Eradication of Coqui Frogs from Maui County, Hawaiʻi

Strategic Plan 2020-2030

Giggle Hill and Māliko Gulch

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Table of Contents

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List of Figures

List of Tables

Executive Summary

This plan lays out a proposed ten-year strategy for the eradication of coqui frogs from Maui. Without a significant and sustained increase in efforts, the vision of a coqui-free Maui will become impossible. If coqui are allowed to spread across the island, impacts are expected to affect tourism, real estate values, nurseries, health, quality of life, cultural resources, and native ecosystems.

The coqui frog's small size, cryptic coloration, year-round reproduction, high fecundity rates, and absence of natural predators make the coqui a formidable target. A single female frog can produce 1,400 eggs per year. Lush vegetation in landscaped yards and wild gulches make our island home a paradise: densities exceed 37,000 frogs per acre in some areas. Coqui currently occur over an estimated 1,285 acres, affecting at least 800 TMKs in Kīhei, Wailuku, Kula, Haliʻimaile, and Haʻikū, with separate infestations ranging in size, density, and complexity. Land use types affected include commercial, residential, rural, and agricultural lands, as well as wildland gulches and irrigation ditches.

Control methods include hand-capture of single frogs, habitat modification, spraying a citric-acid solution, and installation of barrier fences. Most spray operations occur at night, when male coqui frogs produce mating calls, which is the only feasible way to determine the presence and location of the cryptic, quarter-sized animals. Control operations in coqui-infested gulches have been described as some of the hardest conservation work taking place in the state. Without previous management efforts, coqui frogs would already be beyond control for Maui.

MISC has developed and is implementing a robust community engagement program to encourage control activities by local residents. Key components include a sprayer-loan program and distribution of citric acid. Also critical to project success is an ongoing, comprehensive outreach and education program. Key metrics for demonstrating progress include changes in coqui density and in the number of infested acres. Use of passive acoustic monitoring devices will help address challenges associated with attempting to detect changes at high-density sites.

The proposed schedule and cost analysis for eradication projects an initial annual cost of $8 million, decreasing to $4.5 million over a ten-year timeframe, for a total of $63.5 million. Citric acid and labor are the major cost components. Analyses in 2007 projected eradication costs of $3 million; by 2015, estimates were up to $20 million. Unfortunately, available resources have never been adequate and, as a result, costs have increased exponentially as coqui have continued to spread.

Given the scale of the problem and estimated costs, MISC recommends that this plan be used to establish a larger, community-based task force that brings together affected residents, elected officials, industry representatives, and MISC staff and committee members. The group's mandate should include review of the proposed plan and ongoing operations, and helping to identify and implement effective, cost-reduction approaches.

What's at Stake

I komo no ka haʻi puaʻa i ka paʻa ʻole o ka pā.
Other people's pigs come in when the fence is not kept in good repair.

Considerable resources have been invested in control of coqui frogs on Maui and increased investments will be necessary to eradicate coqui from the island. In order to assess whether such expenditures are appropriate, it is essential to consider what is at risk, along with the feasibility and cost of control. This section outlines the threat presented by the unchecked spread of coqui frogs on Maui.

Hawaiʻi has no native amphibians (Kraus 2003) and therefore no natural predators to keep populations of nonnative frogs in check. Since its introduction to Hawaiʻi in the late 1980s, the coqui frog (*Eleutherodactylus coqui*) has become one of the state's most recognizable invasive species.

The continued spread of coqui frogs on Maui threatens:

- Residents' quality of life
- Real estate markets
- Tourism and visitor experiences
- Cultural resources and practices
- Native plants, animals and ecosystems

Work by the Maui Invasive Species Committee (MISC) and its partners have repeatedly demonstrated the potential for success, with nineteen coqui frog population centers eradicated. In the context of this project, the term "population" means a physical property or properties (as defined by a Tax Map Key identifier or other geo-referenced coordinates) that has or has had five (5) or more calling coqui frogs. Successful control of coqui at this level is unprecedented in Hawaiʻi and was once thought to be impossible for Maui. But available resources have never been appropriately scaled to the problem and, as a result, the cost of eradication is now much greater than it was when MISC began control. Control of coqui on Maui is at a critical juncture.

Based on data from the coqui's native range in Puerto Rico and its invaded range in Hawaiʻi, models of potential distribution predict that up to 49% of Hawaiʻi Island would be suitable coqui habitat, including most areas up to 6,500 feet (Bisrat et al. 2012). A similar prediction applies to the potential distribution of coqui on Maui. As the Māliko gulch population has grown, it has become a point-source for the spread of coqui, subverting previous control efforts. Without immediate, sustained, and aggressive action, the feasibility of securing a coqui-free Maui will be lost in perpetuity.

Quality of Life

The sound level of coqui calls often exceed the legislatively-established state health standard of 70 dBA (Hawaiʻi Revised Statutes § 324F-1) (Beard and Pitt 2005). Residents in heavily-populated areas report that the introduction of coqui frogs to their community has negatively affected their quality of life and may influence their willingness to continue to live in invaded areas. Numerous articles in local and national newspapers attest to residents' view of the coqui frog as an unwanted pest (high school plays disrupted in Hilo, Environment Hawaiʻi, 2003; residents band together to control coqui, Maui News, 2018). Impacts include:

- Lost sleep (may also have health effects)
- Need to keep windows closed in the evening
- Community disagreements if some residents refuse to allow control
- Increased costs associated with vegetation removal
- Time spent removing coqui

Cultural Impacts

Love of the land, or aloha ʻāina, has been called the "heart and soul" of Hawaiian culture. Traditional cultural practices include harvesting plant materials for food, hula, weaving, and construction (Figure 1). These resources, as well as our reefs, depend on healthy forests. Hawaiian culture has a rich oral tradition and soundscape, including chants, song, hula and verse. The ʻōlelo noʻeau, or Hawaiian proverbs, tell of the deep connection to specific places and activities. Many of the Hawaiian names for birds encompass the sound made by the birds, such as the ʻuʻau (Hawaiian petrel) or ʻaʻo (Newell's shearwater). Left unchecked, coqui frogs could forever alter the places and sounds that greeted the first Hawaiians and remain culturally significant today.

Figure 1. Lei making from native plants

Health Impacts

A recent concern is the discovery that coqui frogs may act as reservoirs for the rat lungworm (*Angiostrongylus cantonensis*) (Niebuhr et al. 2019), which can have devastating impacts on human health if ingested accidentally. Research on Hawaiʻi Island found that 87% of sampled coqui (21/24) had rat lungworm; in some coqui, the lungworm was found in tissue types other than the stomach-intestine, indicating larval movement within the host's body. A whole semi-slug (*Parmarion martensi*), which is considered a highly competent intermediate host, was found in one coqui, with both the frog and slug testing positive. The presence of abundant coqui, infected with rat lungworm, could aid the completion of the rat lungworm cycle in the wild. Additionally, ingestion of infected frogs poses a threat to companion animals, such as dogs.

Economic Impacts

Coqui frog vocalizations have negatively impacted Hawai'i's economy, including the nursery, real estate and tourism industries, due to the volume and consistency of its piercing vocalizations.

Tourism: Hotels and licensed bed-and-breakfast establishments have reported complaints by guests about coqui frogs and some visitors report that they have changed, or are planning to change, their travel plans to avoid coqui in the future.

Real estate values: Landowners may be required to disclose that coqui are present on the property before selling their property. Coqui frogs on or near a property have been estimated to cause, on average, a 0.16% loss of real estate value per sale (Kaiser and Burnett 2006). The total direct damage to property values for all homes in Hawai'i, if the frogs were to become widespread, is conservatively estimated at $209 million. Some Maui residents have sold their homes due to impacts on rental income.

Nursery industry: An infestation of coqui frogs could reduce local plant sales as well as exports (Figure 2). Inter-island and international shipments of nursery products have been rejected or destroyed due to coqui frog infestations (Kraus and Campbell 2002, Kaiser and Burnett 2006). Residents and nurseries have expressed concern about buying infested plants (Radford and Penniman 2009). The development of a coqui-free nursery certification program on Maui is evidence of the concern consumers and producers of horticultural products have about the spread of coqui frogs (www.coquifreemaui.org).

Figure 2. Coqui frog on ti plant

Ecological Impacts

Maui has a spectacular array of native plants and animals, many found nowhere else in the world. The impact of habitat loss along with the introduction of invasive species has pushed many native species to the brink of extinction. Climate change is exacerbating the problem. Coqui frogs pose a significant risk to the health of Maui's native ecosystems and its biological diversity.

Invertebrates: Invertebrates make up most of Hawaiʻi's endemic fauna (Eldredge and Miller 1995). At high densities, an established population of this sit-and-wait generalist predator may consume as many as 485,000 prey items per night, per acre (Beard et al. 2008; Wallis et al. 2016). Research on the island of Hawaiʻi showed that coqui frogs are associated with a 27% reduction in the total number of leaf-litter invertebrates, likely through direct predation (Choi and Beard 2012). Higher densities of coqui were associated with a 19% increase in *Diptera* (flying insects), especially flies in the *Sciaridae* family (fungus gnats), likely due to increased frog carcasses and excrement.

Coqui movement into predominantly native forests has the potential to significantly impact native species. A diet study showed that coqui frogs consume endemic invertebrates (Beard 2007); Acarina (mites), Coleoptera (beetles), Collembola (springtails), Diptera (flies) and Gastropoda (snails) were the most vulnerable to coqui predation. An estimated 19% of the frog's diet could consist of endemic invertebrates, species found only in the Hawaiian Islands (Pitt 2004).

Soil health: Ecosystem-level effects of introduced species can include impacts on soils and plant growth. A study on Hawaiʻi Island showed that invasion by coqui frogs can increase nitrous oxide emissions in stands already dominated by the nonnative nitrogen-fixing albizia tree (*Falcataria moluccana*) (Hall et al. 2018). The presence of coqui did not increase nitrous oxide emissions in areas dominated by ʻōhiʻa lehua (*Metrosideros polymorpha*), suggesting that impacts may be limited to areas where soil nitrogen levels have already been altered by the presence of nonnative plants.

Native birds: A study on Hawaiʻi Island, which examined abundance of native and nonnative birds in coqui-invaded areas, showed that coqui frogs do not appear to be important competitors with native birds. However, coqui presence is associated with increased abundances of some nonnative birds, which may have other undesirable ecosystem impacts (Smith et al. 2018). The presence of coqui may serve as novel prey for nonnative birds or may change the invertebrate community in ways that benefit nonnative species. The presence of coqui has been associated with a 30% increase in mongoose abundance (Hill et al. 2019), which could harm native birds (Figure 3).

Figure 3. Mongoose with native bird

Hoary bats: A study on Hawai‘i Island observed that aerial insects made up nearly 34% of the coqui diet. The coqui frog may be an insectivorous competitor with the endangered hoary bat (*Lasiurus cinereus semotus*). Potential impacts on prey availability for bats are most likely to occur in newly-invaded, higher-elevation regions if coqui populations are allowed to expand into those areas (Bernard and Mautz, 2016).

Coqui in Hawai‘i appear to have lower thermal limits than those in Puerto Rico, demonstrating an acclimation response after thirty days (Haggerty 2016). While current distribution trends suggest coqui frogs are restricted to warmer temperatures, under a warming climate scenario, the frogs may find suitable habitat in Hawai‘i’s montane ecosystems, thus enhancing the potential for competition with Hawai‘i’s native birds and hoary bats.

Other impacts: Coqui frogs could become a food source that helps sustain other invasive species. In Puerto Rico, coqui frog are prey items for native snakes. If the brown treesnake were to be introduced to island, coqui could help promote the establishment and spread of this invasive snake, which could have profound ecological, economic and quality-of-life impacts on the island.

Target Species: Coqui Frog

‘Alamihi kakani pō‘ele‘ele.
Black crab that makes a noise in the dark.
An expression of annoyance toward one who disturbs the night with noise.

Coqui frogs are endemic to Puerto Rico and are thought to have been introduced to Hawai‘i in the late 1980s via the horticultural industry (Kraus et al. 1999). The coqui frog has since become one of Hawai‘i’s most recognizable invasive species as populations have increased and encroached on human and natural habitats.

Genetic analyses of coqui in Hawai‘i indicate that the introduction of coqui to Maui was a separate occurrence from its introduction to Hawai‘i Island (Peacock et al. 2009). The first voucher specimen for the coqui frog was collected from Maui in 1997, but population sizes and densities were already noticeably larger on Hawai‘i Island (F. Duvall, DLNR, pers. comm.). A former nursery site at the top of Māliko Gulch is believed to have been the site of the initial introduction of the coqui frog to Maui and was apparently the source for the now-extensive infestation throughout the gulch.

Optimal management strategies for invasive species are complicated by the complex interaction of factors such as the extent of the invasion, species ecology, ecosystem dynamics, and how the species responds to different management actions (Taylor and Hastings 2004).

