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Abstract: The coqui frog (*Eleutherodactylus coqui*) is native to Puerto Rico and was accidentally introduced to the State of Hawaiʻi through contaminated nursery products from the Caribbean. Since its introduction in the late 1980s, coqui have become widely dispersed and in some areas population densities have reached 55,000 frogs/ha. The coqui frog is a species of concern because individual frogs can produce sound levels of 80 decibels (at 0.5 m), which has caused sleep loss to residents and affected the quality of life in Hawaiʻi. Economic concerns in infested areas include diminished property values and sales, impacts on tourism, and decreased sales in the floriculture and nursery industry. In addition, research indicates that the coqui has potential ecological effects as they might predate on endangered invertebrates and shift nutrient cycling processes in native forests. Control efforts have focused on habitat modification and applying chemical solutions of either 16% citric acid or 3% hydrated lime. Hot water or vapor treatments of plants are also effective control methods. Eradication of the coqui frog is not considered attainable on the Island of Hawaiʻi and seems unlikely for Maui, but may be possible on the islands of Kauaʻi and Oʻahu.

Key Words: amphibian, biological invasions, chemical application, *Eleutherodactylus coqui*, Hawaiian Islands, invasive species, island conservation.

Managing Vertebrate Invasive Species: Proceedings of an International Symposium (G. W. Witmer, W. C. Pitt, K. A. Fagerstone, Eds). USDA/APHIS/WS, National Wildlife Research Center, Fort Collins, CO. 2007.

INTRODUCTION

The State of Hawaiʻi lacks any native or endemic amphibian species due to the geographic isolation of the Hawaiian Archipelago. The nearest continent, North America, lies 3,200 km to the east and the nearest Pacific atolls are 1,600 km to the south. In spite of these distances, approximately 27 species of herpetofauna have been introduced to Hawaiʻi (Kraus 2003), with coqui frogs (*Eleutherodactylus coqui*), Jackson's chameleons (*Chamaeleo jacksonii xantholophus*), and brown anoles (*Anolis sagrei*) expected to have negative effects on native ecosystems (E. W. Campbell, Fish and Wildlife Service, personal communication). In particular, the coqui frog, has been a species of focus for both control and research efforts.

The coqui frog is endemic to Puerto Rico and is thought to have been introduced to Hawaiʻi in the late 1980s via the horticultural industry (Kraus et al. 1999). Although the first voucher specimen for the coqui frog was collected from the Island of Maui in 1997, population sizes and densities were already noticeably larger on the Island of Hawaiʻi (F. Duvall, DLNR-DOFAW, personal communication). The coqui frog has since become one of Hawaiʻi's most recognizable invasive species as populations have steadily encroached on human habitats.

Currently, the coqui frog occurs in all types of habitats from sea level to 1,300 m in elevation (H. Sin, DLNR-DOFAW, unpublished data) and can reach population densities up to 55,000 frogs/ha in some areas (N. Tuttle, Utah State University, unpublished data), with their highest densities occurring in wet locations on the windward sides of the islands (Kraus and Campbell 2002). Such high densities are partly due to high fecundity rates (4-6 clutches/yr, 16-41 eggs/clutch) (Townsend and Stewart 1994), direct development of eggs (no tadpole stage), lack of predators and competitors (Beard and Pitt 2006), abundant food sources, and generalist feeding behavior (Stewart and Woolbright 1996).

ECOLOGICAL EFFECTS

Left unchecked, the coqui frog is expected to adversely affect native and endemic invertebrates and change certain ecological processes. At such high densities, this sit-and-wait, generalist predator can possibly consume greater than 400,000 invertebrates a night/ha, based on 55,000 frogs/ha with an average of 7.6 prey items consumed per night per individual (Beard 2007a). This direct consumption has significant potential to reduce Hawai‘i's invertebrate populations, which make up most of Hawai‘i's endemic fauna (Eldredge and Miller 1995). One recent diet study in particular has provided evidence that the coqui frog predates on endemic invertebrates. Beard (2007a) suggests that Acarina (mites), Coleoptera (beetles), Collembola (springtails), Diptera (flies) and Gastropoda (snails) are the most vulnerable to predation and that each order comprised more than 1.5% of its total diet in a variety of habitats including nurseries, disturbed habitats, and natural areas.

The coqui frog may contribute to significant increases in nutrient recycling rates in the ecosystem from its excrement, which in turn may increase certain invasive plant growth and increase leaf litter decomposition rates (H. Sin et al. In Press). Increased leaf litter decomposition can in turn release additional nutrients for plant use, particularly invasive plants. Invasive plants in Hawai‘i are usually able to utilize certain resources, such as nutrients, more efficiently than native plants (Pattison et al. 1998, Ostertag and Verville 2002). Specifically, in a small-scale enclosure experiment, the presence of the coqui frog reduced herbivory rates, increased certain nutrients in ‘ōhi‘a (*Metrosideros polymorpha*) leaf litter, increased ‘ōhi‘a leaf litter decomposition rates and increased the number of new leaves of strawberry guava (*Psidium cattleianum*) (H. Sin et al. In Press). These results are consistent with similar small- and large-scale experiments conducted in the coqui frog's home range in Puerto Rico (Beard et al. 2002, 2003).

