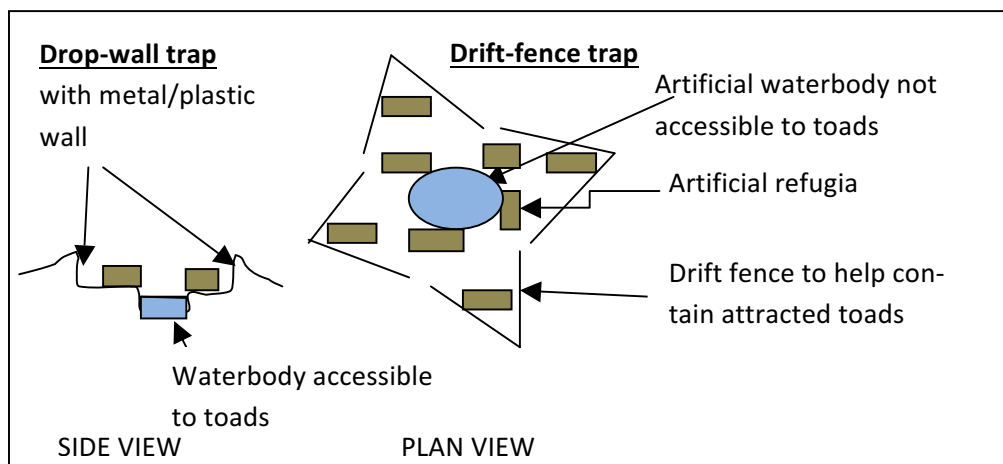


Fig. 3. Two toad trap designs, a drop-wall trap and a drift fence trap with easily searched refugia.

Logistics and cost: The construction of toad traps need not be terribly expensive or complicated. The issues for both designs will be the regular checking of traps for collection and destruction of toads. The “drop-wall” design will need some maintenance to ensure that the traps remain effective and the drift fence trap will need both maintenance and regular toad checking as they are more able to escape from this design. It is estimated that a team of three workers could construct these traps quickly so that 3–4 might be constructed per day. Allowing for US\$100 materials per trap and the labour of two workers plus a driver and vehicle we would expect the construction of these traps to

cost **US\$520** per day or **US\$130** per trap without servicing costs. It might be possible to contract local communities to service these traps and keep records of toads captured and disposed of.

For a trial of the methods we would want to closely monitor toad entry and any escapes from the traps preferably within an enclosed area containing marked toads so we can evaluate the effectiveness of the traps over time and parameterise exposure times to maximize captures of both sexes and of the maximum demographic range. With expert involvement and field time this work is expected to cost no more than **US\$10,000**.

2.3 Prioritisation of methods and proposed testing schedule

The purpose of proposing the testing of methods is to reduce the risk of committing to a large and expensive body of work without knowing that we have appropriate tools.

1. **PHASE ONE – TESTING AND CAPACITY DEVELOPMENT:** Raise initial funds and create capacity to test key eradication and detection tools to evaluate options to eradicate Asian toad. This work should start immediately and be completed within 12 months.
2. **PHASE TWO – ERADICATION:** If eradication is viable, fund raise while developing a strategic plan to deploy detection and eradication tools for the removal of Asian toads with a probable field commitment of three years. If eradication is not feasible, then research into mitigation and impacts become the priority. The eradication operation is necessarily iterative in its progress informed by levels of toad detections. We guess that it will take at least three years of the application of most, if not all of the tools described here to progress to a point where toads are no longer detected. If the rates of detection do not diminish according to expectation then the project will need re-evaluation. However the project should be evaluated annually for performance against goals and expectations.
3. **PHASE THREE – POST ERADICATION MONITORING:** After hopefully three years (or less) of eradication operations no more toads will be detected by the existing surveillance methods. At this point the programme needs to prioritise toad detection across the entire incursion area and maintain a strong communication strategy to ensure that any residual toads are located and destroyed. This phase could easily last for a decade.

By adopting a process that first tests efficacy of potential eradication tools and if proved ineffective, we can abandon the goal of eradication with clear and quantitative reasons for such a decision.

Due to the costs of employing these techniques, it will be important to implement the least expensive and most efficacious (by area) methods as early as possible, delaying use of more costly measures until there are far fewer toads to be located. It is also important to ensure the methods used later in an eradication programme are adequately sensitive to toads to be effective for toads in extremely low density, as we would hope they would be by the final stages of an eradication effort.

We also have to consider monitoring and response options for evaluating eradication results across the incursion area and triggers for declaring success or abandonment of the project. Although the

methods proposed here might comprise an eradication effort, we need clear measures of success or points of failure. We estimate that even if the proposed methods prove extremely successful, it is likely to require at least three years of eradication effort to achieve an eradication outcome. However, with our ability to detect toads at extremely low densities untested, we must be prepared for at least a further three years of monitoring to ensure that no small toad populations were able to escape the effort. Methods of monitoring, as described above, are as yet unproven for extremely low-density toad populations.

Therefore, we propose the following immediate actions:

1) Designate the governance group and invest in operational capacity building with local organisation based within the incursion area.

2) Identify collaborators and supporters to begin Phase One of methodology testing that will examine at the very least, the following methods:

- Hand capture methods.
- Test of citric acid/sucrose spray.
- Test of toad traps.
- Test of tadpole traps.

And equal priority is the development of a national communication and response plan to identify any satellite populations and to prevent further inadvertent spread.

It is also critical that drift fencing and toad capture programmes be developed and installed at all major waterbodies suitable for their breeding prior to the next rainy season.

At the end of the Phase One operational period so at minimum, before July 2016, the expert group must convene to evaluate results and consider the evidence for proceeding to a full eradication plan. Accompanying this must be a strategic plan for the eradication operation that is informed by trial outcomes.

3 Budget planning:

Year one cost estimates.

Infrastructure for organization overseeing operations.

In the cost determination detailed above labour has been accounted for, for the trial effort however other demands must be met by the host organization and these must be cost determined:

Project manager FTE (full time equivalent)	US\$35,000–75,000
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Assistant manager FTE	US\$8,000
Data management capacity 0.5 FTE	US\$4,000
Human resources (employment and pay) FTE	US\$5,000
Community liaison staff 2.0 FTE	US\$6,000
Accountant FTE	US\$6,000
Driver FTE	US\$2,400
Additional office space	US\$12,000
Communications materials	US\$1,000
Internal travel between Tana and Tamatave	US\$3,000
4WD rental/purchase one year	US\$15,000
Computing capacity	US\$3,000
Communications costs (postage, internet, phone)	US\$1,000
GIS operator	US\$8,000
Consultation (time & travel of eradication experts)	US\$40,000
Evaluation workshop and support (for year one review)	US\$60,000
<u>INFRASTRUCTURE & SUPPORT TOTAL</u>	<u>US\$243,400</u>

Minimum essential operational costs year one	
Test hand capture	US\$62,360
Density estimation	US\$3,760
Test citric/sucrose spray	US\$8,000
Test toad traps	US\$10,000
Test tadpole traps	US\$5,000
Communication plan and biosecurity development	US\$6,000
Further delimitation effort (using combined methods)	US\$15,000
<u>OPERATIONAL TOTAL</u>	<u>US\$106,360</u>
Contingency (10%)	US\$32,000

YEAR ONE PROJECT TOTAL US\$385,520