Description

The coqui frog is a small, arboreal, cryptic tree frog that lays its eggs in vegetation.

Key characteristics include:

- Slightly longer than 1 inch (2.5 cm) – about the size of a quarter
- Round body shape
- Coloration is variable, from light yellow to dark brown
- Snout is broad and rounded
- Obvious toe pads
- Maui coqui near the presumed introduction site (Māliko gulch) have a horizontal band across the forehead, which is lacking on coqui introduced to Hawaiʻi Island

The coqui's small size and cryptic coloration allows it to blend in well with background foliage, making visual detection challenging, if not impossible.

Reproduction

Coqui frogs are highly fecund:

- Coqui have 4-6 egg clutches per year
- Each clutch includes at least 16-41 eggs (Figure 4)
- Intervals between clutches are as few as eight weeks (Kraus et al. 1999)
- Eggs develop directly into froglets, with no intermediate tadpole stage
- Developmental period lasts 17-26 days
- New generations occur approximately every eight months (from egg-laying to adult frog)
- In laboratory conditions in Hawaiʻi, a single female can produce 1,400 eggs per year and possibly over 8,000 eggs in a lifetime

High fecundity rates, lack of predators or other competitors (Beard and Pitt 2006), abundant food sources, and a generalist feeding behavior (Stewart and Woolbright 1996) have allowed coqui frogs to reach density levels unparalleled in the world, including in its native Puerto Rico:

- Higher reproductive capacities in Hawaiʻi, compared to Puerto Rico
- Highest densities in wet locations on the windward sides of the islands (Kraus and Campbell 2002)
- Population densities can reach nearly 37,000 frogs per acre in some areas (Beard et al. 2008), two to three times those reported in rainforests of Puerto Rico

Figure 4. Male coqui frog guarding eggs

Habitat Use and Behavior

Coqui frogs occur in all types of island habitats, generally from sea level to 4,200 feet elevation:

- Occur around plant-related businesses, homes, resorts, public parks, and forested areas
- Primarily nocturnal
- Seek shelter during the day in moist areas covered by brush or debris
- Prefer hot, humid environments that receive abundant rain

The most noted characteristic of the coqui frog is the piercing mating call of male frogs:

- To attract a mate, males call to females, with the greater mating advantage going to males with the highest call rates (Townsend and Stewart 1986; Lopez 1996).
- Coqui frog calls include two notes—a “co” note and a “qui” note. The “co” note is intended to warn other males, while the “qui” advertises to local females.
- Calls typically begin at sunset and continue throughout the night.
- Calls can reach 80 – 90 decibels.
- Males may call from protected places within vegetation or rock formations.

Despite high decibel levels, pinpointing the location of a calling male can be extremely difficult as calls reverberate off the surrounding background.

Territories and Dispersal

Male and female coquis are highly site specific, with individual frogs inhabiting the same area for several weeks to several years.

- Male home range encompasses approximately 6.5 feet in diameter, and includes calling sites and diurnal retreat sites
- Males use 1-4 calling sites within a limited area; retreats are usually within 6.5 feet of the most-distant nightly perch (Woolbright 1985)
- Males defend calling sites and retreat sites by producing aggressive calls (Stewart and Rand 1991; Stewart and Bishop 1994)
- Males guard eggs to keep them from drying out (Taigen et al. 1984)
- In dry conditions, males will leave the nest, gather moisture, and return to rehydrate the eggs (Michael 1995)
- Individuals exhibit a strong tendency to return to same area when displaced, with some coqui returning from up to 330 feet (Gonser and Woolbright 1995)

Coqui are easily spread to additional sites through the transportation of infested plants (Kraus et al. 1999) and other materials, or on vehicles. Genetic studies confirm the importance of human-mediated dispersal for explaining the spread of coqui throughout the Hawaiian Islands (Everman and Klawinski 2013).

Diet

Studies in Puerto Rico indicated that in its native range, coqui frogs consume a diet consisting mostly of insects, but may include other invertebrates, such as mollusks, arachnids, centipedes and millipedes. On Hawaiʻi Island, studies found that the most important prey categories were Formicidae (primarily ants), Coleoptera, Amphipoda, Hemiptera, and Collembola (Beard 2007; Wallis et al. 2016). Coqui appear to forage mostly in leaf litter. There is little or no evidence that coqui are reducing important invertebrate pests, such as mosquitoes, which have not been found in coqui stomachs.

Predators

Species that prey on the coqui frog in its native range include numerous invertebrates and at least 19 species of vertebrates. Vertebrate predator species include two frogs, three lizards, three snakes, eight birds, and three mammals, with birds consuming the most frogs (Stewart and Woolbright 1996). Only a few of these species are found in Hawaiʻi. The major predator of coqui eggs are the coqui frogs themselves. Both sexes, but especially males, will eat coqui eggs (Townsend 1984, Townsend et al. 1984). Giant centipedes are also known to consume coqui.

The Challenge: Nature and Scale of the Problem

Aia ka puʻu nui i ke alo.
A big hill stands right before him.

The focus of this management plan is the island of Maui, but also serves as a resource for response activities on Molokai, where similar strategies would be applicable if coqui were to become established there. MISC staff would be available to assist the Molokai Invasive Species Committee (MoMISC) as needed.

This section describes the nature and scale of the coqui invasion on Maui, including the spatial extent of the infestation and relevant site characteristics.

Spatial Extent

In addition to single-frog sites, which can occur anywhere on the island, coqui are currently established in Kīhei, Wailuku, Kula, Haliʻimaile, and Haʻikū, which also includes the Māliko gulch infestation (Figure 5). The estimated island-wide invasion encompasses at least 1,285 acres and 800 TMKs (Table 1). Infestations range in size, density, and complexity.

Table 1. Size of infestations by location on Maui

Area	Acres
Haʻikū / Maliko Rim	782
Māliko gulch only	425
Haʻikū Outliers	54
Island Outliers	24
Total	1,285

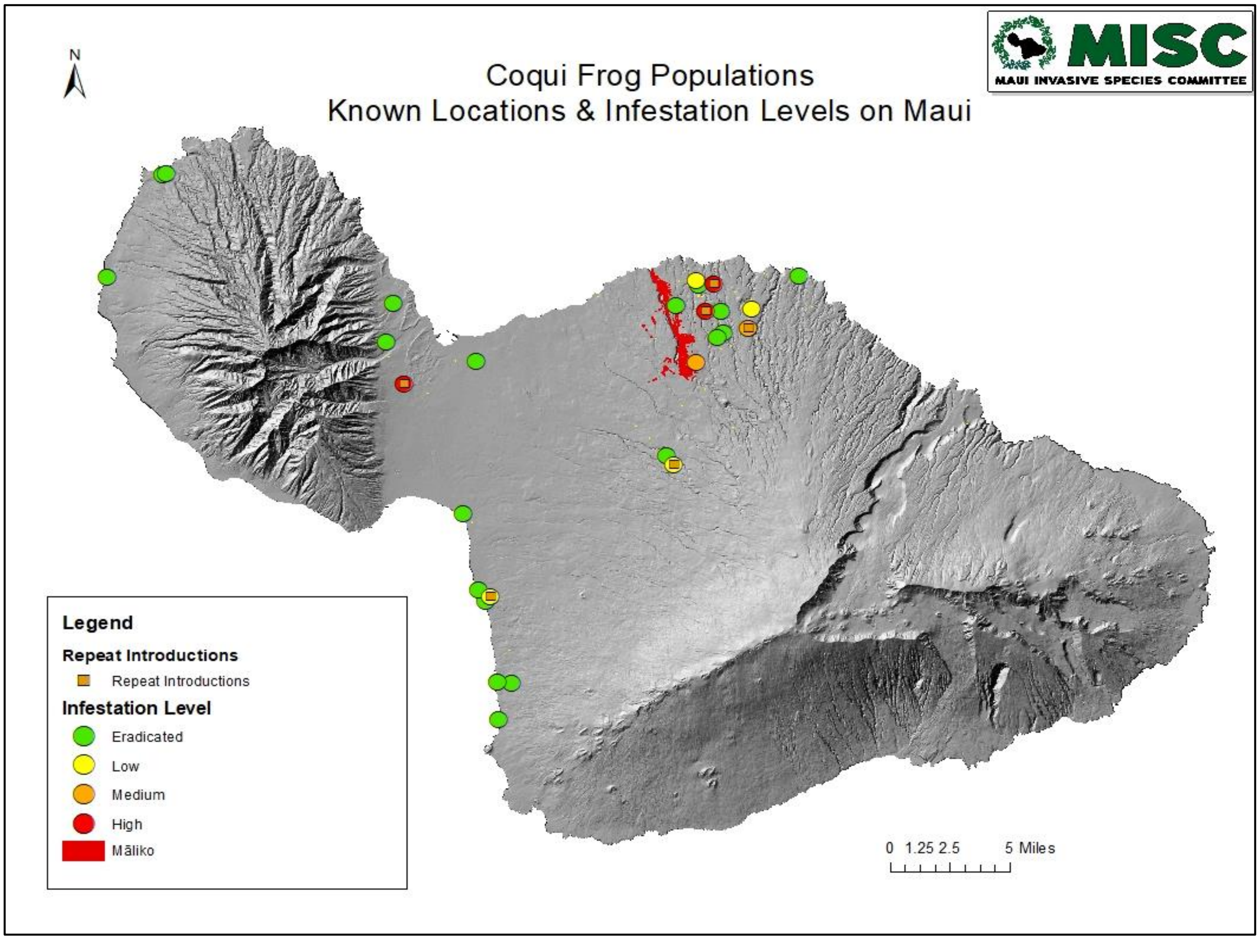

Figure 5. Historical and current locations of coqui frog populations

Land Use

Land use characteristics affect all aspects of control operations and include the following general categories, along with relevant considerations:

- Commercial properties (visitor accommodations, nurseries)
  - Concerns about public perception and noise from operations
  - Potential damage to nursery stock
  - Potential for repeat introductions through imported plants
- Residential / urban
  - Landowner concerns about potential damage to plants or structures
  - Concern about noise from control operations at night
- Residential / rural (Haʻikū / Māliko)
  - Larger parcels with significant landscaping, not always maintained
  - Some properties are adjacent to the gulch, with ongoing spillover of coqui
  - Recalcitrant or absent landowners (won't allow access or control)
- Agricultural / Pasture lands (Haʻikū / Māliko)
  - Lands under active management require coordination with operations
  - Unmanaged / fallow lands harbor coqui in dense stands of cane grass
  - Presence of old machinery or other hazards

- Finger Gulches (Haʻikū / Māliko)
  - Steep-sided slopes, heavily vegetated
  - Provide corridors for coqui movement
- Irrigation ditches (east and west of Māliko gulch)
  - Vector coqui from Māliko, creating undetected populations to the west
  - Access is limited
  - Difficult to navigate at night
- Māliko gulch (wildland, a few residences)
  - Irregular terrain; loose substrate / potential of falling rocks
  - Limited access points; some inaccessible areas (waterfalls)
  - Steep-sided slopes, heavily vegetated in areas

Types and Locations of Infestations

Infestations vary from a single male calling from a banana tree in a backyard to a roar of coqui echoing off the walls of a deep gulch. Operations also vary, depending on the nature and extent of infestations. For management purposes, infested sites on Maui are categorized as follows:

- Single-frog sites (only a few coqui present)
- Outlier populations (populations outside of Māliko)
- Haʻikū / Māliko rim (populations in Haʻikū and Haliʻimaile)
- Māliko gulch (wildland portion of the gulch)

Single-frog sites

Rapid response to reports of single coqui frogs represents the most cost-effective approach to preventing the further establishment of new populations on Maui. Single-frogs typically arrive as "hitchhikers" on plant material obtained from an infested nursery, or on vehicles, equipment, or materials that have traveled from an infested area (Figure 6). Historically, nearly all single-frog reports outside the Māliko area represented new introductions from Hawaiʻi Island, although some coqui certainly spread from infested nurseries or the Māliko area. In recent years, however, that trend has likely shifted as coqui have increasingly spread from Māliko to new locations. Absent constant vigilance, these small infestations would have created populations across the island, making eradication infeasible (Figure 7).