The coqui frog also has been hypothesized to compete with native birds for food, the majority of these birds being insectivorous (Kraus et al. 1999). Some variables to consider when discussing potential competition of native birds and the coqui frog are: overlapping range, habitat, and common prey of these species. Currently, the majority of Hawaiian endemic birds are above 500 m in elevation (Stattersfield et al. 1998) and high densities of frogs are below this elevation (Beard and Pitt 2005, H. Sin, unpublished data). The current status of this condition suggests minimal competition between native birds and coqui frogs. However, there is a strong potential for coqui frogs to naturalize in these higher-elevation areas as they are capable of occurring in all types of habitats from sea level to 1,300 m in elevation (H. Sin, unpublished data).

There is also a degree of overlap in common prey items where native birds and coqui frogs co-occur. For example, the coqui frog has the potential to compete for food with such species as the ‘elepaio (*Chasiempis spp*.), the ‘i‘iwi (*Vestiaria coccinea*), and particularly the endangered Hawaiian hoary bat (*Lasiurus cinereus semotus*) as they share common prey items and elevational range (Beard and Pitt 2005). Conversely, frogs might be a possible food source for native birds, though unlikely due to different activity periods of these groups. Furthermore, research indicates that the coqui frog is an opportunistic feeder foraging upon abundant prey items. This generalist feeding behavior may interrupt key ecosystem processes and reduce the availability of preferred invertebrates for native bird and bat populations.

The coqui frog may also increase populations of native bird predators, such as the black rat (*Rattus rattus*) and the small Indian mongoose (*Herpestes javanicus*), by serving as a food source (Kraus et al. 1999). However, a recent diet study of rodents (*R. rattus* and *R. exulans*), cane toads (*Bufo marinus*), and the small Indian mongoose (*H. javanicus*) on the Island of Hawai‘i found that only the small Indian mongoose had consumed coqui frogs (Beard and Pitt 2006). These results are similar to those found in Puerto Rico, which has the same non-native rat, mongoose, and toad species (Beard 2007b). Further research is necessary to determine if coqui frogs are indeed bolstering mongoose populations. The coqui frog may also serve as a food source for other potentially devastating bird predators such as the brown tree snake (*Boiga irregularis*) (Beard and Pitt 2005).

ECONOMIC EFFECTS

The coqui frog has adversely affected Hawai‘i's economy, particularly through the nursery and real estate industries, due primarily to the volume and consistency of its vocalizations. The mating call of male coqui frogs, which typically begins at sunset and continues throughout the night, can reach sound levels of 80-90 decibels (at 0.5 m), exceeding the legislatively-established state health standard of 70 dBA (Hawai‘i Revised Statutes § 324F-1) (Beard and Pitt 2005). Coqui frog vocalizations have resulted in sleep loss for both residents and tourists, which has decreased accommodation revenues in some areas and has negatively affected real estate markets (Kaiser and Burnett 2006). Hotels have reported complaints of coqui frogs and some visitors report that they have changed, or are planning to change, their travel plans to avoid coqui frogs in the future (W. C. Pitt, USDA-APHIS-WS-NWRC, personal communication). 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 live, or continue to live, in impacted areas. Effects on hotels, resorts, and displacement of residents are largely anecdotal and more research is needed to quantify these impacts.

Property owners on the Island of Hawaiʻi have also felt the economic effects of coqui frogs and are currently required to disclose if frogs are present on the property before selling their property or homes, similar to termites; which has resulted in an average of 0.16% loss of real estate value per sale (Kaiser and Burnett 2006). Though this percentage appears small on a per household basis, the total direct damage to property values for all homes in the State of Hawaiʻi is conservatively estimated at $208.8 million (Kaiser and Burnett 2006).

The nursery industry has been particularly affected by the presence of coqui frogs. The State of Hawaiʻi has designated the coqui frog as a “pest” and “injurious wildlife” under Hawaiʻi Revised Statutes (HRS) 141-3 and 124-13, respectively. These laws establish provisions for both cooperative and mandatory control of the coqui frog, and make it illegal to release, transport or export coqui frogs. These requirements have resulted in rejection of nursery goods at ports of entry, lost time in shipping, added labor costs for nurseries, and more stringent preventative/ treatment measures for invasions of coqui frogs. Indirect costs to nurseries and plant providers have increased as consumers have become more selective purchasers. Although no citations have been issued to businesses or individuals, the Hawaiʻi Department of Agriculture’s (HDOA) website (www.hawaii.gov/hdoa) states: Any person or organization who intentionally transports, harbors or imports with the intent to propagate, sell, or release the coqui is in violation of State law and may be charged with a class C felony and subject to a minimum fine of $50,000 and a maximum fine of $200,000, plus 3 years in prison.

