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Earl W. Campbell III
USDA APHIS Wildlife Services, National Wildlife Research Center

Fred Kraus
Department of Land and Natural Resources, Honolulu, Hawaii

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Earl W. Campbell III[1]
USDA APHIS Wildlife Services, National Wildlife Research Center, Hawaii Field Station, Hilo, Hawaii
Fred Kraus[2]
Dept. of Land and Natural Resources, Honolulu, Hawaii

[1]Present affiliation: U.S. Dept. of the Interior, Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, Honolulu, Hawaii
[2]Present affiliation: Bishop Museum, Honolulu, Hawaii

Abstract: Two species of neotropical frog, *Eleutherodactylus coqui* and *E. planirostris*, have been introduced into the state of Hawaii via the horticulture trade. Since 1997 frog colonies within the state have rapidly spread from accidental and intentional causes, and frog abundance within colonies has grown rapidly. Colonies of these frogs are currently known from 262+ locations on the island of Hawaii, 45+ on Maui, 35+ on Oahu, and 2+ on Kauai. Although these frogs were originally restricted to horticulture sites, they are now found in residential areas, resorts and hotels, and public lands. Within their native range, they may reach densities of 20,000 frogs/ha. Given the current population irruptions of these frogs in Hawaii, similar densities are being reached and exceeded. Due to the high potential biomass of introduced frogs there are realistic anthropogenic (economic and quality of life) and ecological concerns associated with their spread. Since 1998, research has been conducted with the goal of developing control techniques for these frogs. A primary result of this research effort was the determination that a spray application of a 2.0% concentration caffeine and water solution can effectively eliminate local frog populations. The aforementioned research result was used to support a United States Environmental Protection Agency Sec. 18 (Emergency) Registration for the use of a 2% caffeine solution for *Eleutherodactylus* frog control in the State of Hawaii by the Hawaii Department of Agriculture. Although this tool is available for localized control of frogs, efforts by federal, state, and county agencies to control this pest in Hawaii has been hampered by a lack of funding, unclear legal jurisdiction, and bureaucratic inertia.

Key Words: alien species, agriculture, conservation, *Eleutherodactylus* spp., frogs, Hawaii, invasive species, native species

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INTRODUCTION

Two species of tree frogs (*Eleutherodactylus coqui* and *E. planirostris*) native to the Caribbean have recently become established in the Hawaiian Islands (Kraus et al. 1999, Kraus and Campbell 2002). Since their introduction via the import horticultural trade, the frogs have rapidly expanded their range on the islands of Hawaii, Maui, Oahu, and Kauai. There are two modes of spread for tree frogs. The first is the accidental transport via horticultural products or material from infected nurseries or gardens to uninfected areas. The second mode is the intentional introduction of frogs by citizens into sites that aren't infested. Theoretically both activities are illegal under Hawaii state law (Kraus and Campbell 2002), though enforcement is difficult. There is a concern on the part of federal, state, and private agencies/entities managing natural and agricultural resources in Hawaii that introduced *Eleutherodactylus* frogs pose a serious threat to these resources. *E. coqui* can reach densities of greater than 24,000/ha and is capable of consuming approximately 114,000 arthropod prey items per hectare in a single night in its native range in Puerto Rico (Stewart and Woolbright 1996). It is believed that these frogs, once established in native habitats, could prey on endemic arthropods as well as compete indirectly and directly with native birds for limited food resources (Kraus et al. 1999). Tree frogs may be a vector for plant nematode eggs, and the recent discoveries of frogs in certified nurseries make the frogs a potential quarantine issue that could greatly impact the exportation of disease and pest-free nursery products from the state. Surveys indicate that frog populations have become firmly established in nurseries, parks, residential gardens, resort areas, and lowland forest habitats on the islands of Hawaii (262+ reported sites) and Maui (45+ reported sites). The number of reported locations has significantly increased on these islands in the last 3 - 4 years (Kraus and Campbell 2002). Frog populations have been documented on the islands of Oahu (35+ reported sites) and Kauai (2 reported sites), and there is grave concern that these populations will continue to spread. In one horticultural site on the island of Hawaii, one species of tree frog (*E. coqui*) has been documented to obtain densities comparable to the native range (>2.1 frogs/m^2 or ~21,000 frogs/ha; Kraus et al. 1999). Localized loud vocalization of male frogs (80 - 90 dB, Campbell 2001b) throughout the nighttime hours has also been a source of numerous angry complaints from sleepless residents and tourists alike.