Figure 6. Immature frog on plant

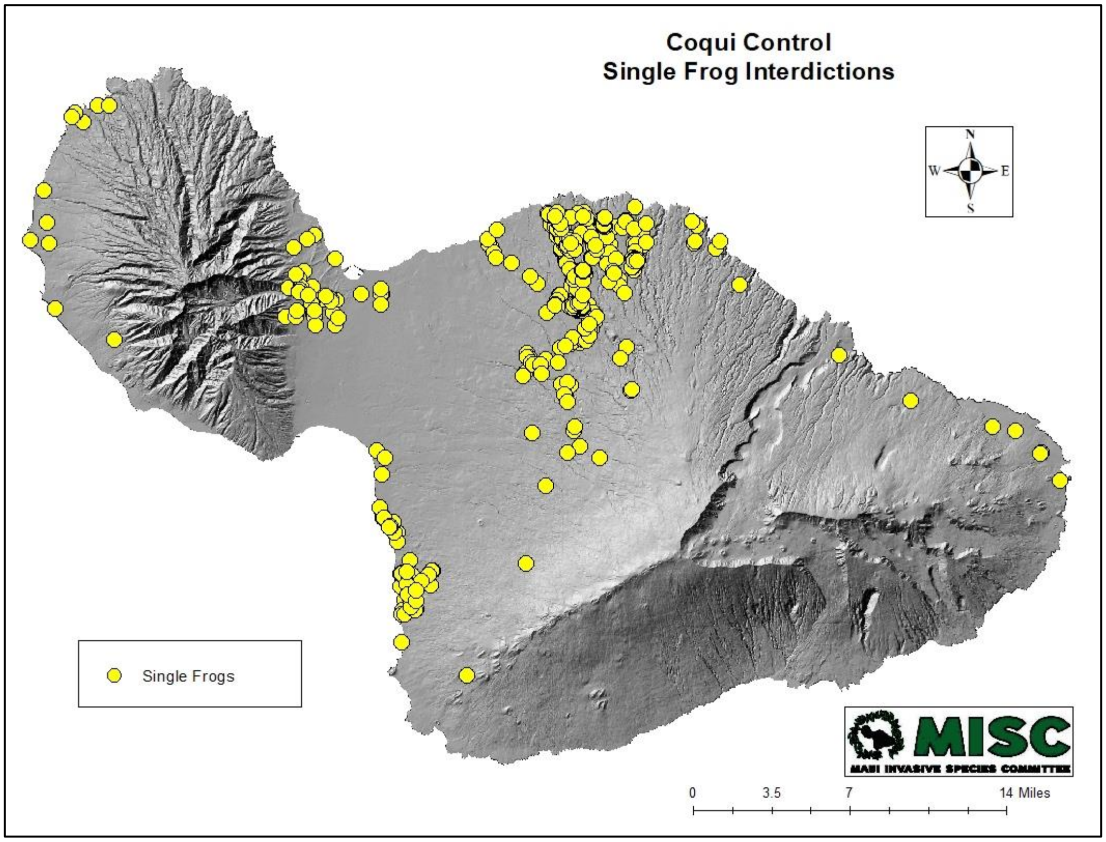

Figure 7. Locations of single-frog captures, 2000-2019

Eradications

A population is considered eradicated if no coqui frogs have been detected for a year from the date the last vocalizing coqui frog was heard, based on repeat surveys conducted post-treatment. MISC has eradicated a total of 19 coqui frog populations, with some sites taking many years to complete (Table 2, Figure 8).

Figure 8. Site of a successful eradication: a junkyard in East Maui

Table 2. Eradications of coqui frogs from Maui

Site Name	Control Start	Eradicated	Acres
Kahului Store	2004	2006	0.3
Huelo Honopou	2004	2008	16.5
Kīhei “C” Nursery	2004	2008	8.1
Kāʻanapali Resort	2005	2007	0.3
Haʻikū Post Office	2005	2006	0.8
Haʻikū “H” Gulch	2005	2007	1.3
Kapalua Flemings	2005	2008	4.4
Junkyard	2005	2009	4.7
Kapalua Resort	2005	2009	3.5
Kīhei “P” Nursery	2006	2007	3.4
Waiheʻe	2007	2009	3.3
Kīhei “K” Nursery	2007	2017	2.7
Wailea “H”	2008	2013	0.4
Mākena	2008	2018	0.7
Wailea “P”	2012	2016	0.5
Kula Kulamalu	2014	2017	1.8
Haʻikū “K” Site	2015	2016	0.4
Haʻikū “Coco”	2015	2018	3.0
Wailuku “E”	2016	2017	0.5

Active Populations

MISC has categorized population centers outside the Māliko gulch area as “outliers.” These included locations in other towns and populations in the Haʻikū area where frogs were established by human-dispersal (i.e., the coqui didn’t move there on their own).

Island Outliers: Currently, only three outlier populations occur away from the North shore; these are located in Kīhei, Wailuku, and Kula (Figure 10). All three sites involve nurseries. One location has been the focus of control efforts for more than a decade, due to apparent repeat introductions of coqui from off island, and the presence of discarded nursery supplies, which have created coqui refugia and breeding sites (Figure 9). Although the infestation level remains high, over the last year, with consistent involvement of staff from Hawaiʻi Department of Agriculture (HDOA), and increased efforts by the business, this property has steadily come under control.

Figure 9. Unmanaged nursery materials exacerbate control efforts

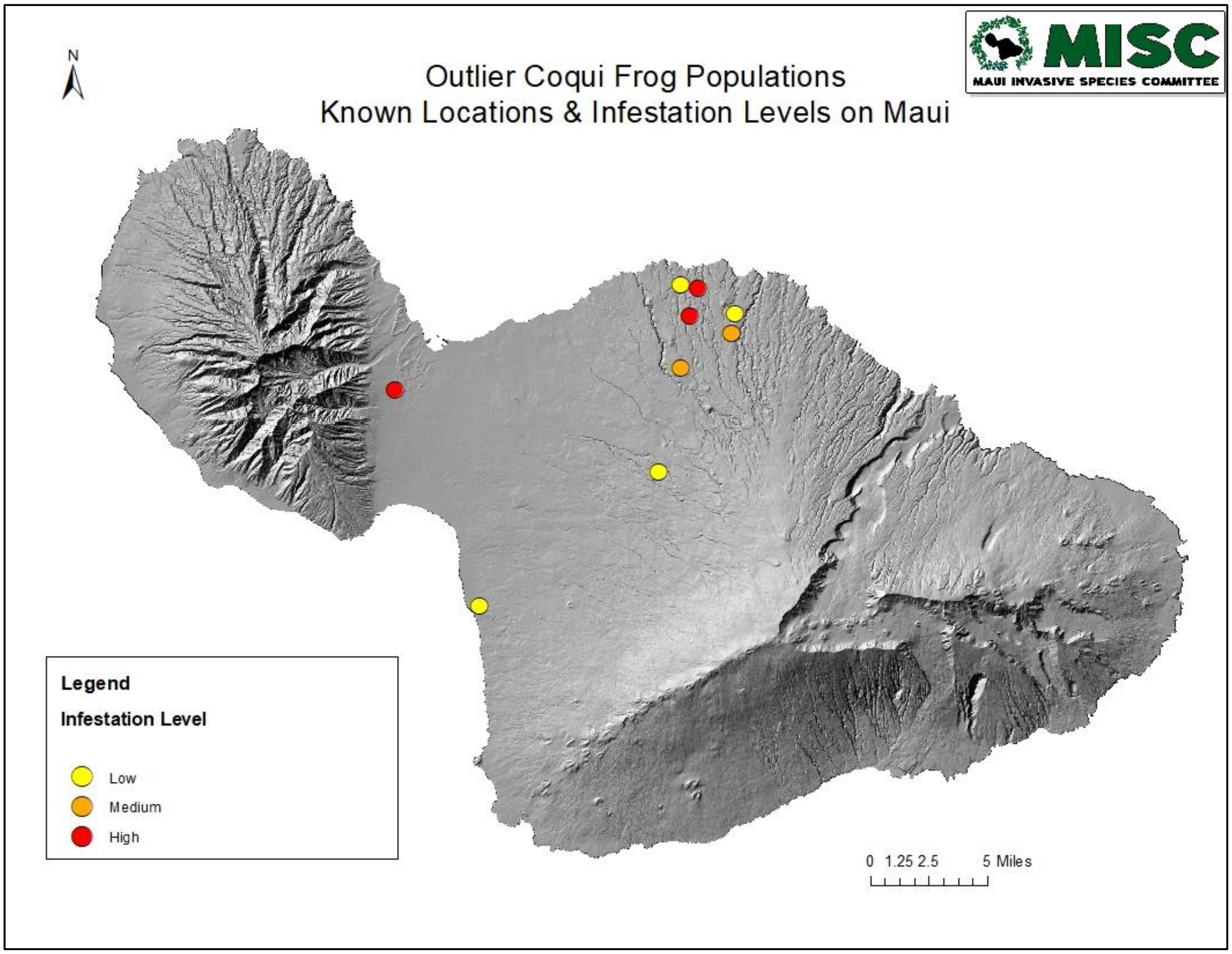

Figure 10. Infestations outside the Māliko gulch area

Ha'ikū-area Outliers: Four populations in Ha'ikū are steadily decreasing; these include a nursery and roadside locations. Coqui numbers at two other Ha'ikū locations are relatively high.

Ha'ikū / Māliko Rim: The largest concentration of coqui frogs is located in and near Māliko gulch (Figure 11). This area is characterized by:

- Residential and agricultural properties adjacent to Māliko Gulch
- Non-adjacent sites near Māliko Gulch where coqui have likely moved on vehicles or other infested materials (Ha'ikū and Hali'imaile areas)
- A number of engaged and supportive communities, who are actively working to remove coqui from their neighborhoods

The total area in Māliko that must be managed is estimated to cover approximately 1,285 acres (see Table 1). This acreage was calculated using geospatial data (polygons) collected during coqui treatments from 2009 to 2019, and then geo-processed to create generalized polygons. This approach helps capture areas between infested sites where surveys or treatment actions may not have occurred, but are suspected of having frogs. Infestation levels are not uniform throughout the area, nor are coqui present on every acre. Spillover from Māliko gulch continues to occur in portions of this area.

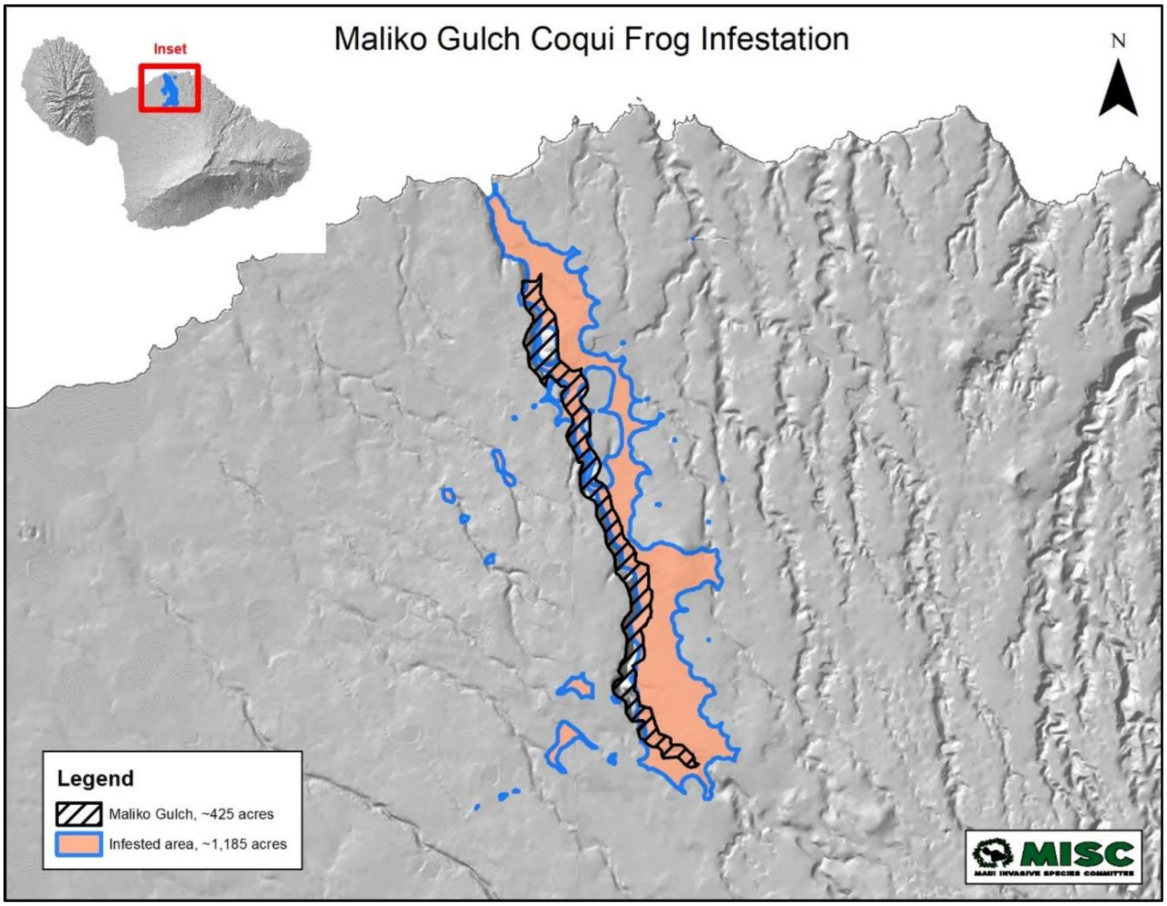

Figure 11. Infested areas in and adjacent to Māliko gulch

Māliko Gulch: Māliko gulch is one of the largest drainages on Maui's north shore, stretching from its terminus at the ocean well into high-elevation native forests. High densities of coqui are present within the gulch, which is steep-sided and densely vegetated in portions. Coqui have spread down a four-mile stretch, from Kaluanui Road to Māliko Bay. The gulch infestation is conservatively estimated to cover approximately 425 acres, including the wildland portion of the gulch. Due to resource limitations, work in the gulch has largely been put on hold as operations have focused on single frogs, outlier populations, and Haʻikū / Māliko rim areas. Some work still occurs at the top and bottom of the gulch and along Kaluanui Road (the upper extent of the infestation).

