Eleutherodactylus Frog Introductions to Hawaii

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As an oceanic archipelago isolated from continental source areas, Hawaii lacks native terrestrial reptiles and amphibians. Polynesians apparently introduced seven gecko and skink species after discovering the islands approximately 1500 years ago, and another 15 reptiles and five frogs have been introduced in the last century and a half (McKeown 1996). The Polynesian introductions are probably inadvertent because the species involved are known stowaway dispersers (Gibbons 1985; Dye and Steadman 1990). In contrast, most of the herpetological introductions since European contact with Hawaii have been intentional. Several frog species were released for biocontrol of insects (e.g., *Dendrobates auratus*, *Bufo marinus*, *Rana rugosa*, Bryan 1932; Oliver and Shaw 1953), and most of the remaining species are released or escaped pets (e.g., *Phelsuma* spp., *Chamaeleo jacksonii*, *Iguana iguana*, McKeown 1996). Government-approved releases have not occurred for many years, but the rate of establishment of new species has increased in the past few decades because of the importation and subsequent release of pets.

We report the recent establishment in Hawaii of three new species of frogs native to the Caribbean: *Eleutherodactylus coqui*, *E. martinicensis*, and *E. planirostris*. Several Antillean *Eleutherodactylus* species have been introduced outside their natural ranges (Table 1) by hitchhiking with nursery plants, but these represent the first reports of establishment of the genus outside the general Caribbean region. *Eleutherodactylus coqui* recently

has been reported from Hawaii in the hobbyist literature (R. Campbell 1996; McKeown 1998), but either vouchered specimens were not provided and identification was unconfirmed (R. Campbell 1996) or claims as to identity and distribution included inaccuracies because they were based on erroneous assumptions and second-hand information from newspaper articles (McKeown 1998). McKeown (1998) did provide one vouchered specimen of *E. coqui* (USNM 515162, identified by R. Crombie, unexamined by us), although the locality data he provided are vague (USNM database records, R. Crombie, pers. comm.). We provide accurate locations for *Eleutherodactylus* species currently known to be introduced to Hawaii and, to the extent possible, information on the methods and rate of spread of these species, their habitat associations in Hawaii, their potential environmental impact in the state, and alternatives for management.

Eleutherodactylus coqui is documented with voucher material from three locations on Maui and five locations on Hawaii Is. (Fig. 1). One Hawaii Is. site and one Maui site are outdoor commercial plant nurseries. One Maui site is a resort hotel with grounds that are planted with horticultural species obtained from nearby nurseries. Two sites on Hawaii Is. and one on Maui are located in residential areas, at least one of which has considerable plantings of nursery material. The last two sites, both on Hawaii Is., are located in ornamental vegetation in a public park and in native forest, respectively. Frogs in the latter site probably originated from ornamental plantings at a nearby residence. The known elevational range of this species in Hawaii is 40–430 m. Populations seem to vary from a few calling individuals at the resort to several thousand individuals at the nursery on Hawaii Island, but all populations appear to be established and expanding, based on discussions with landowners or nearby residents. Population estimates at the Hawaii Is. nursery were based on collecting 105 frogs from an approximately 50m^2 area in 50 minutes of casual night-time collecting during very dry conditions lacking calling frogs, and extrapolating across the acreage known to have calling frogs. Virtually all of these captured frogs were adults. This density is approximately ten times that reported for *E. coqui* in unmanipulated native rainforest in Puerto Rico (Turner and Gist 1970, referenced as "*E. portoricensis*"; Stewart and Pough 1983). Although these frogs probably do not occur at this density uniformly throughout the nursery, it illustrates the large numbers and densities that have built up over the relatively short period of time (ca. 5 years) since the first calling frog was noticed.

Eleutherodactylus martinicensis is documented with preserved material from both a nursery at Kokomo, Maui (430 m elev.), which also has *E. coqui* (Fig. 1), and from a residence in Omaopio (~670 m elev.). The former apparently is an established population; the latter may only represent a translocation of a few calling individuals. The numbers of frogs at the nursery was not assessed because the call of this species is readily masked by syntopic calling *E. coqui*.

Eleutherodactylus planirostris is documented from three sites on Hawaii Is., all of which are at or adjacent to commercial plant nurseries, and one residential site on Oahu (Fig. 1). All are established populations. Elevations of sites are low, ranging from 60–190 m. In Jamaica, where this species also has invaded, it can occur up to 610 m elevation (Schwartz and Fowler 1973). Due to this species' cryptic habits and weak call, we did not estimate population sizes at any of the locations, but we routinely collected scores of individuals at night by walking the roadside grass margins at the Pahoa site. This site is adjacent to extensive ohia forests on 'a'a lava, suggesting that frogs also may occur in the native forest, as they do elsewhere where the species has invaded (Goin 1947; FK, pers. obs.).