Currently, the HDOA and other public and private entities are working on both mandatory and voluntary “Coqui-Free” certifications for nurseries to minimize the possibility of inadvertent distribution. These programs are also intended to help reassure apprehensive consumers and build confidence that the inadvertent spread of coqui frogs is being limited.

CONTROL METHODS

A number of methods are currently being used to control the proliferation of coqui frogs in the State of Hawaiʻi. Both chemical and non-chemical control methods continue to emerge and are evaluated on a case-by-case basis by researchers from the HDOA, University of Hawaiʻi’s College of Tropical Agriculture and Human Resources (CTAHR), and USDA-APHIS-NWRC in Hilo. Given the overwhelming abundance of coqui frogs on some private properties, unregulated independent trials, misuse of chemicals, and experimentation with control methods occur. Often new approaches and successful strategies are shared via e-mail lists, informal conversations, and at community and professional meetings throughout the state. Federal, state and county organizations work hard to help facilitate cooperative control initiatives and to ensure that chemical labels are being followed.

Chemical Control Methods

The most widely used chemical methods for controlling coqui frogs are to apply either 16% citric acid or 3% hydrated lime solutions to an infested area. Both chemicals have been shown to be effective toxicants for frogs while also reducing egg hatch rates. However, direct application of solutions onto frogs and eggs are necessary to be effective; thus, several applications may be needed to ensure that all frogs and eggs are eliminated (Beard and Pitt 2005). Historically, laboratory and field studies demonstrated that a 2% caffeine solution was an effective frog toxicant and did not have significant harmful effects on non-target species (Campbell 2001a, b; Pitt and Sin 2004a). However, caffeine is no longer registered for use as a frog toxicant and there are no future plans for registration given extensive testing requirements associated with concerns over potential human health effects. USDA-APHIS-WS-NWRC has also reviewed a long list of additional chemicals, both non-restricted and restricted use, but additional products have yet to emerge that are both lethal and cost-effective.

A 16 % citric acid solution was found to be effective at controlling frogs in laboratory and field settings (Pitt and Sin 2004b, c). Citric acid is classified as a “minimum risk” pesticide and is exempt from requirements of the Federal

Insecticide, Fungicide, and Rodenticide Act (FIFRA) 40 CFR 152.25. Subsequently, this product was put to use in the field after it was found to be effective on frogs. Citric acid does not affect most non-target arthropods (Pitt and Sin 2004c). However, citric acid may result in some phytotoxic effects and may not be appropriate for all greenhouse plants (Pitt and Sin 2004d). These potential phytotoxic effects, along with the relatively high cost (~$1.00/gallon), make this product undesirable in some situations. Some variation in the percent of active ingredient and addition of pyrethrins has occurred with citric acid use in an attempt to improve efficacy and minimize phytotoxic effects (Scott Williamson, DLNR, personal communication).

On April 26, 2005, a 3% hydrated lime solution was registered for use by HDOA under a Section 18 quarantine exemption from the US Environmental Protection Agency. This registration will expire on April 26, 2008. The 3% hydrated lime solution has proven to be an effective frog toxicant in both laboratory and field settings and has minimal non-target effects on arthropods (Pitt and Doratt 2005). Laboratory tests revealed that higher concentrations of hydrated lime (6%) will be more effective, especially when used as a soil drench. However, the label for hydrated lime currently restricts the concentration to 3%. Hydrated lime may be corrosive and results in white residue on plants and surfaces. As a result, hydrated lime is often not a preferred method in the floriculture industry where slight blemishes on plants make them undesirable. Hydrated lime does have a lower cost (~$0.06/gallon) than citric acid and is often more attractive to homeowners because costs tend to rapidly accumulate when treating large areas. However, there are more safety and environmental concerns with using hydrated lime than with citric acid, such as the caustic effects to skin by hydrated lime exposure.

Chemical Application

The most common method for applying citric acid and hydrated lime is through comprehensive sprays of infested areas using 100- to 400-gallon agricultural sprayers with agitators. Hose size varies from 0.3 to 1.5 inches, and sprayer capacities range from small 1-gallon sprayers to 400-gallon spray tanks. The most effective applications are conducted during early evening hours when frogs are emerging from retreat sites. Multiple applications of selected chemicals are necessary to achieve control in areas with high densities of frogs. Water cannons and large volume irrigation equipment techniques are also being evaluated as application tools.