Although the gulch is several hundred feet deep in most places, two roads and four irrigation ditches cross it. Coqui have spread along the ditches west from the gulch; smaller numbers of coqui have also spread to the east on the ditch system. Multiple finger gulches feed into Māliko gulch and also act as conduits for the spread of coqui into adjacent areas.

The eastern half of the gulch is owned by the State of Hawai'i; the western half, comprised of former sugar-cane lands, is owned by Mahi Pono, LLC, and a variety of other owners. A few parcels are under private ownership at the top of the infested area and also at the bottom or makai section. Permission to control coqui frogs has been obtained from most public and private property owners in and around the gulch.

MISC conducted control operations in the gulch from 2007 to 2014, supported, in part, by an infusion of federal funds. (Federal funding for MISC's operations, along with other invasive species committees statewide, has since evaporated.) As part of those operations, MISC developed and installed a network of PVC-pipes and spray stations to deliver a citric-acid solution throughout most of the gulch (Figure 12). The same type of system, which includes water tanks, gravity-fed pump / tank units, and fire hoses, is used to control coqui in smaller gulches on the north shore. Because MISC has not focused resources on the gulch in recent years, the current status of the infrastructure is uncertain, as is the nature of the infestation; most certainly, both the extent and density within the gulch have increased.

Figure 12. PVC-pipe system in Māliko gulch

On the Ground: Operational Strategy

Hele no ka ʻalā, hele no ka lima.
Keep both hands going to do good work.

This section outlines the overall approach for the eradication project. The Maui Invasive Species Committee has primary responsibility for project management, but the participation of partners and community groups is essential to project success. A modified version of an Incident Command System is used to identify roles and responsibilities, manage logistics, identify operational needs, obtain and allocate resources, address safety considerations, and ensure appropriate communications.

Objectives and Outcomes

This strategic plan outlines the resources needed to achieve the goal of island-wide eradication, with an assumed timeline of ten years. A different allocation of resources (whether more or less) would affect the timeline and overall costs. Objectives and outcomes are outlined in Table 3.

Table 3. Objectives and outcomes

Objectives	Outcomes
Respond to and remove coqui from all "single-frog" locations.	- Eradication of all new single-frog locations.
Eradicate coqui from all residential, commercial and agricultural properties in the Haʻikū / Māliko rim areas in the next 8-10 years.	- Steady progress in eradicating coqui from the list of infested management units. - New populations are assessed as discovered and appropriate action is taken.
Contain coqui within the wildland portion of Māliko gulch, reducing infestation edges over time, with a long-term goal of eradication.	- Implement barrier system at critical points on gulch edge. - Resume control operations in the gulch by year five.
Engage community groups in eradication efforts.	- Phased expansion of community engagement groups, with addition of 4 groups per year.

Field Operations

Management options and strategies vary, depending on the level of infestation and connectivity with the main infestation in Māliko gulch, but some elements are constant for all sites.

Key elements include:

- Access and scheduling
- Detection and delimitation
- Control operations
- Data collection and analysis

Access and Scheduling

More than 90% of the properties (individual TMKs) that have coqui frogs are privately owned. As a project of the University of Hawaiʻi, MISC does not have enforcement authority to require landowners or residents to allow survey or control activities on their property. Over the duration of the coqui control project, only a few residents have declined to cooperate.

Both the County of Maui and State of Hawaiʻi have legal authority to enter private property to control invasive species, which requires obtaining a warrant from the court.

HRS §46-1.52. This authority has never been exercised to control coqui frogs in Maui County, however, it was successfully used by the Hawaiʻi Department of Agriculture to control little fire ants in East Maui. MISC's preferred approach for uncooperative or non-responsive owners or tenants uses a phased approach: attempt to obtain permission directly from the resident / owner; send a certified letter to the owner explaining the importance of controlling coqui; involve Hawaiʻi Department of Agriculture; and seek support (letters to owner) from elected officials (county and state). Court-ordered access is a last resort.

Access and scheduling requires obtaining and recording in a centralized database the following information:

- Address
- Primary contact and phone number
- Permission granted or denied
- Other relevant information (dogs present, gates, sensitive areas)

Timing of notification for proposed activities at each site varies depending on the circumstances (new report; ongoing control; opportunistic). All activities and outcomes for each site visit are recorded in the coqui information system.

Detection and Delimitation

Detectability is the probability of detecting the species when it is present at a site; and delimitation is the process of determining the extent of an invasion. A cryptic invader, such as the coqui frog, is likely to be more widespread than known and therefore more difficult to control because individuals are easily missed. Females and juveniles do not make loud calls and adult males do not call continuously.

Surveys on Hawaiʻi Island found that the probability of detecting coqui when present at a site ranged from 50 to 73 percent; probability of detection decreased with higher wind speeds and elevation, and increased slightly with higher relative humidity (Olson et al. 2012). These results confirm what MISC already knows from field experience: repeat visits to a suspect or infested site are necessary to confirm presence / absence of coqui.

Detection methods vary depending on site characteristics. Surveys and control actions typically occur during the same visit. Detection / delimitation activities include:

- Establishing safe access routes (Figure 13)
- Conducting night-time surveys and collecting information about presence / absence, estimated numbers, and locations of coqui
- Ensuring surveys occur during appropriate field conditions (e.g., not during a downpour, high winds, or extremely dry, hot, or cool periods)
- Recording GPS points of any coqui detected on mobile devices
- Depending on field conditions and infestation levels, broader sweeps may be required to establish the perimeter of an infestation
- Communicating outcomes with residents / property owners, including recommended actions

Figure 13. Establishing safe access routes for control work

Single-frog sites: For new reports of coqui frogs, surveys last thirty minutes. If no coqui are detected and the report is credible (reporter is familiar with the sound of coqui or provided a recording), two additional detection surveys will be scheduled and conducted. Occasionally, MISC will ask reporters to submit another report if they hear the frog again. If no coqui are detected, a follow-up contact with the resident will be scheduled. Other key elements include:

- Emphasis on determining the source of coqui frogs (new plantings, vehicle or materials recently in known infested areas on Maui or Hawaiʻi Island)
- Periodic map updates to capture locations of new reports
- Scheduling repeat visits or work with reporters for appropriate follow-up

New Populations: When new populations (more than five calling frogs) are discovered, the following protocols apply:

- Day-time surveys conducted to determine access routes and hazards
- Night-time delimitation surveys conducted to determine extent and level of infestation
- Operational plan developed for control operations

Known Populations (Outliers and Haʻikū / Māliko Rim): Surveys in known population centers are conducted to document:

- Changes in coqui abundance and distribution in response to control operations
- Potential expansion of coqui into new areas where control operations have not occurred

Control Methods

A variety of complementary approaches, which are least injurious to the environment, are used. No single element is a panacea, but a synergistic, integrated approach offers the best chance for eradication.

Management Unit Framework: A management unit framework supports effective planning efforts, tracking progress, and community engagement. Management units are based on land use, subdivisions, and terrain considerations. Site-specific plans may also be developed to work with individual landowners or community groups. MISC has established 49 different management units. Currently, 41 are considered “active” units with established coqui frog populations (Table 4).

Table 4. Management units with active coqui frog populations, by size

Size of Infestation	Management Unit
< 5 Acres	South Maui Kalama
< 5 Acres	Haliʻimaile ML&P
< 5 Acres	Haloa-Kukuna
< 5 Acres	Kuiaha Plateau
< 5 Acres	Maunaolu Plantation
< 5 Acres	Kula Plant Gulch
< 5 Acres	Giggle Hill Makai Fields
< 5 Acres	Kuiaha Greenwaste
< 5 Acres	Kapiʻi
5-20 acres	HCS Fields
5-20 acres	Haupoa
5-20 acres	Māliko Bay
5-20 acres	Kaluanui Makai West
5-20 acres	Lokelau Gulch
5-20 acres	Wailuku Waiʻale
5-20 acres	Haʻikū Town Acres
20-70 acres	Lanikai
20-70 acres	Haliʻimaile Baldwin Ranch Estates
20-70 acres	Strawberry Lilikoi Gulch
20-70 acres	Kaluanui Coffee
20-70 acres	ʻAikane to Kaluanui
20-70 acres	Jaws Gulch
20-70 acres	Haʻikū Road Makai
20-70 acres	Pololei to Puʻuomalei
20-70 acres	Haʻikū Cannery Residential West
20-70 acres	Kauhikoa Residential
20-70 acres	Giggle Hill Makai Residential
20-70 acres	Haʻikū Makai
20-70 acres	Haʻikū Hill Subdivision and Mini Gulch
20-70 acres	Piʻialiʻi
20-70 acres	Haʻikū Cannery Residential East
20-70 acres	Lilikoi Residential East
20-70 acres	Kaluanui Mauka
20-70 acres	Huna Wai Gulch and Residential
20-70 acres	HCS Fields
20-70 acres	Māliko Bay Nursery to Siphon
20-70 acres	Haʻikū Mauka

Size of Infestation	Management Unit
20-70 acres	Lilikoi Residential West
70+ acres	Haʻikū Hill
70+ acres	Giggle Hill
70+ acres	Māliko Proper

Control methods vary according to site requirements and may include:

- Hand capture
- Habitat modification
- Barrier fences
- Spot spray or drench spraying with a citric acid solution (12-16%) applied via hand-held hoses and nozzles or sprinkler systems

Hand Capture and Alternatives
Hand capturing of frogs typically targets calling male coqui and is effective in dealing with an incipient infestation of a few individuals. Removing the males suppresses reproduction (Kraus et al.1999). Hand-captures are most appropriate at single-frog sites, usually followed by a limited spray operation to ensure control of silent males, juveniles and / or females.

Mechanical control includes the use of traps or artificial hiding places. These methods have not been used on an operational level to control frog populations, but have been used to study coqui and may be appropriate in some situations. No traps have proven to be effective on a broad scale (Sin and Radford 2007). This method is not currently proposed for controlling coqui on Maui.

Hot water has proven to be an effective method of controlling coqui in confined settings or easily managed locations (e.g., nurseries, home gardens, etc.) (Hara et al. 2010). The logistical complications and costs associated with this method preclude its use over broad geographic areas. MISC tested use of a portable hot-water spray system to address a resident's concern about sensitivity to citric acid and found it to be ineffective and / or infeasible for controlling more than a few coqui.

Habitat Modification
Eliminating nonnative, coqui-friendly habitat can significantly reduce the amount of required control efforts. In Puerto Rico, areas with denser undergrowth tend to harbor greater populations of coqui frogs (Fogarty and Vilella 2001). Removing or reducing the undergrowth helps to reduce availability of sites for refugia and egg-laying. Spray operations are much less effective and more costly in dense stands of cane grass, which can also conceal unknown hazards.

Residents are strongly encouraged to remove coqui-friendly habitat on their properties. MISC conducts extensive habitat removal throughout the residential rim area before treatment to increase efficacy. Techniques include: mowing, chainsaw work, chipping, and herbicide treatment of vegetation. Habitat modification is mostly limited to smaller properties, with higher coqui densities. MISC continues to explore other options for habitat modification within Māliko gulch.

Barrier Fences

Use of barrier fences have proven successful for preventing coqui movement out of infested areas (Figure 14). Design features include a 90-degree angle that forces coqui to hang upside down. Made of a fine mesh material, coqui are unable to maintain a “toe-hold” and fall to the ground. This operational strategy is especially appropriate where active control operations are occurring adjacent to heavily-infested areas, such as along the rim of Māliko gulch. MISC previously used this strategy to slow or prevent the spread of coqui across Kaluanui Road. FY20 and FY21 funding from the State of Hawaiʻi is expected to support development and installation of barrier fences in strategic portions of the Māliko area.

Figure 14. Barrier fence along Kaluanui Road

Citric Acid Solution

Application of a 12-16 percent citric-acid solution (diluted in water) is currently the most effective control strategy (Figure 15).