Maui has the greatest number of reported locations with *Eleutherodactylus*. Radio public service announcements broadcasting the call of *E. coqui* and asking the public to report encounters with these animals have been playing on Maui since May 1998. This has resulted in our receiving additional reports of calling frogs from Honokowai, Ka'anapali, Kula, Ulumalua, Wailea, and Wailuku (Fig. 1). These are probably *E. coqui*, *E. martinicensis*, or mixed choruses of the two, given that they are the only two species known from the island, their calls are similar, and most reports have been in response to the broadcast calls. Most unverified sites are at resort hotels or from residential areas. Hotels from which frogs are reported are near sea level on the dry, leeward side of Maui. However, each is thickly planted with horticultural material and watered frequently, apparently providing sufficient moisture for frogs to thrive.

The route of entry of these frogs into Hawaii clearly appears associated with horticultural trade. The largest known populations of *Eleutherodactylus* in the State are found at active nurseries and their immediate surroundings. This is not surprising, given the propensity of each of these species to travel in greenhouse materials (Barbour 1930; Goin 1944; Gorzula 1989; Günther 1895; Lescure and Marty 1996) and the direct developmental mode of each. Although it is possible that each species has invaded the State more than once, we have no way to test this. Most populations appear to be the result of intra-state transport of frogs from infected nurseries to residential or resort sites landscaped with nursery materials. In at least two instances, calling frogs appeared after the purchase and installment of bromeliads for landscaping purposes. In one instance, bromeliads obtained from the Maui nursery with a large population of *E. coqui* and *E. martinicensis* were planted on 19 December 1996, and the first calling frogs (*E. coqui* only) at that residence were heard on 4 January 1997. However, we doubt bromeliads always are involved as vectors in the transport of these frogs. At the nurseries we have visited, *E. coqui* is common on palms, bamboo, *Dracaena*, and among unused pots and pallets. The nurseries around which *E. planirostris* is abundant specialize in raising *Dracaena*.

A second means by which *Eleutherodactylus* frogs may have dispersed in Hawaii is by intentional transport to establish new populations. In at least one case, a nursery owner with a conspicuous population of calling frogs allowed individuals inter-