Aerial application of citric acid has been explored as an alternative method when it is not feasible to conduct ground operations due to challenging terrain or inaccessible frog populations. The label for hydrated lime does not allow aerial application. This airborne approach is similar to fire fighting methods where a helicopter uses a bambi bucket (100-gallon capacity) to drop citric acid solution instead of water. Common mixing procedures consist of using 400 gallon agriculture sprayers to prepare the chemical and transfer it to the large-volume dipping tank.

This application procedure has comparable costs on a per acre basis with ground operations largely because more area can be treated in a shorter period of time. Additionally, aerial application has been found to reduce densities of frogs (N. Tuttle, Utah State University, unpublished data). However, after several trials on the Island of Hawaiʻi this approach did not appear to have comparable control efficacy to ground-based operations in areas that are dry and have complex a'a substrates, which provides numerous retreat sites for the coqui frog (H. Sin, unpublished data). This reduced efficacy, compared with ground operations, maybe in part due to time of application (daytime) and substrate. Thus, this application technique may prove to be more effective in areas that have a greater soil substrate and where chemicals can have easier access to the frogs.

There have been no observed or reported harmful non-target effects from application of citric acid, though there is concern about potential effects on the endangered Hawaiian hoary bat. Preliminary exposure tests by the USDA/NWRC using bat effigies suggested no negative impacts during an aerial application (Pitt and Swift 2006). To further address concerns about citric acid exposure to hoary bats, USDA/NWRC proposes to conduct an LD50 study using the big brown bat (*Eptesicus fuscus*) as a surrogate species (W. C. Pitt, USDA-APHIS-WS-NWRC, personal communication).

To determine efficacy of chemical treatment, follow-up monitoring is necessary; this can be performed by both listening for calling males and conducting line transect searches for frogs. Additionally, there is continuing research and development for efficacy of treatment using sound decibel readings (M. Warrington et al., University of Hawaiʻi at Hilo, unpublished data). Preliminarily data suggests that once a frog population reaches a certain density sound levels plateau even if the population continues to grow.

Non-Chemical Control Methods

Several non-chemical control methods are available for plant quarantine, the nursery industry, and homeowners. These methods include hand capture, habitat management, hot water treatment, and placement of coqui barriers. Coqui frog traps, in a variety of forms, have been tested. Some data suggests that small PVC pipes placed one to two-feet off of the ground can trap coqui frogs (A. Hara, CTAHR, unpublished data). However, no traps have proven to be effective on a broad scale to date.

In areas with few frogs, hand capture can be accomplished with an observer slowly approaching the frog at night and quickly grabbing or placing a plastic tube over the individual. Locating females and juveniles in the field can be difficult though because only adult males vocalize.

Habitat management through physical removal of dense vegetation reduces the carrying capacity of the site for frogs by making the area less hospitable for them. The coqui frog prefers dense vegetation, which provides more food, cover, and higher moisture levels compared with a more open area, such as a manicured lawn (W. J. Mautz, University of Hawai‘i at Hilo, unpublished data). Additionally, more open areas appear to greatly improve the efficacy of chemical applications (A. Radford and H. Sin, unpublished data).

Treating plants with hot water or hot water vapor has been shown to be effective in removing frogs and eggs. Research indicates that treating plants at 113°F for five minutes can kill frogs and eggs with minimal damage to most common nursery plants (A. Hara, CTAHR, unpublished data). Furthermore, if temperatures remain constant for longer periods, or the temperature is raised to 120°F, other quarantine pests, such as scales and mealybugs, can also be removed. Certain plants, especially flowering ones, may become more susceptible to damage from raised water temperatures (A. Hara, CTAHR, unpublished data). These findings, coupled with subsequent field trials of hot water treatment facilities, have yielded positive results. Plans are in progress to install treatment facilities at many of Hawai‘i’s ports of entry.

Another preventive technique being explored is the use of a coqui barrier or fence. Designed by the HDOA, the fence restricts coqui frog movements from infested areas to frog-free areas. The fence consists of a two- to three-foot high fine insect mesh supported by posts spaced several feet apart. The barrier has a 90° lip at the top that extends approximately one foot toward the infested area. Laboratory tests have demonstrated that a frog can climb up the vertical portion but falls off the horizontal lip due to lack of traction from its toe pads (Kyle Onuma, HDOA, personal communication). Additionally, the height of the fence adequately discourages the frog from jumping over the structure. However, the barrier needs constant maintenance to ensure there is no overhanging vegetation and to ensure the structure remains intact. This technique is more applicable to small areas such as greenhouses rather than larger natural areas.

Biological Control

Biological controls that have been considered include chytrid fungus (*Batrachochytrium dendrobatidis*) and internal parasites. Chytrid fungus is known to cause a lethal amphibian disease called chytridiomycosis and has affected amphibians in Australia, South America, Central America and the United States (Berger et al. 1999). This fungus is a water born pathogen that will not likely affect the coqui frog as it does not have a tadpole stage. Additionally, chytrid fungus has already been found in low percentages of frogs in Hawai‘i and does not appear to affect coqui populations (Beard and O'neill 2005). Internal parasites have been found during examination of coqui frogs collected in Puerto Rico. Further research will investigate the effects of these parasites on the health of coqui frogs and potential effects on non-target organisms (S. Marr, CTAHR, unpublished data).