Figure 15. Citric acid supplies and storage

Efficacy: Laboratory and field tests have established citric acid as an effective ranicide for coqui frogs (Pitt and Sin 2003; Chun et al. 2003). Citric acid also is effective in reducing the hatching success of coqui frog eggs.

Safety of citric acid: Citric acid is an all-natural product and is listed as a minimum-risk pesticide by the Environmental Protection Agency (EPA) (40 CFR 152.25f). Its use is exempt from EPA oversight and no further testing is required by EPA for operational use. Citric acid has been approved for general use by Hawaiʻi Department of Agriculture (HDOA) and is available to the public to control tree frogs. The citric acid label is included as Appendix A.

Citric acid occurs naturally in soil, water, plants, animal tissues and fluids, and is a key component of cellular respiration (Hickman et al. 1986). Citric acid has no significant adverse effects on humans or the environment associated with proper use as a pesticide (Environmental Protection Agency 1992). It is a mild organic acid and may cause skin and eye irritation. It is commonly used in disinfectants, sanitizers, fungicides, and as a food additive. Citric acid is generally recognized as a safe multiple-purpose food substance (21 CFR 182.1033).

Using citric acid, as outlined under the proposed action, is expected to have no effect on water quality in terms of acidity (pH). USDA-Wildlife Services National Wildlife Research Center (NWRC) tested the pH of an agricultural reservoir for 11 consecutive days before and after treatment at three separate sampling locations along the shore adjacent to a treatment area that was 2.5 acres in size. The pH pre- and post-treatment measurements did not change.

In 2007, the Maui County Department of Water Supply (DWS) stated that citric acid is not regulated under the Safe Drinking Water Act or the Clean Water Act. DWS concluded there was no evidence of harm to groundwater quality from its use and supported the use of citric acid for the control of coqui.

Non-target impacts: Studies conducted by the NWRC found that non-target animal species are not likely to be adversely affected by citric acid. Although some mortality has been reported in nonnative soft-bodied species that absorb air and water through their skin (e.g., earthworms, slugs and cane toads), these occurrences are uncommon and no mortality has been observed in hard-bodied species (Pitt and Sin 2004). NWRC, in collaboration with the USDA-Wildlife Services operational program, HDOA, and the Kauaʻi Invasive Species Committee, studied the effects of spray operations at Lāwaʻi, Kauaʻi. These studies found no significant difference between the pre-treatment and post-treatment diversity and number of non-target invertebrates (Pitt and Sin 2004). Consultations with USFWS resulted in a decision that activities in the gulch area are not likely to adversely affect the hoary bat.

Application: For spray operations to be effective, the spray solution must make contact with eggs, young, and adults. The most effective applications are conducted during evening hours when frogs have emerged from daytime retreat sites (Figure 16). Three systems for spraying citric acid have been developed which have proven to be effective:

- Ground operations use trailered tanks, sprayers, and hoses in residential areas
- Large-capacity tanks for mixing and holding citric acid connect to sprayers or a gravity-fed system of PVC pipes, valves and hoses in the bed of the gulch
- High-volume sprinklers attached to fixed stands have been installed at strategic locations along the edge of the gulch
- Aerial spraying has been used to control areas of the gulch that are not accessible by any other means; this method is less precise and more expensive.

Repeat Visits: Control operations are conducted throughout the year, with teams moving systematically through smaller management units, or sub-units. Successful control efforts have shown that eradication of a coqui frog population requires repeat control operations at consistent intervals, ideally spaced at 6-to-8 week intervals. To be successful, this strategy requires working through the entire area targeted for control and silencing all calling frogs. Repeat visits will occur until no calling frogs are heard for one year. Annual surveys will be conducted for a period of five years at sites that had medium- or high-density infestations.

Figure 16. Spray operations conducted at night

Natural Enemies / Biological Control

The use of natural enemies or biological control is often suggested as a possible approach. At this time, there are no known effective, safe biological control agents that could be used on a landscape level to control coqui frogs. One potential area for further exploration is the fungal pathogen (*Batrachochytrium dendrobatidis*), known as chytrid fungus, which has been linked to the decline of amphibian species worldwide. This chytrid fungus is already present in Hawai‘i and research has indicated that juvenile coqui frogs suffer higher mortality rates than adults when exposed to the fungus; Hawai‘i juveniles are more susceptible than those from Puerto Rico (Langhammer et al. 2014). Additional research on the potential to exploit this vulnerability could be worthwhile.

Safety

The safety of field staff while conducting field operations is of paramount importance. Work on coqui frogs involves inherent risks (Figure 17). Safety considerations include, but are not limited to:

- Terrain issues (steep slopes, irregular terrain, loose substrate)
- Equipment noise
- Night-time operations limit visibility
- Uncontained dogs, livestock, and feral animals (pigs, deer)
- Homeless encampments in remote areas
- Hidden hazards (equipment or junk in cane grass)
- Flash flood potential
- Use of hand tools and cutting tools (machetes, chain saws)
- Operating heavy equipment (pump-spray rigs, large trucks with heavy loads, forklift, tractor)

MISC has comprehensive safety protocols, which include: a written Safety Plan; Job Hazard Analyses for recurring activities in the workplace; required and provided personal protective equipment (PPE); regular safety checks; and required training for all staff, including prior to the operation of any hand or power tools, pumps, sprayers, trailers, vehicles, and heavy equipment.

Figure 17. Coqui infestations in remote, inaccessible areas

Information Management

Effective operations require timely and accurate feedback systems to capture information about effort expended and to evaluate progress toward established goals and objectives. Information about all field activities is recorded using an integrated GPS and geodatabase system. Information tracked includes:

- Location area
- Acres surveyed and treated
- Estimated number of coqui present within the treated area pre-treatment; number present post-treatment; number present outside the treated area

- Staff present and hours worked
- Gallons of citric acid applied

A continuous history of control efforts from each location provides a wealth of information for assessing efficacy of the work and guiding future field operations, including scheduling, priority-area identification, staffing, and logistics. The coqui information system also includes a tracking process to ensure follow-up with key contacts.

Pulling Together: Stakeholder Involvement

Hoʻokāhi ka ʻilau like ana.
Wield the paddles together.

Much of the coqui management strategy on Maui has focused on working with landowners, but other stakeholders also have important connections to the project. Eradication of coqui will require an approach that engages stakeholders across Maui.

Governance

In 1999, the MISC Committee, comprised of voluntary representatives from public and private land management agencies, came together to develop a dynamic strategy for combating invasive species on Maui. They selected priority target species and secured initial funding to hire staff. MISC's success led to the formation of Invasive Species Committees (ISCs) on Oʻahu, Kauaʻi, Molokai and Hawaiʻi Island. MISC provides fiscal and administrative support to MoMISC, but MoMISC has its own committee and target species. Funding sources typically cover work on both Maui and Molokai.

MISC and MoMISC are projects of the University of Hawaiʻi, housed under the Pacific Cooperative Studies Unit (PCSU) (Figure 18). The Research Corporation of the University of Hawaiʻi (RCUH) provides administrative services, including personnel (hiring, payroll, etc.), purchasing and accounting, and insurance. Project staff are RCUH employees. MISC management staff works closely with PCSU in the day-to-day management of the program and seeks RCUH guidance as needed.

University of Hawaiʻi - Pacific Cooperative Studies Unit (PCSU)

- Overall guidance
- standard operating procedures
- Financial and human resources management

Research Corporation of the University of Hawaiʻi (RCUH)

- Procedures and policies
- Human resource management, including payroll and benefits management

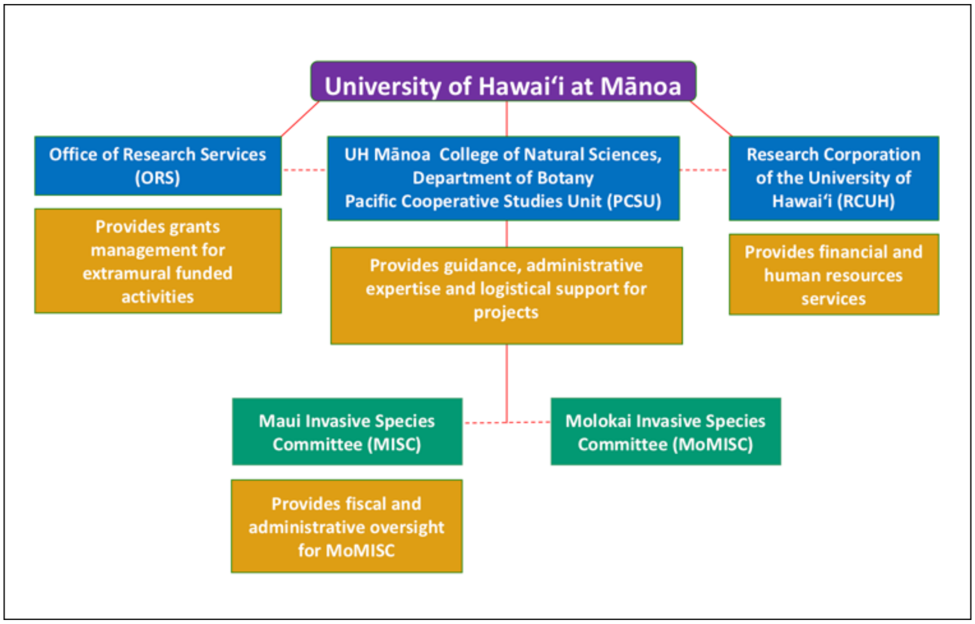

Figure 18. Fiscal and administrative oversight of MISC and MoMISC

Partnerships

MISC and MoMISC's partners bring a wealth of resources to the projects, including funding, administrative support, scientific expertise, policy coordination, training, and shared field efforts. Partners involved with the coqui project include:

Local Agencies and Organizations

- Maui County: Mayor's Office, County Council
- Office of Economic Development (OED)

State Agencies and Projects

- Hawai'i Invasive Species Council (HISC)
- Hawai'i Department of Land and Natural Resources (DLNR)
- Hawai'i Department of Agriculture (HDOA)
- University of Hawai'i, College of Tropical Agriculture and Human Resources (UH-CTAHR)
- Hawai'i Biodiversity Information Network (HBIN)

Federal Agencies

- U.S. Fish and Wildlife Service (USFWS)

Cooperating Organizations

- Coordinating Group on Alien Pest Species (CGAPS)
- East Maui Watershed Partnership (EMWP)
- Maui Nui Seabird Recovery Project
- Maui Forest Bird Recovery Project
- Invasive Species Committees of other Islands (ISCs)

Community Groups

Public awareness campaigns often erroneously assume that an informed public will take appropriate action. Peer-learning approaches can help foster conservation actions on private lands through the use of social norms. Actions to encourage public discussion, public commitment making, collective goal setting, and increased observability of contributions can enhance participation, as shown by a public engagement program for control of little fire ants (*Wasmannia auropunctata*) on Hawaiʻi Island (Niemic et al. 2019). Additionally, motivations may differ depending on the level of invasion, with normative messages more effective during early stages, and messages about specific control practices more suitable for communities that already have experience with control actions (Kalnicky et al. 2019).

MISC has implemented a community-based program to encourage control activities by local residents, using principles from community-based social marketing (McKenzie-Mohr 2011) and successful programs on Hawaiʻi Island. Key elements include:

- Identifying specific management units where control by community members seems feasible (e.g., some community members already controlling coqui)
- Organizing and facilitating an initial meeting to encourage public discussion, commitments, and goal setting
- Identifying community resources (e.g. vehicles, community leads to coordinate scheduling, expertise for habitat work, willingness to assist neighbors)
- Providing the community with resources (e.g., lawn signs, scheduling assistance)
- Scheduling spray weeks, providing equipment (sprayers, citric acid), and training
- Periodically working with community members to resolve issues
- Maintaining communication to receive and provide updates
- Implementing a recognition program
- Providing training, equipment (sprayers), and supplies (citric)

In 2018, MISC created a full-time Coqui Community Liaison position; since then, four community groups have formed and are actively working to control coqui (Figure 19). The goal is to add at least four new community groups each year for the next two years.

Figure 19. Lawn sign demonstrating community engagement

Sprayer-loan program and citric acid distribution: MISC has provided sprayers and citric acid supplies to local residents ever since coqui operations began. Initially, Maui County also helped distribute small amounts of citric acid to residents. All community members (individual or representatives for community groups) must sign out equipment and acknowledge in writing that they have read the citric acid label. Distribution of citric acid to the community has grown steadily over the years, but increased significantly with initiation of the community-engagement program (Figure 20).