DEVELOPMENT OF CONTROL TECHNIQUES

Restricting the transfer of infected plant materials via the horticultural trade or by the casual public has the potential of stemming further spread of frogs to uninfected areas. However, enforcement of laws dealing with the transportation of alien species within the State of Hawaii has been limited at best. Currently, an enforceable legal mechanism that specifically restricts the movement of plant hosts harboring *E. coqui* within the state has been proposed by Hawaii Department of Agriculture staff but has not been enacted.

Though the status of an enforceable quarantine on the movement of frogs is currently in question, there is an immediate need to: 1) reduce or eradicate localized frog populations that serve as reservoirs for new infestations and 2) treat infested plant material to insure this situation does not get any worse. Since 1998, research has been conducted with the goal of developing control techniques for these frogs. Current trapping techniques proved in field trials to be inefficient (Boughton 1997, Campbell 2001b). Cultural practices (destruction of infected plant material or habitat) or hand capture may be effective on a small scale; however, chemicals appear to be the only broad-range and cost-effective immediate method of controlling frog populations. A laboratory study was conducted to screen 35 selected 1) pesticides registered for invertebrate control in ornamental nurseries and floriculture in Hawaii, 2) human pharmaceutical and food products, and 3) surfactants as potential chemicals for *E. coqui* and *E. planirostris* frog control (Campbell 2001a). During initial screening, one of two commercially available pesticides containing resmethrin (7.1 mg AI/ml), a synthetic pyrethroid, was found to cause mortality to slightly greater than 50% of tree frogs (N = 5) tested at registered or recommended dosage rates (use of a broad-scale field application of a registered pesticide with fairly high concentrations of a synthetic pyrethroid for frog control raised realistic concerns about potential non-target effects). No surfactants tested were found to cause frog mortality rates greater than 50%. Of the human pharmaceuticals and food products tested, food grade caffeine (99% purity), applied as a topical spray, proved effective against both *E. coqui and E. planirostris*. The lowest concentration solution of caffeine and water that resulted in 100% tree frog mortality (N = 20) was a 12.5 mg/ml solution applied to tree frogs topically with a spray bottle.

Following the completion of laboratory screening of potential chemicals for *Eleutherodactylus* control, field trials were conducted on the directed spray application of three different caffeine solutions for controlling introduced *Eleutherodactylus* frogs in floriculture and nursery crops in Hawaii (Campbell 2001b). The directed spray application of 0.5%, 1.0% and 2.0% caffeine solutions reduced *Eleutherodactylus coqui* abundance in test situations on or bordering infested ornamental plant nurseries in East Hawaii. Treatment of plots with a single spray application of a 2.0% concentration caffeine solution caused a 100% decline in the relative abundance of *Eleutherodactylus* frogs and in the relative abundance of frogs adjusted for nightly variation in frog activity before and after treatment on control and treatment plots.

The Hawaii Department of Agriculture's Pesticide Branch prepared and submitted to the United States Environmental Protection Agency (EPA) an application for an Emergency Registration (Section 18) for the spray application of caffeine for localized frog control in the State of Hawaii. The U.S. EPA granted the requested registration for a one-year period beginning on 27 September 2001 with the stipulation that data were collected on potential non-target impacts and monitoring of soil and ground water contamination concerns. There has been limited use of caffeine for frog control since the granting of the EPA registration, and the Hawaii Department of Agriculture's Pesticides Branch has had to be revise and simplify data collection requirements considered cumbersome to potential users. Reporting requirements, relatively high cost in comparison to other commercially available compounds for the control of pest insects and weeds, and limited data on non-target effects have been concerns raised by potential users of caffeine for frog control.