QUARANTINE

Continued inter- and intra-island movement of coqui frogs through the nursery trade and other inadvertent vectors (e.g., movement of vehicles, household goods, or green waste) seriously undermines efforts to control the spread of the coqui frog. Inter-island inspection of nursery plants is being conducted by the HDOA for the presence of frogs. Nurseries that are known to have frogs are required to treat plants before shipping to other islands and may be rejected at ports of entry if products are found to be infested. Both nurseries and plant material are also subject to random HDOA inspections. A nursery grant program is underway to provide matching funds for individual nurseries to develop on-site hot water treatment facilities.

PUBLIC OUTREACH AND EDUCATION

Public involvement is crucial to the discovery of new frog populations. Hotlines on all islands allow the public to report frog locations. Residents in many areas are the only source of information regarding the current level of infestation. Public support is necessary for control because a large portion of infestations occur on private property. Consequently, public education and awareness building are necessary ingredients to facilitate reporting, identification, and control of coqui frogs. Public service announcements, brochures, websites, newsletters, and presentations are some of the methods used to reach to the public on this issue. On the Island of Hawaiʻi, residents are largely responsible for their own control efforts. Thus, training the public on control strategies, personal safety when handling chemicals and awareness of available resources are extremely important. This training occurs at some level on all affected islands. Additionally, there have been instances where the public has intentionally moved frogs or have hampered control efforts, which further highlight the need for public outreach and education to prevent such cases.

ISLAND-SPECIFIC MANAGEMENT STRATEGIES

Management goals are island-dependent since each island has various levels of coqui frog infestations with funding availability and the infestation level influencing control efforts. However, common strategies do exist and include: containing or eradicating known populations; protecting high-value areas; rapidly responding to new reports; removing incipient populations; preventing reintroduction; continuous monitoring of infested and treated sites; collecting data and appropriately documenting efforts; disseminating information and resources to the public; and developing situation-dependent plans and protocols. A broader statewide plan is being developed which may assist with on-the-ground efforts, provide clear identification of responsibilities and duties, and improve consistency in data collection and reporting. These elements will help ensure a coordinated response to new reports of coqui frogs. Public reporting also has been a key element in successful statewide management of coqui frogs. As a result of thousands of reports, the current infested areas are relatively well known.

For management purposes in the State of Hawaiʻi, incipient populations are generally considered to be four or less vocalizing males heard in one location or in the surrounding area. A naturalized population is generally considered to be five or more vocalizing male coqui heard in one location or in the surrounding area. A naturalized population is declared eradicated if no frogs have been detected for a year from the date the last vocalizing coqui frog was heard, based on surveys conducted periodically post-treatment.

Hawaiʻi County

Anecdotal evidence suggests that coqui frogs were first detected on the Island of Hawaiʻi in the late 1980s. The strategy, where coqui populations are numerous and dense, is to control and minimize distribution in priority areas. However, incipient populations and occurrences of single coqui frogs are also targeted for eradication as they become known. Areas of priority are high-value natural areas, nurseries, residential areas, parks, waste transfer stations, and other potential distribution centers. The Island of Hawaiʻi has the largest number of naturalized populations and largest total infestation, with more than 20,000 infested acres, concentrated on the northeast, or Hilo, side of the island (Figure 1). All levels of government are involved in coqui management on the Island of Hawaiʻi and as a result the Coqui Frog Working Group (CFWG) was initiated as a cooperative entity to help coordinate management strategies. Groups involved with the CFWG include the Big Island Association of Nurserymen, County of Hawaiʻi, University of Hawaiʻi, CTAHR, USDA-APHIS-Wildlife Services, USDA-APHIS-WS-NWRC, Department of Land and Natural Resources, HDOA, and the Big Island Invasive Species Committee. Management approaches include all available techniques and the majority of coqui research and development of new control methods occurs on the island. State and county sprayer loan programs, community grant programs, and matching chemical cost programs, are in place to assist and encourage affected residents to take action.