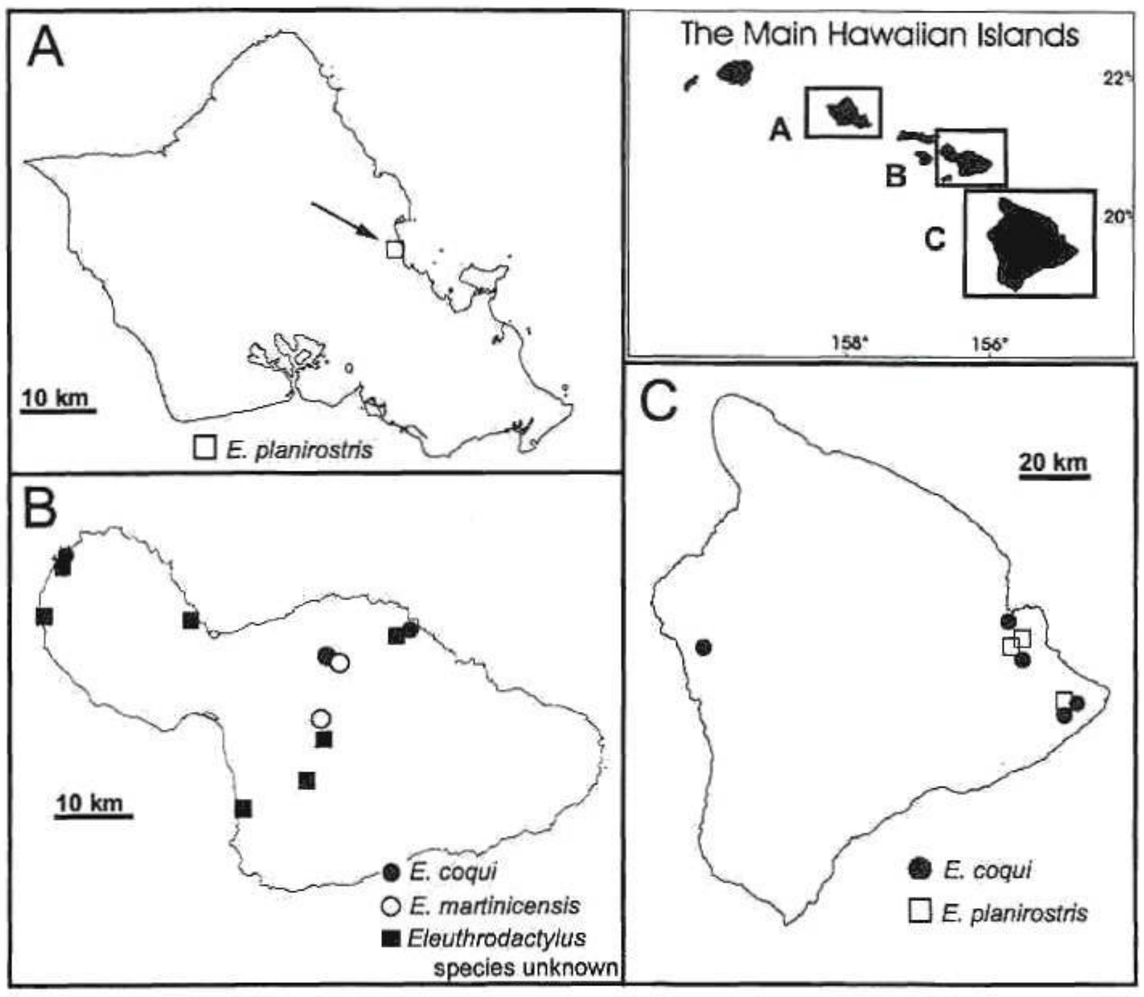

FIG. 1. Map of the Hawaiian Islands showing known localities of *Eleutherodactylus* on A) Oahu, B) Maui, and C) Hawaii Island.

TABLE 1. Introduced populations of Caribbean *Eleutherodactylus*.

Species	Location	Reference
E. antillensis	Panama	DeSousa et al. 1989
E. coqui	US: Florida	Austin and Schwartz 1975; Dalrymple 1994
	US: Hawaii	this paper
	US: Louisiana	Conant & Collins 1991; Schwartz & Henderson 1991
	Virgin Islands	MacLean 1982
E. gossei	Bermuda	Pope 1917; Wingate 1965
E. johnstonei	Anguilla	Censky 1989
	Bequia	Lazell & Sinclair 1990
	Bermuda	Pope 1917; Wingate 1965
	Curaçao	Hardy & Harris 1979
	Dominica	Kaiser & Wagenseil 1995[1]
	England: Kew Gardens	Günther 1895
	French Guiana	Lescure & Marty 1996
	Guadeloupe	Hardy & Harris 1979; Henderson et al. 1992
	Guyana: Georgetown	Hardy & Harris 1979; Bourne 1997
	Jamaica	Barbour 1910a; Dunn 1926; Perkins 1942
	Marie-Galante	Henderson et al. 1992
	Martinique	Lescure 1966
	Mustique	Henderson et al. 1992
	Panamá: Panamá City	Ibáñez & Rand 1990
	Trinidad	Kenny 1980[2]
	Venezuela	Hardy & Harris 1979; Gorzula 1989
E. martinicensis	St. Barts	Kaiser 1992
	US: Hawaii	this paper
E. planirostris	Caicos Islands	Schwartz & Henderson 1991
	Grenada	R. Crombie, pers. comm.
	Jamaica	Lynn 1937, 1940; Lynn & Dent 1943
	México: Veracruz	Schwartz 1974
	US: Alabama	Carey 1982
	US: Florida	Cope 1863; Barbour 1910b; Goin 1947; Conant & Collins 1991
	US: Hawaii	this paper
	US: Louisiana	Plotkin & Atkinson 1979; Dundee & Rossman 1989; Dundee 1994; Platt & Fontenot 1995; Williams & Wygoda 1997
Eleutherodactylus sp.[3]	Union Island	Henderson et al. 1992

[1] Not Kaiser (1992), as erroneously cited by Kaiser and Hardy (1994).
[2] Described by Kenny (1980) as *E. martinicensis*; referred to by Kaiser and Hardy (1994) and Kaiser and Wagenseil (1995) as *E. johnstonei*.
[3] Not *E. johnstonei*, as apparently erroneously cited by Kaiser and Hardy (1994) and Kaiser and Wagenseil (1995).

ested in establishing frogs at their residences to capture frogs from his property. We have been unable to confirm whether these intentional introductions have been successful, but the apparent ease of accidental establishment suggests this could be a viable route of range expansion for the frogs.

Of the three species discussed here, only *E. coqui* has been well-studied in its native range. It lays 4–6 clutches/yr, each with 16–41(mean = 28) eggs/clutch (Townsend and Stewart 1994). Generation time is approximately eight months (deduced from information provided in Townsend et al. 1984; Townsend and Stewart 1994; Turner and Gist 1970). We have received anecdotal reports indicating that population expansion of *E. coqui* at two sites has been rapid and in accordance with expectations based on this prior ecological knowledge. The owners of the large Hawaii Is.nursery reported to us that they initially had a single calling frog in 1992 or 1993, that there were several more calling the next year, and hundreds calling after two years. This is the earliest record of invasion that we have been able to discover so far. As noted above, our estimate is that many thousands of frogs are now calling from several acres at this site. In the instance of the bromeliad shipment noted earlier, landowners heard a single calling frog on 4 January 1997. They then left the State for six months. Upon their return in September, 1997, a few dozen individuals were calling around their residence. Approximately 25–30 calling males were removed from this site between 7 November and 6 December, 1997. These examples illustrate the short time required for *E. coqui* to expand in numbers from a small inoculum of individuals.