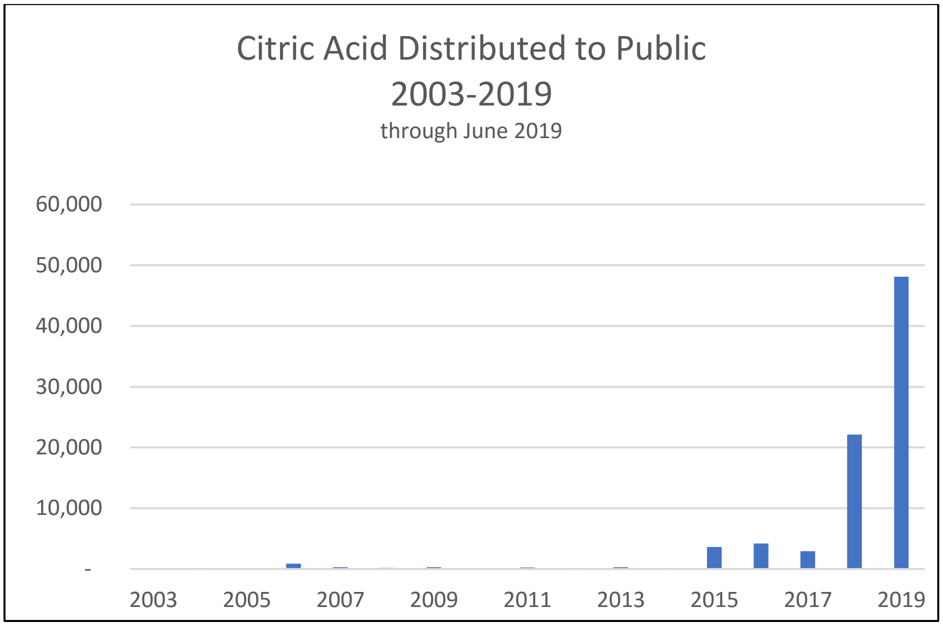

Figure 20. Citric acid distributed to the public, 2003-2019

Communications and Outreach

Achieving and maintaining a coqui-free Maui will require close cooperation and effective internal and external communications with stakeholders, including, but not limited to:

- Landscape industry (nurseries, landscapers)
- County, state, and federal agencies
- Elected officials, especially those in affected areas
- Community groups
- Cultural groups
- Real estate industry
- Tourism industry
- Researchers
- Natural resource managers
- Partner agencies and organizations
- MISC Committee members
- University of Hawaiʻi – Pacific Cooperative Studies Unit
- Research Corporation University of Hawaiʻi

MISC’s communications and outreach strategy will include the following activities, focused on specific stakeholders:

- **Public outreach:** informing local residents about the importance of stopping the spread of coqui and how they can help
- **Landscape industry:** promoting participation in MISC’s Coqui-free Certification program; annual recognition of proactive businesses through Mālama i ka ʻĀina award; targeted campaigns to raise awareness
- **Realtors:** periodic updates to Maui Realtors’ Association
- **Local, State, and Federal Agencies:** Updates and presentatios at regular and periodic meetings (e.g., Coordinating Group on Alien Pest Species; Hawaʻi Invasive Species Council Working Groups)
- **Elected officials:** updates in person; invitations to participate in site visits; presentations at relevant committee meetings
- **Community groups:** quarterly email blasts; annual recognition awards
- **Cultural representatives:** meet with Aha Moku representatives to request and receive input
- **MISC Committee members:** updates during quarterly meetings; in-depth review of coqui project once a year
- **Ad-hoc Advisory group:** MISC may periodically convene an *ad-hoc* advisory group to obtain input from community leaders and enhance transparency
- **Funders:** In addition to required reports, schedule review meetings and provide opportunities for site visits

Outreach activities relevant to the general public and all stakeholders will include:

- Articles and / or press releases in local newspapers
- Presentations and displays at public events (Figure 21)
- Classroom lessons to reach local students
- Use of online websites, social media platforms, and email lists

Figure 21. Keiki learning about coqui frogs at public event

MISC will continue to provide resources to businesses certified as "coqui-free" to help promote their participation (banner, stickers, and handouts; Figure 22) and will list participating businesses on MISC's coqui-free website, www.coquifreemaui.org

Figure 22. Coqui-free logo provided to participating businesses

Measuring Progress: Monitoring and Evaluation

E kaupē aku mo i ka hoe a kō mai.
Put forth the paddle and draw it back.
Go on with the task that is started and finish it.

Meaningful measures to gauge progress are essential to ensure effective and efficient control operations and engagement and support among relevant stakeholders

Efficacy

The goal of eradication requires a steady decrease in the number of coqui present at each site. Measuring such progress is relatively easy when populations contain only 5-10 frogs, but becomes increasingly difficult as populations exceed 20 frogs, and extremely challenging when numbers reach 100, 1,000, or thousands of frogs.

Changes in Coqui Density

A study funded by USFWS confirmed that the approaches used by MISC in Māliko gulch were effective at reducing coqui densities, especially in areas that had previously been treated more than once (81-93% reductions in coqui density estimates; Choi and Beard 2011). Despite an independent demonstration that citric acid is effective, the scale of resources required to eradicate coqui frogs requires ongoing, meaningful measures to gauge progress and efficiently allocate resources. Obtain accurate measurements of changes in coqui density will require treating the entire infested area within a management unit before beginning a non-treatment interval.

Abundance counts: Historically, MISC staff has measured coqui density at a site by estimating the number of coqui present before and after control operations. This approach requires the ability to distinguish between simultaneous or overlapping calls from coqui that are at variable distances from the observer. The scale for estimating the level of infestation includes: none; 1-5; 6-10; 11-20; 21-62; and 63+ frogs. Staff also records the approximate area treated (sprayed with citric acid) and estimates the number of coqui calling outside the treated area after treatment. This approach has three limitations: it fails to adequately capture a decrease from thousands of frogs to hundreds of coqui present at a site because both levels would be classified as 63+ frogs; it is prone to subjective decision making; and there is no spatial measurement of the adjacent area where coqui are still calling.

Options to address these challenges include:

- Mark-recapture studies
- Distance-sampling techniques (line transects)
- Passive acoustic monitoring

The Māliko study found that mark-recapture was the most effective at accurately capturing treatment differences, but was time- and labor-intensive. The distance-sampling technique was more efficient, but also more variable in accuracy. The study concluded that sound pressure levels were less effective at capturing post-treatment changes, but noted the results may have been affected by gulch topography (Choi and Beard 2011).

Passive acoustic monitoring: In recent years, advances in estimating animal density using acoustic monitors have created new methods to address these challenges (Marques et al. 2013), including calculations obtained from sound pressure data (Benevides et al. 2019). MISC plans to deploy a series of autonomous digital recorders in management units under active control and work with independent consultants familiar with the required programming to generate results (Figure 23). Deployment of acoustic monitors will include locations managed by MISC staff and by community groups.

Figure 23. Acoustic monitoring devices for detecting coqui frogs

MISC staff will continue to collect pre- and post-treatment data during all control operations.

Acres, Citric Acid, and Hours

Additional metrics to demonstrate progress over time will include changes in:

- Infested acres
- Citric acid used
- Time required to cover an infested acre
- Percent area covered during each treatment cycle

Operational Efficiency

Key elements of operational efficiency for invasive species management include focusing survey and control efforts in priority areas, establishing clear roles and responsibilities, and establishing appropriate timescales for action. As discussed above, a robust data management system is critical for efficient operations.

Priorities

Top priorities include removing single-frog introductions to prevent establishment of new populations, and working through management units in a systematic manner. Ideally, all management units would be on a 6-8 week revisit schedule; however, current resources are not adequate to work across the entire island at the same time. Priority considerations for deciding where to work include:

- Size and level of infestation (acreage and density)
- Community-based efforts (active involvement maximizes resource use)
- Potential for infestation to vector coqui to new areas (nurseries, or proximity to roads, waterways, or gulches)
- Proximity to high-value natural areas
- Feasibility of control (safety, access, terrain)

Roles and Responsibilities

A number of different entities are currently engaged in coqui control efforts. A collective, coordinated approach is necessary to ensure efficient project management. The following outlines proposed responsibilities.

Maui Invasive Species Committee: MISC will maintain responsibility for the following activities:

- Overall project management
- Securing permission to access properties
- Identifying, securing and allocating necessary resources
- Maintaining a comprehensive information management system
- Ensuring communication among all entities
- Working with community members and groups

Hawaiʻi Department of Agriculture: The Hawaiʻi Department of Agriculture on Maui includes staff from the Plant, Pest Control (PPC) and Plant Quarantine (PQ) Branches. HDOA staff often responds to reports of single coqui frogs and may occasionally assist with control efforts. Work by HDOA PQ staff remains critical to intercepting and preventing new introductions of coqui frogs.

Hawaiʻi Department of Land and Natural Resources: Staff from the DLNR Division of Forestry and Wildlife (DLNR-DOFAW) are making substantial progress with removal of coqui-friendly habitat. MISC will continue to coordinate with DLNR-DOFAW on how best to use these resources.

Community Groups: Community engagement in response to MISC's efforts to create a community-based program has been phenomenal. Some areas are particularly well-suited to a community-led approach. Four "official" community groups have been established, with more in development. Others will require more involvement of MISC staff (e.g., areas that include mini-gulches or which present other operational hazards).

Other partners: Other partners may also assist as feasible. For example, the East Maui Watershed Partnership and Maui Nui Seabird Recovery Program have helped fill temporary staffing gaps by helping with field work.

Metrics

Key metrics for measuring operational effectiveness, efficiency, and stakeolder involvement are summarized in Table 5.

Table 5. Metrics for effectiveness of coqui program

Objective: Coqui density decreases with treatment.		
Actions	**Metrics**	**Timeline**
Deploy series of acoustic monitors	- Numbers and locations of monitors - Data analyzed	Deploy in 2020; annual analysis
Update infestation estimates for unit	- Acres infested with coqui	Complete by 2021
Track citric use and distribution	- Citric acid used	Annual (calendar year) assessment
Track hours spent on control actions by MISC, DLNR, and Community	- Time required to treat an infested area	Annual assessment
Track ability to treat entire infested area	- Percent area covered during each treatment cycle	Annual assessment
Objective: Priorities and responsibilities are clear and transparent.		
Actions	**Metrics**	**Timeline**
Assign priorities for each management unit	Majority of work occurs in highest priority areas	Annual (calendar year) assessment
Collect and analyze data	Share results of cooperative work with all partners	Annual meeting or summary

Objective: Key stakeholders are informed, engaged, and supportive.		
Actions	**Metrics**	**Timeline**
Work with community groups	- Each group has a subset of community leaders promoting and assisting with control - Meet with each group twice a year - Updates provided regularly - Pounds of citric acid distributed - Percentage of properties participating in control efforts	Annual review
Maintain effective partnerships	- Annual report - Hours contributed to project - Funds secured - Annual meeting of *ad-hoc* group	Annual review
Conduct comprehensive outreach and education program	- Number of public events - Number of publications - Social media metrics - Number of coqui-free businesses	Annual review

Proposed Schedule

The ability to implement the proposed strategy and achieve eradication of coqui frogs from Maui will depend on available resources. The proposed implementation uses a phased approach. It will take more years to eradicate coqui from more densely-infested areas.

Table 6 outlines proposed responsibilities, broken out by size of the infested areas. An important caveat is that these estimates are based on previous control operations and do not reflect recent delimitations. Infestations could be significantly larger; in some cases, they are likely less. Additionally, it is unlikely that community groups will work across an entire management unit. Such groups may organize across different geospatial areas that are more representative of the local community. Thus, it is not realistic at this stage to estimate or assign a total number of acres for which different groups would be responsible.

Table 6. Proposed responsibilities by size and number of management units

	Size of Infestation (Acres)				
Lead Responsibility	**< 5 Acres**	**5-20 acres**	**21-70 acres**	**70+ acres**	**Total Units**
Community Groups	2		5	1	8
MISC and Community	1	5	7		13
MISC Field Crews	6	2	10	2	20
Totals	9	7	22	3	41

Tables 7 and 8 outline projected timelines, and a potential schedule of operations for each management unit.