Maui County

Coqui frogs were first detected on Maui in 1997, on Lānaʻi in 2002, and on Molokaʻi in 2001. No coqui frogs have been observed on Kahoʻolawe. Since 1997, thirteen naturalized population centers

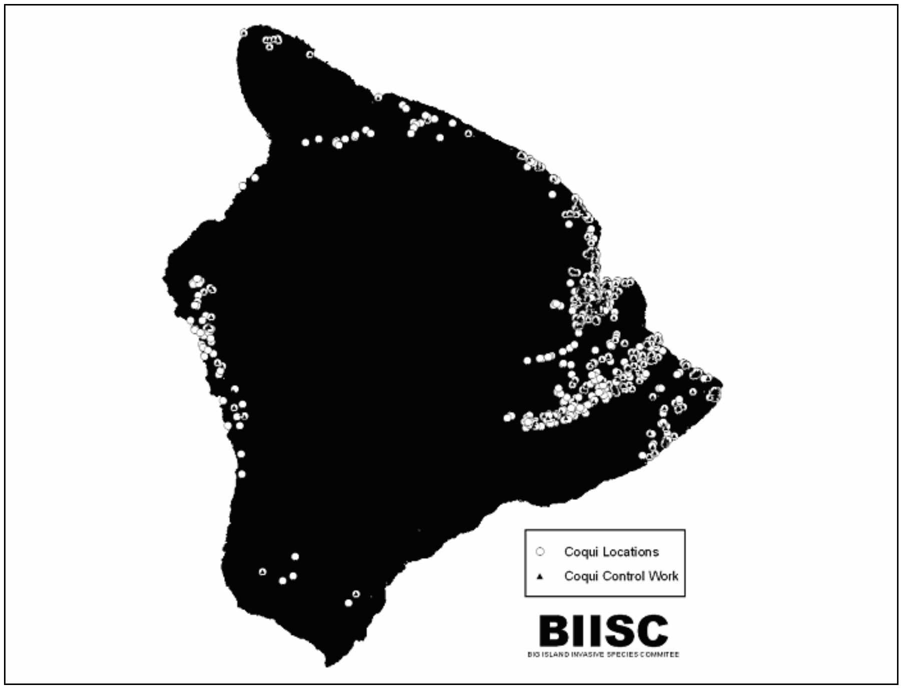

Figure 1. Current locations and control efforts of the coqui frog (*Eleutherodactylus coqui*) on the Island of Hawai'i. Given the large scale of the map some points were consolidated into one point. Furthermore, most of the locations are based on hotline calls and are not necessarily indicative of coqui frog densities.

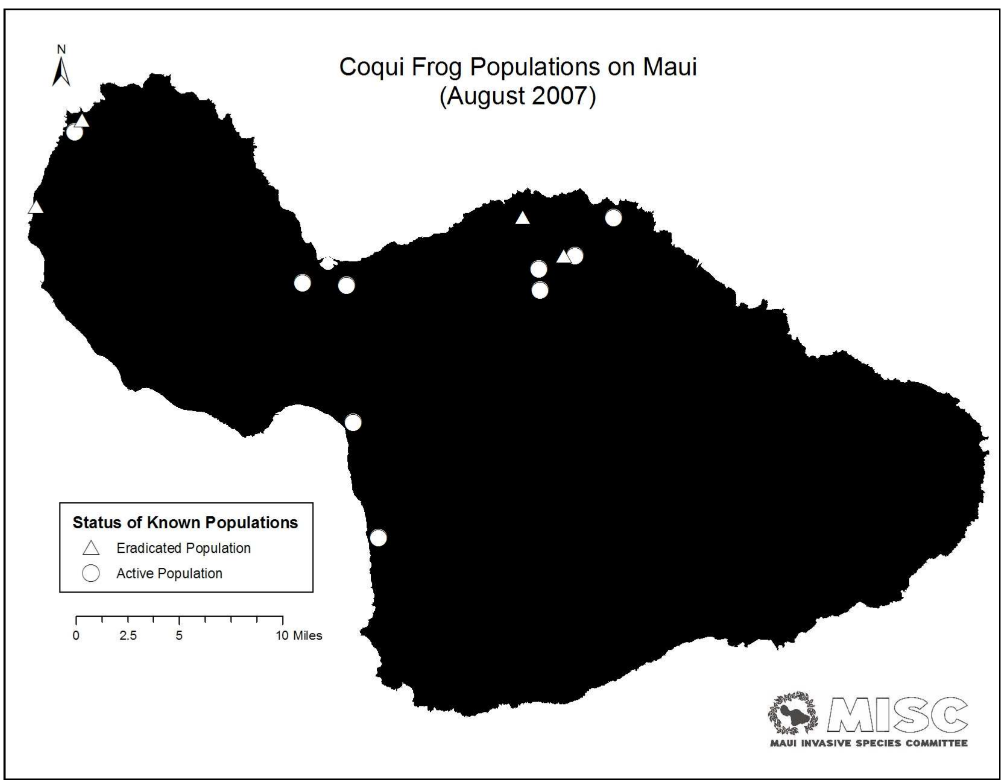

Figure 2. Current naturalized and eradicated populations of the coqui frog (*Eleutherodactylus coqui*) on the Island of Maui.

have been identified on Maui covering 161 acres (Figure 2). No coqui frog populations are known to exist on Lānaʻi or Molokaʻi and the four occurrences of calling males have been removed from these islands through a combination of hand capture techniques, and spraying of citric acid.