Efforts have been made by other researchers and managers to identify additional compounds for frog control. Anecdotal laboratory observations and field applications suggest that the spray application of a concentrated hydrated lime and water solution (K. Onoma, A. Hara, and L. Wong, pers. comm.) may be an additional tool for frog control. As hydrated lime and water solutions are being sprayed on vegetation (above ground as a pesticide) versus being applied to the ground as a soil supplement, this specific use pattern may need to be registered with the U.S. Environmental Protection Agency. Standardized data collected with some level of scientific rigor (two or three biologically realistic measures of frog abundance collected simultaneously before and after treatment with hydrated lime) showing efficacy is needed to support the legal application of this solution for frog control. Other research is being conducted to determine if natural or synthetic pyrethroid compounds could be used for frog control (H. Ako, pers. comm.). In late 2000, several species of potted plants were successfully treated for frogs in test situations using short term drenching with hot water (42°C for 3 minutes; F. Kraus and A. Hara, unpubl. results).

DISCUSSION

Since the first documentation of the presence of *Eleutherodactylus* frogs in Hawaii, populations have spread quickly and local abundance of frogs has grown dramatically, particularly in sites with higher levels of rainfall (Kraus and Campbell 2002). Though this issue has garnered significant attention in the local and national media, efforts to control the spread of the frog have been limited. Frogs have, and will continue to, affect the quality of life of citizens who live in infested sites.

Citizen frustration with a lack of progress dealing with this situation in infested residential and commercial sites has been building and will continue to build.

There is a realistic concern that *Eleutherodactylus* frogs will be accidentally transported from Hawaii to mainland states within the United States and to other countries in infested cargo. *Eleutherodactylus* frogs are frequently found in Hawaii at retail nurseries associated with large department and hardware store chains. *Eleutherodactylus* frogs have been reported in California and Connecticut and these individual frog captures have been attributed to shipments of infested Hawaiian plant products (as opposed to shipment from Puerto Rico or Florida where these frogs naturally occur, Kraus et al. 1999). Though *Eleutherodactylus* frogs may not become established in many mainland sites within the United States, *Eleutherodactylus* infesting shipments within Hawaii or infesting shipments going to other Pacific Islands, tropical, and sub-tropical destinations internationally is a realistic quarantine concern. There is a clear need to establish if *Eleutherodactylus* frogs within certified nurseries are a potential vector for plant nematode eggs (Kraus et al. 1999), as particular species of plant nematodes are a significant quarantine issue for plant products being shipped from Hawaii to the State of California.

It is worth asking the question "why hasn't there been a significant coordinated effort mounted to deal with introduced *Eleutherodactylus* frogs in Hawaii?" A primary reason is the lack of techniques to control the spread of frogs; hot water drenching was not tested as a quarantine technique until late 2000, and U.S. EPA emergency registration of the spray application caffeine and water solution for local control was not obtained until late 2001. It would be very hard to enact a quarantine on a pest that impacts a major industry without the ability to control the pest in a simple, cost effective manner. Lack of funding, unclear legal jurisdiction, and bureaucratic inertia are other reasons why the spread of the frogs has continued until it is unrealistic, given current progress dealing with this issue, to believe that frogs will be eradicated from the island of Hawaii (Kraus and Campbell 2002). There have been significant efforts by individual staff members of various state, county, federal and non-governmental entities and private citizens to try to stem the spread of invasive frogs and eliminate local populations. USDA APHIS Wildlife Services staff and Hawaii Department of Agriculture staff have written a plan to control and/or eradicate frogs in the State of Hawaii (Pitzler et al. 2001). Funding for this plan is the most realistic means to deal with this situation. It is clear that decisive action to eradicate an introduced pest when it has a limited distribution is far less expensive than eradicating or controlling the pest when it is broadly established. Unfortunately, the window of opportunity for effective action against the *Eleutherodactylus* frogs in Hawaii is becoming shorter while the problems associated with these pests will become greater as more sites become infested and local frog abundance increases in previously infested sites.

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