Table 7. Management units and years to eradication

Number of Years to Eradication	Number of Management Units
1	9
2	2
3	1
5	13
7	3
8	13
Total Units	41

Table 8. Proposed schedule of work on management units

Size of Infestation	Management Unit and Kuleana	No. of Years*	FY Begin**	FY End
	Community Groups			
20-70 acres	Ha‘ikū Makai	5	2021	2026
70+ acres	Ha‘ikū Hill	8	2021	2029
< 5 Acres	Kapi‘i	1	2021	2022
20-70 acres	Ha‘ikū Cannery Residential West	5	2021	2026
20-70 acres	Ha‘ikū Mauka	8	2021	2029
20-70 acres	Lilikoi Residential West	8	2021	2029
< 5 Acres	Mauna‘olu Plantation	1	2021	2022
20-70 acres	Ha‘ikū Cannery Residential East	5	2021	2026
	MISC and Community			
5-20 acres	Wailuku Wai‘ale	2	2021	2023
< 5 Acres	Kuiaha Plateau	1	2021	2022
5-20 acres	Māliko Bay	8	2021	2030
20-70 acres	Ha‘ikū Road Makai	7	2021	2028
20-70 acres	Māliko Bay Nursery to Siphon	8	2021	2029
5-20 acres	Lokelau Gulch	5	2021	2026
5-20 acres	Ha‘ikū Town Acres	5	2021	2026
20-70 acres	Giggle Hill Makai Residential	7	2021	2028
20-70 acres	‘Aikane to Kaluanui	5	2021	2026
20-70 acres	Pololei to Pu‘uomalei	5	2021	2026
20-70 acres	Lilikoi Residential East	8	2023	2031
20-70 acres	Huna Wai Gulch and Residential	8	2021	2029
5-20 acres	Kaluanui Makai West	5	2021	2026

Size of Infestation	Management Unit and Kuleana	No. of Years*	FY Begin**	FY End
	MISC Field Crews			
< 5 Acres	South Maui Kalama	1	2021	2022
< 5 Acres	Kula Plant Gulch	1	2021	2022
< 5 Acres	Haloa-Kukuna	1	2021	2022
< 5 Acres	Kuiaha Greenwaste	1	2021	2022
5-20 acres	Haupoa	2	2021	2023
20-70 acres	Lanikai	5	2021	2026
20-70 acres	Jaws Gulch	8	2021	2029
20-70 acres	Kauhikoa Residential	8	2021	2029
70+ acres	Giggle Hill	8	2024	2032
20-70 acres	Piʻialiʻi	8	2021	2029
< 5 Acres	Giggle Hill Makai Fields	1	2021	2022
20-70 acres	Haʻikū Hill Subdivision and Mini Gulch	8	2023	2031
20-70 acres	Strawberry Lilikoi Gulch	5	2021	2026
20-70 acres	Kaluanui Coffee	7	2021	2028
20-70 acres	Kaluanui Mauka	8	2021	2029
< 5 Acres	Haliʻimaile ML&P	1	2021	2022
20-70 acres	Haliʻimaile Baldwin Ranch Estates	5	2021	2026
5-20 acres	HCS Fields Makai	3	2021	2024
20-70 acres	HCS Fields	5	2026	2031
70+ acres	Māliko Proper	5	2026	2031

* “No. of Years” = years of control efforts before a site moves to a monitoring phase.
** Work is already occurring in many units. “FY Begin” = beginning of enhanced effort.

What it Takes: Cost Analysis

I haʻaheo no ka lawaiʻa i ka lako i ka ʻupena.
The fisherman may well be proud when will supplied with nets.
Good tools help the worker succeed.

Determining resource needs and availability is essential for project success and is especially critical when partnering with other agencies or community groups. However, estimating the cost of eradicating an invasive species has challenges similar to those associated with attempting to eliminate human disease. The last pockets of infestation will be those that are hardest to reach, either geographically or socially. Expansion of efforts is costly, and prolonging the end game can lead to funder fatigue and community disengagement (Klepac et al. 2015).

Resource Needs & Gaps

Costs will vary depending on the level of infestation, site characteristics, weather variables, unanticipated spread, and reintroductions from off-island. The probability of missed detections adds another element. Thus, it is neither possible to predict with 100% certainty how many acres are infested with coqui nor how many site visits will be required to eradicate the last coqui from each location.

Cost factors:

- Personnel (full or part-time): wages and benefits for: field staff; crew leaders; project coordinator; data / GIS specialist; operations associate (mechanic); operations / safety manager; procurement / fiscal specialist; community liaison; outreach specialist; and project manager.
- Supplies and repair: citric acid; pipes, hoses, and fittings; field gear; and fuel.
- Facility costs: rent; utilities; maintenance.
- Equipment: sprayers, pumps, tanks, trucks, forklift, tractor-mower.
- Other administration costs (includes insurance, grant management).

Cost basis: Cost estimates are based on data from MISC's previous control efforts:

- Pounds / gallons of citric acid per acre per treatment: 1,000 (range: 765-1,120)
- Person-hours per acre, per treatment: 30 (up to 50)
- Treatments needed to eradicate coqui from an infested area: 10-30 (varies by infestation level)
- Non-coqui specific supplies, repairs, and facility costs, (does not include citric acid)
- Cost projections have not included any discounted cash flow analyses

Some cost factors are beyond the control of the project, including:

- Weather, which can limit efficacy and feasibility of control operations
- Cost of citric acid
- Labor market

MISC already has considerable resources for this project (Figure 24). These include trained personnel, infrastructure, supplies, equipment, and a record of control operations. The following outlines current and needed resources under each cost factor.

Figure 24. Equipment for coqui operations

Personnel

Many MISC staff have been with the project for more than a decade (Appendix D). The collective knowledge of operational protocols, administrative functions, data collection standards, neighborhoods, key contacts, and residents is a significant asset (Figure 25). Table 9 outlines currently-filled and needed staff positions (not all positions would be full-time):

Table 9. Personnel resources and gaps

Position	Current Staff	Additional Staff Needed
Invasive Species Field Associates I	7.00	41.00
Invasive Species Field Associates III		12.00
Crew Leaders	2.00	1.00
Operations Associate (Maintenance)	0.60	
Community Liaisons		2.00
Data/GIS Specialist	0.25	0.75
Outreach & PR Specialist	0.50	0.50
Coordinator	1.00	
Program Specialist	0.25	0.25
Operations Manager	0.50	0.50
Project Manager	0.30	
Total FTE	**12.40**	**58.00**

Figure 25. MISC field staff at work

Supplies

Citric acid: Supplies, mostly citric acid, constitute a major cost component. Citric acid costs have varied over the years, ranging from $0.58 to $0.73 per pound. The least expensive citric acid has often come from China and it is unknown whether trade issues might affect price or availability. Additional supply costs include pipes, hoses, fittings, field gear, safety equipment, fuel, and outreach materials.

Equipment
Equipment purchased for the project reflects years of research and field experience, as well as finding vendors who can provide or manufacture equipment to the required specifications. Table 10 outlines current heavy equipment dedicated to the project.

Table 10. Equipment resources and gaps

Equipment	Existing	Needed	Notes
100g skid-tank bed/pump	2	15	For sprayer-loan program
200g skid-tank bed/pump	1		
200g skid-sprayer system	1	2	For field crews
300g tank trailer/pump	2	1	For field crews
400g skid tank bed/pump	3	1	For field crews
1,025g tank trailer/pump	1		
Transfer pump	1		
Trucks*	6	12	Includes replacement of 3 trucks
Skytrack forklift	1		
Kubota tractor	1		

*Models for existing vehicles: (2001, 2005, 2007, 2010, 2016, 2017).

Information Management: Existing data provide the foundation for all future field operations including information about site access, contacts, hazards, and a full history of previous efforts. These data are critical for evaluating progress over time. MISC needs to invest in an improved data management system, due to the complexity and dynamic nature of the operation.

Communications: In addition to staff skills, MISC has existing relationships with the state and local media outlets, as well as appropriate software for communications. No resource gaps have been identified that would affect cost estimates.

Facilities: The MISC operation has been based in Makawao at the UH-CTAHR Haleakalā Experimental Field Station on Piʻiholo Road since 2003. This location has provided an excellent operational base for the coqui project due to its proximity to Māliko gulch, storage capacity, maintenance and office space, and easy access for community members who pick up sprayers or citric acid. MISC has just learned that it must vacate the Piʻiholo baseyard by January 2020. Even if a suitable location is found for little-to-no rent, the costs of moving the entire MISC operation will result in unanticipated costs and significant disruption. Projected costs for establishing a new facility are unknown, but are expected to be substantial.

Research: Planning for the eradication of coqui frogs has benefited tremendously from research on coqui frogs conducted in Hawaiʻi and Puerto Rico, including through collaborative projects with MISC. As a project of the University of Hawaiʻi, MISC has a close connection with UH professors, which can afford opportunities to work with undergraduate and graduate students to address knowledge gaps. The coqui frog program would benefit from focused economic modeling and research into innovative techniques. Research on the following topics would be especially helpful:

- Barrier-fence design and cost-savings analyses
- Large-scale habitat modification options for Māliko gulch
- Less-expensive alternatives to citric acid
- Mapping potential coqui distribution on Maui
- Model to address uncertainties related to probability of detection or reintroduction
- Economic model for most efficient resource allocation, including choosing between different management strategies
- Model for estimating costs and time to eradication
- Feasibility of using chytrid fungus to reduce survivorship of juvenile coqui

Resource gaps in personnel, supplies, and equipment will be identified on an annual basis as part of the funding cycle.

Cost Estimates

Different approaches have been used to help improve cost estimate reliability. Previous analyses of control efforts have established that costs vary considerably, based on the density and extent of an infestation, as well as terrain. As a result, it is not possible to overemphasize the word "estimate." What is not in doubt, however, is that costs continue to escalate over time, as the invasion spreads. Analyses conducted in 2005 projected that eradication would cost $3 million (Hawaiʻi DLNR 2007); by 2015, MISC estimated costs of up to $20 million. This increase is consistent with invasion biology models (Figure 26).

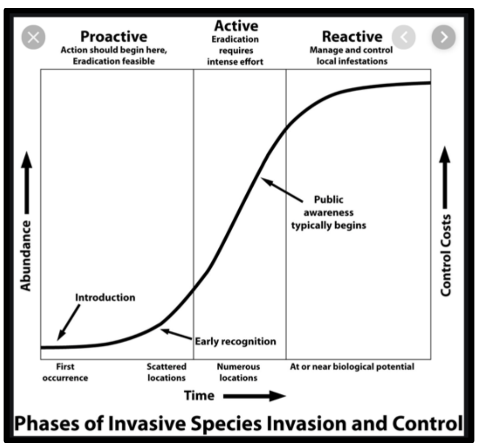

Figure 26. Phases of invasive species invasion and control

Key Assumptions: Treatment costs per acre are assumed to vary, based on who has lead responsibility for control operations in an area (Table 11). The cost-per-acre estimate is based on historical cost data. The calculations assume reduced labor costs through community involvement (12.5% reduction in labor costs for areas where MISC conducts most of the control work, but community members participate; and 25% reduction in labor costs where community groups are actively engaged. The level of infestation, along with overall size of the infested area affects the number of visits required and number of years to eradication (Table 12).

Table 11. Estimated cost per acre by lead responsibility

Lead Responsibility	Cost per Acre
Community Groups	$1,575
MISC Crew & Community Groups	$1,838
MISC Crew	$2,100

Table 12. Level of infestation and years to eradication

	Number of Management Units & Years to Eradication						Total
Infestation Level	1	2	3	5	7	8	
Low	8	1	1	3		1	14
Medium		1		2	1	4	8
High		1		8	2	8	19

* No. of years = years of control efforts expected before a site moves to a monitoring phase. Monitoring continues for at least one year after the last calling coqui is heard. More densely-infested sites will likely require more years of post-eradication monitoring.

Table 13 shows cost estimates based on lead responsibility and level of infestation. Table 14 outlines cost estimates, timelines, and lead responsibility for individual management units. Assuming adequate resources, the proposed timeline would achieve eradication of coqui frogs from all areas other than Māliko gulch by 2029 and from Māliko gulch by 2031. There following are relevant caveats:

- It will not be possible to begin systematic work across all areas of the island at the same time.
- Size of a management unit does not provide a basis for prioritization. Within larger-sized units, development of sub-units will help guide prioritization.
- Infrastructure will be needed to achieve successful eradication. Ramping up to the scale proposed will require dedicated space for equipment, vehicles, citric acid storage, maintenance, and meeting space.
- Maui’s labor market may create challenges to filling positions.