Work has begun in all known infested areas on Maui and eradication seems likely for all locations with the exception of a heavily-infested gulch. Four of the thirteen coqui frog populations are considered eradicated. Eight of thirteen populations are considered contained and appear to be headed toward eradication. The thirteenth population center includes a 76-acre gulch that has proven difficult to manage due to inaccessible terrain. Maui managers are hopeful that coqui frogs can be contained or eradicated from the gulch. Long-term strategy will focus on monitoring historic population centers and continuing to rapidly respond to new reports and introductions. The Maui Invasive Species Committee (MISC) spearheads control work on Maui with a supplemental sprayer loan program sponsored by the HDOA. Management approaches on Maui include citric acid applications in infested areas, distribution of citric acid to affected residents, habitat modification and removal, hand capture, and systematic follow-up.

Oʻahu and Kauaʻi County

Coqui frogs were first detected on Oʻahu in 1998 and on Kauaʻi in 2000. Coqui frogs have never been observed on Niʻihau. Oʻahu and Kauaʻi each have one population center with each island headed toward a coqui-free status. On Oʻahu, the first observation of a coqui frog was made in 1998. Since then, there have been confirmed reports of coqui frogs scattered across the island. Most individuals or small numbers of coqui frogs have been removed and work continues at the one known population at the Schofield Barracks in Wahiawa. Wahiawa is located in central Oʻahu and no coqui frogs have been reported in the 12-acre area since November of 2006 (Figure 3). Work on Oʻahu occurs under the oversight of a cooperative Coqui Working Group with participation by multiple agencies. Participant agencies include the Department of Public Works, US Army Environmental, US Fish and Wildlife Service, City and County of Honolulu, DLNR-DOFAW, HDOA, and the Oʻahu Invasive Species Committee (OISC). Suppression efforts include citric acid applications in previously infested areas and in areas with incipient populations, maintenance of previously reduced habitat, and systematic follow-up.

Kauaʻi's population of coqui frogs is located in Lawai, on the southwest corner of the island and covers approximately 15 acres (Figure 4). Control work is spearheaded by the Kauaʻi Invasive Species Committee (KISC), with cooperative assistance from the HDOA and Kauaʻi County. Management approaches rely on both citric acid and hydrated lime applications in infested areas, habitat modification and removal, hand capture, and systematic follow-up.

CONCLUSION AND MANAGEMENT IMPLICATIONS

The coqui frog is a highly adaptable, prolific species that has demonstrated an ability to spread rapidly, if not controlled, in Hawaiʻi. It poses serious direct and indirect threats to Hawaiʻi's unique ecosystems given its ability to attain some of the highest densities ever observed for terrestrial amphibian populations (Stewart and Woolbright 1996). The presence of coqui frogs poses major economic and quality of life concerns for local residents and Hawaiʻi's tourist-based economy. Control efforts in Hawaiʻi have cost millions of dollars to date. Although remarkable progress has been made in some areas, without improved inter- and intra-island quarantine measures, it is expected that coqui frogs will continue to be reintroduced to all islands, including areas where the frogs have already been eradicated.

More research is needed to better understand and quantify the ecological and economic impacts of the coqui frog. Specifically, research to find if coqui frogs can indeed bolster mongoose populations and to quantify if the frogs can compete with native birds and the native bat for food. Additional research to quantify the coqui frog's effects on the nursery and tourist industries would also be helpful.

Eradication of the coqui frog is not considered attainable on the Island of Hawaiʻi, and seems unlikely for Maui, but may be possible on the islands of Kauaʻi and Oʻahu. Overall, coqui populations are continuously expanding on the Island of Hawaiʻi, with some levels of control, but all other islands are experiencing declining coqui populations due to management practices. Current control techniques and methods must continue to evolve to improve control efficacy, especially given the scale of the infestation on the Island of Hawaiʻi and particularly with regard to finding more cost-

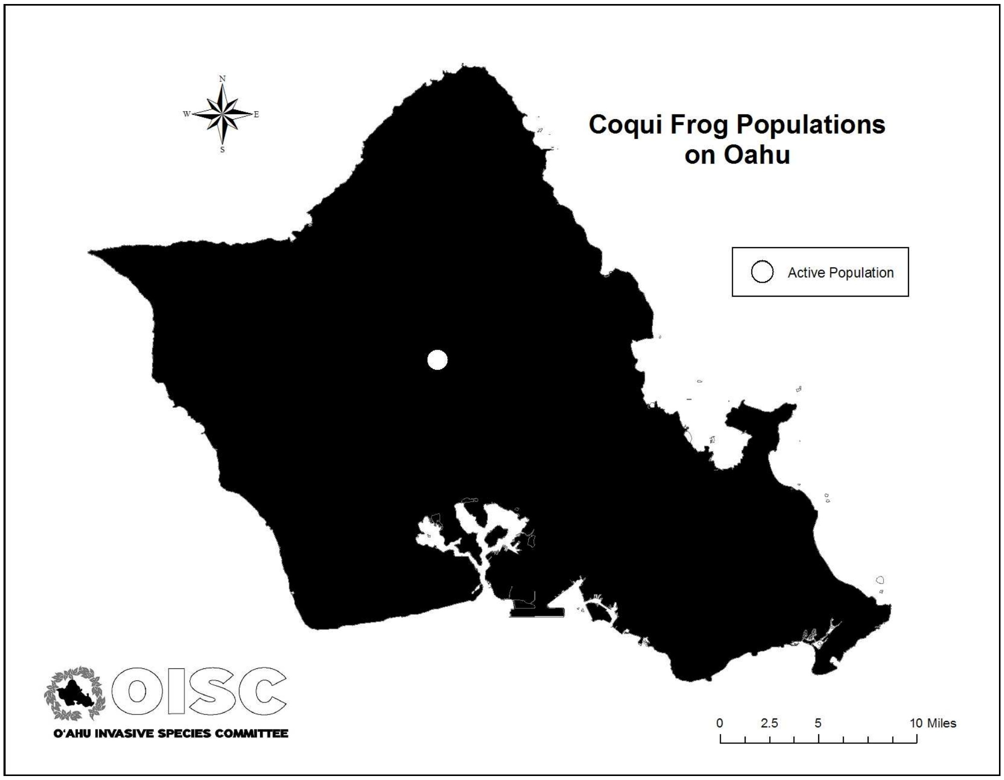

Figure 3. Current naturalized populations of the coqui frog (*Eleutherodactylus coqui*) on the Island of Oʻahu.

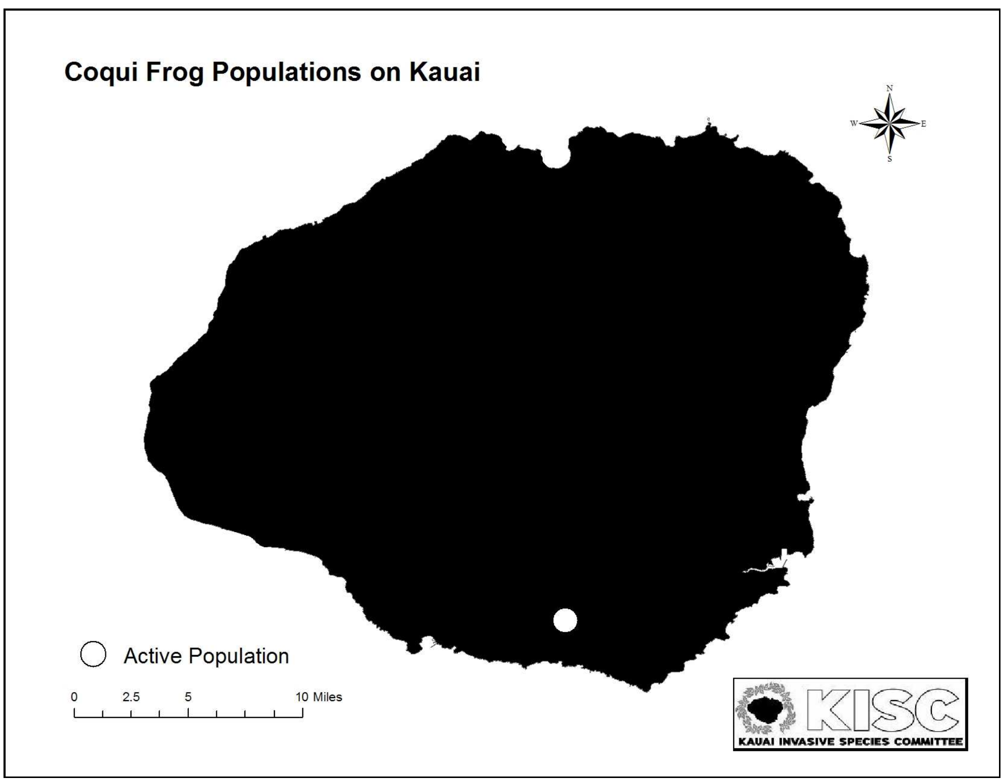

Figure 4. Current naturalized populations of the coqui frog (*Eleutherodactylus coqui*) on the Island of Kauaʻi.

effective frog toxicants. If coqui frog populations continue to grow and/or move within and between islands, managers will rely more than ever on public reporting. In order to gain or keep public support, every tool at the disposal of respondents will be needed to ensure that appropriate control ensues. The full extent of the ecological and economic impacts of the coqui frog are still being determined, but the costly lessons from this invasion underscore the importance of adequate quarantine and enforcement of existing regulations, timely and relevant research, effective response and control techniques, and unified public support and involvement.

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