Table 13. Cost estimates for eradication by size of infestation and responsibility

Lead Responsibility	Low	Medium	High	Totals
Community Spray Groups	$85,821	$6,065,148	$7,650,421	$ 13,831,390
MISC and Community	$1,667,001	$5,380,265	$6,852,215	$ 13,899,481
MISC Field Crews	$1,164,132	$1,375,827	$33,312,219	$ 35,852,177
Totals	**$2,916,953**	**$12,851,239**	**$47,814,855**	**$63,583,048**

Table 14. Cost estimates and timelines by management unit

Lead Responsibility	Management Area	Management Unit	Infestation Level	No. Years	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	Total Cost
MISC and Community	Island Outliers	Wailuku Waiale	Low	2	282,962	282,962									$ 565,924
MISC Field Crews	Island Outliers	Kula Plant Gulch	Low	1	33,177										$ 33,177
MISC Field Crews	Island Outliers	South Maui Kalama	Low	1	1,350										$ 1,350
MISC Field Crews	Haiku Outliers	Haloa-Kukuna	Low	1	9,090										$ 9,090
MISC Field Crews	Haiku Outliers	Haupoa	Medium	2	125,836	125,836									$ 251,671
MISC and Community	Haiku Outliers	Kuiaha Plateau	Low	1	12,860										$ 12,860
MISC Field Crews	Haiku Outliers	Kuiaha Greenwaste	High	2	134,161	134,161									$ 268,322
MISC Field Crews	Haiku Outliers	Lanikai	Low	5	185,415	185,415	166,873	166,873	139,061						$ 843,636
MISC Field Crews	Haiku Outliers	Jaws Gulch	High	8	200,965	200,965	200,965	200,965	180,869	180,869	150,724	150,724			$ 1,467,048
MISC Field Crews	Kauhikoa Stand	Giggle Hill	High	8	717,531	717,531	717,531	717,531	645,778	645,778	538,148	538,148			$ 4,699,829
Community Groups	Kauhikoa Stand	Kapii	Low	1	73,422										$ 73,422
MISC Field Crews	Kauhikoa Stand	Kauhikoa Residential	Medium	8	153,994	153,994	153,994	153,994	138,595	138,595	115,495	115,495			$ 1,124,156
Community Groups	Haiku Road Makai	Haiku Hill	High	8	487,250	487,250	487,250	487,250	438,525	438,525	365,438	365,438			$ 3,556,928
Community Groups	Haiku Road Makai	Haiku Makai	Medium	5	327,283	327,283	294,555	294,555	245,462						$ 1,489,138
MISC and Community	Haiku Road Makai	Haiku Road Makai	Medium	7	220,228	220,228	220,228	220,228	198,205	198,205	144,524				$ 1,421,845
MISC and Community	Haiku Road Makai	Maliko Bay	Low	8	26,134	26,134	26,134	26,134	23,521	23,521	19,601	19,601			$ 190,780
MISC and Community	Haiku Road Makai	Maliko Bay Nursery to	Medium	8	244,766	244,766	244,766	244,766	220,290	220,290	183,575	183,575			$ 1,786,795
MISC Field Crews	Haiku Road Makai	Piialii	High	8	294,686	294,686	294,686	294,686	265,217	265,217	221,014	221,014			$ 2,151,207
Community Groups	Giggle Makai	Haiku Cannery Residential E	Medium	5	386,755	386,755	348,080	348,080	290,066						$ 1,759,736
MISC Field Crews	Giggle Makai	Giggle Hill Makai Fields	Low	1	59,560										59,560
MISC and Community	Kokomo Middle	Giggle Hill Makai	High	7	253,068	253,068	253,068	253,068	227,761	227,761	166,076				$ 1,633,868
Community Groups	Kokomo Middle	Haiku Cannery Residential W	High	5	273,337	273,337	246,004	246,004	205,003						$ 1,243,685
MISC Field Crews	Kokomo Middle	Haiku Hill Subdivision and	High	8	279,634	279,634	279,634	279,634	251,670	251,670	209,725	209,725			$ 2,041,326
Community Groups	Kokomo Middle	Haiku Mauka	Medium	8	389,900	389,900	389,900	389,900	350,910	350,910	292,425	292,425			$ 2,846,274
MISC and Community	Kokomo Middle	Haiku Town Acres	High	5	214,716	214,716	193,245	193,245	161,037						$ 976,959
MISC and Community	Kokomo Middle	Lokelau Gulch	High	5	163,238	163,238	146,915	146,915	122,429						$ 742,735
MISC and Community	Kokomo Upper	Aikane to Kaluanui	High	5	278,534	278,534	250,680	250,680	208,900						$ 1,267,328
MISC and Community	Kokomo Upper	Huna Wai Gulch and	High	8	305,661	305,661	305,661	305,661	275,095	275,095	229,246	229,246			$ 2,231,326
MISC and Community	Kokomo Upper	Lilikoi Residential East	Medium	8	297,483	297,483	297,483	297,483	267,735	267,735	223,112	223,112			$ 2,171,626
Community Groups	Kokomo Upper	Lilikoi Residential West	High	8	390,385	390,385	390,385	390,385	351,346	351,346	292,789	292,789			$ 2,849,808
MISC and Community	Kokomo Upper	Pololei to Puuomalei	Low	5	103,195	103,195	92,875	92,875	77,396						$ 469,537
MISC Field Crews	Kokomo Upper	Strawberry Lilikoi Gulch	High	5	296,774	296,774	267,097	267,097	222,581						$ 1,350,322
MISC Field Crews	Mauka & West	Haliimaile Baldwin Ranch Es	High	5	282,059	282,059	253,853	253,853	211,544						$ 1,283,367
MISC Field Crews	Mauka & West	Haliimaile ML&P	Low	1	1,680										$ 1,680
MISC Field Crews	Mauka & West	Kaluanui Coffee	High	7	221,017	221,017	221,017	221,017	198,916	198,916	145,043				$ 1,426,943
MISC and Community	Mauka & West	Kaluanui Makai West	Low	5	94,044	94,044	84,640	84,640	70,533						$ 427,900
MISC Field Crews	Mauka & West	Kaluanui Mauka	High	8	346,970	346,970	346,970	346,970	312,273	312,273	260,228	260,228			$ 2,532,884
Community Groups	Mauka & West	Maunaolu Plantation	Low	1	12,399										$ 12,399
MISC Field Crews	Mahi Pono	HCS Fields	High	5						638,214	638,214	638,214	638,214	638,214	$ 3,191,069
MISC Field Crews	Mahi Pono	HCS Fields Makai	Low	3			71,879	71,879	71,879						$ 215,638
MISC Field Crews	Deep Gulch	Maliko Proper	High	5						1,289,990	1,289,990	2,579,981	3,869,971	3,869,971	$ 12,899,903
Totals					$8,181,520	$ 7,695,020	$ 7,246,367	$ 7,246,367	$ 6,372,598	$ 6,274,910	$ 5,485,367	$ 6,319,715	$ 4,508,185	$ 4,508,185	$ 63,838,234

Conclusions and Recommendations

This plan presents an aggressive path forward for eradicating coqui from the island of Maui. The plan also seeks to inform elected officials and the broader community about the scale of the problem, efforts to date, and existing infrastructure. Ultimately, the public must decide whether the future includes a coqui-free Maui, or we accept the eventual establishment of coqui in all our neighborhoods and into our forests.

The plan should be considered as a starting place for more analyses and discussions. While the projected costs are substantial, more minds and backs working together can surely bring those costs down. MISC has traditionally focused its resources “on the ground” and not on research. Investment in further planning and modeling could help sharpen the focus on more cost-effective strategies.

Key recommendations include:

- Establishment of an *ad hoc* coqui frog task force to help with:
  - Reviewing and refining the strategic plan
  - Identifying alternative approaches to address identified challenges
  - Identifying and helping to secure resources
  - Providing enhanced transparency and communication
- Securing a long-term facility for MISC operations
- Development of an internship program, with housing, to help reduce labor costs
- Scheduling annual updates on the program to share progress and challenges
- Hosting a conference to address research gaps
- Exploring regulatory options to encourage businesses to help shoulder the costs of coqui control, while balancing incentives to report infestations
- Exploring natural enemies to reduce coqui population densities

A coqui-free Maui is still possible.

Figure 27. Community meeting in Haʻikū

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Appendix A   Citric Acid Label

HAWAI‘I DEPARTMENT OF AGRICULTURE
PLANT INDUSTRY DIVISION

December 11, 2002

Citric Acid Anhydrous

Label for use of Citric Acid Anhydrous for Control of
Caribbean Tree Frogs *

Active Ingredient: Citric Acid Anhydrous, 99.85 %

Inert Ingredient: Water, 0.15 %

*Citric Acid Anhydrous is available from different companies. These directions for use apply to Citric Acid Anhydrous that can be used as an ingredient in food products, e.g., Citric Acid Anhydrous, Technical, BP, USP, FCC Grade

Safety Precautions:
Citric acid anhydrous is a highly irritating and corrosive chemical. Follow safety precautions on the product label to avoid eye, skin and respiratory irritation. Follow product label directions in the event of a spill of the product.

Toxicity to Plants:
Citric acid anhydrous powder and solutions of citric acid in water can be toxic to plants. Do not apply to plants of value. Do not apply powder directly to plants. Evaluate the toxicity of citric acid solution on test plants before treating plants for the control of coqui and greenhouse frogs.

Directions for Use:
Citric acid in water solution is toxic to the coqui (Eleutherodactylus coqui) "and greenhouse (E. planirostris) frogs. Tests and field trials conducted by state and federal agencies in Hawai‘i indicate a 16% solution of citric acid in water (1.28 lbs citric acid anhydrous in 1 gallon of water) will kill both species of tree frogs shortly after initial contact.

To avoid damage to plants, wash down treated area with fresh water, preferably within an hour after citric acid application.

For questions regarding the use of citric acid for frog control, contact the Hawai‘i Department of Agriculture at 808-974-4141 (Hilo), 808-973-9538 (Oahu)~ or 808-873-3555 (Maui).

Appendix B MISC Committee Members and Staff

The following outlines key responsibilities for project implementation as well as the education, work experience and qualifications of relevant committee and staff members.

MISC Committee: Committee members provide scientific and natural resource management expertise in target species selection, survey and control methodology, and evaluation. The Committee includes current and retired professional scientists and natural resource managers, with a combined cumulative experience of over 150 years working on Hawaiʻi's natural resource issues: Fern Duvall (Chair), PhD (Program Manager, DLNR-NARS); Marshall Loope (Inspector, HDOA); Kerri Fay (Invasive Species Specialist/Data Analyst, TNC); Jeffrey Mallinson (Natural Resource Manager, HALE-NPS); and Bob Hobdy (Botanist and District Manager (retired), DLNR-DOFAW).

MISC Manager (Adam Radford): Provides overall project management and staff supervision, vision, and leadership. Develops proposals and prepares project reports. B.A. Recreation; M.A. Natural Resource Management. Has 15+ years' experience working on Hawaiʻi's natural resource issues, including 14 years with MISC. Certified rappel instructor and helicopter manager.

MoMISC Coordinator (Lori Buchanan): Responsible for overall project management for operations on Molokai, including outreach. Supervises staff of 4 (includes 1 part-time staff). Ensures strong partner support. More than 16 years' experience working on natural resource protection. Strong background in land use planning at county and state levels and community development.

MISC Operations Manager (Adam Knox): Responsible for developing and ensuring appropriate on-the-ground implementation to meet project goals and objectives; project safety officer and helicopter manager. Eight years' experience in natural resource management throughout the Pacific, including with brown treesnakes. B.S. Consumer Affairs; Master of Environmental Science and Management.

MISC Coqui Coordinator (Abe Vandenberg): Coordinates field and management logistics for coqui; interfaces with landowners. Bachelor of Arts degree; 12 years' experience with MISC, primarily with coqui operations.

MISC Program Specialist (Elizabeth Anderson): Coordinates field and management logistics; human resource management; provides fiscal management, tracking and evaluation. Assists with proposal development and report writing; 30+ years' experience working in natural resource management; 18 years with MISC; B.A. Wildlife Biology; post-graduate work with the National Park Service in resources management.

MISC PR & Education Specialist (Lissa Strohecker): Develops and implements comprehensive outreach and education program; develops displays and outreach materials; works with print and broadcast media on invasive species messages; oversees Hōʻike o Haleakalā curriculum project. B.S. in Biology; 10+ years in research and natural resource management; 13 years working with MISC; extensive training in publications software.

MISC GIS Data Analyst (Brooke Mahnken): Oversees and provides quality control for data collection, entry and analysis. Also manages little fire ant project. Uses existing data to provide maps to guide field operations; develops database and geospatial analytical tools; prepares comprehensive analyses for publication and presentation; more than 10 years' experience with MISC. B.S. in Biology; B.S. in Botany.

PCSU Special Projects and Development Director (Teya Penniman): Project guidance; partner development and relations. Has 25+ years' experience in research and natural resource management, including 16 years with MISC; B.S., zoology; M.B.A.; J.D., (natural resources and environmental law); trained mediator, facilitator, arbitrator, attorney (HI).

Invasive Species Field Crew Leaders (Darrell Aquino, Aja Akuna, Kamalani Pali and Imi Nelson): Provide direction for crews in the field under the direction of Field Coordinators. MISC's crew leaders have a wealth of experience in the areas of plant identification; tree cutting; chainsaw use; herbicide application; and use of large and small mechanized equipment; and helicopter operations. Most have been with the project for more than 10 years.

MISC & MoMISC Invasive Species Associates: Conduct ground-based and aerial surveys for MISC and MoMISC target speces, using GPS units to record all data. Implement manual and chemical control techniques to remove target species, Work occurs in residential, rural and remote locations and requires hiking and use of helicopters. Participate in outreach activiites as needed. All field staff receive in-depth training in target species identification, detection and control techniques, proper and safe use of all tools and equipment. Many staff have undergraduate degrees in biology or natural resource management and/or extensive field experience.