Most alien *Eleutherodactylus* species have become introduced to regions relatively near their native ranges that already contained a native frog fauna (Table 1) and, hence, these introductions have not introduced novel ecological challenges to the native fauna. The situation in Hawaii is different because of the original absence of reptiles and amphibians, and leads to concern about the ecological ramifications of introducing these animals to Hawaii or other herpetologically depauperate islands of the Pacific Ocean.

Of primary concern is that the elevational range tolerated by *E. coqui* (Schwartz and Henderson 1991) may allow it to invade native rainforest and mesic forest in Hawaii. In their native Puerto Rico, *E. coqui* can occur at densities greater than 20,000 animals/ha and crop an average of 114,000 prey/night/ha (Stewart 1995; Stewart and Pough 1983). We have seen no reason to expect lesser densities in Hawaiian settings and have evidence that they can match or exceed this. Should *E. coqui* invade native forest, consequent effects on native communities may be substantial: 1) they may exert a tremendous predation pressure on a wide array of native arthropods, primarily insects and spiders, many of which are already stressed to the edge of extinction due to the establishment of other alien predators and parasitoids (Cole et al. 1992; Gagné and Howarth 1985; Gillespie and Reimer 1993; Howarth 1985, 1990); 2) from this, one may expect a resulting indirect negative effect on native forest birds, the majority of which are partially or completely insectivorous (Munro 1944; Perkins 1903; Scott et al. 1986); 3) this rending of the native food web may result in the frogs serving as nutrient sinks (cf. Burton and Likens 1975) in the communities into which they insert themselves or, more likely, serving to enhance already large populations of introduced predators, such as rats and mongooses, which in turn will further increase predation pressure on native birds, a dynamic documented for alien predators elsewhere (E. Campbell 1996; Rodda et al. 1997) and suspected to occur for other taxa in Hawaii (Howarth 1985; Tomich 1986, p. 95). *E. martinicensis* may have a similar effect because its ecology seems similar in most respects to that of *E. coqui*. *Eleutherodactylus planirostris* should have less effect in this regard because it: 1) is currently restricted to relatively low elevations, which retain fewer native arthropods; 2) forages in leaf litter and on the ground surface instead of in tree canopies, reducing potential competition with birds; and 3) will probably not occur at most elevations dominated by native insects or birds.

From a more anthropocentric viewpoint, *E. coqui* and *E. martinicensis* are becoming nuisance species because of their loud calls and ability to live in the horticultural plantings around human dwellings. Several reports from Maui have come to our attention as complaints from residents whose sleep is disturbed by calling frogs. This has been a consequence of *Eleutherodactylus* introductions elsewhere as well (Lescure and Marty 1996; Pope 1917). Complaints from visitors at Maui hotels also have been lodged with resort managers, and at least one hotel has consulted with a pest control professional. In another instance, residents have vowed to move from Hawaii if the calling frogs on their property could not be eliminated. We expect these complaints to increase with time, unless introductions become actively managed. *E. planirostris* may be a lesser problem in this regard because of its less conspicuous call, although the one reported locality for this species on Oahu came to our attention because of dissatisfaction with the frogs' noise. A preliminary effort to investigate whether *E. coqui* transports plant nematode eggs on their skins has met with inconclusive results, but this ability would have potentially important consequences for nursery owners.

Most, and possibly all, populations of *E. coqui* and *E. martinicensis* are susceptible to eradication because numbers are still low at most sites and because males can readily be targeted for removal, thereby halting reproduction. Hand-capture, however, is inefficient, and efforts will soon be made to begin registration with the U.S. Environmental Protection Agency of a weak detergent solution for localized use in killing frogs. However, such efforts will be pointless until such time as relevant State officials actively pursue a program to ensure nursery material imported into Hawaii or offered for sale in-state is free of frogs or their eggs. This is difficult because of the magnitude of the ornamental plant trade in Hawaii, but can probably be achieved when nursery owners understand the potential problems the frogs may create for them. Public education of the threats posed by these frogs is ongoing in the form of public service announcements, fact sheets, and public talks, but is currently insufficient to meet the need for outreach to nursery owners, hotel managers, and agricultural officials, whose active support is necessary to control these frogs in Hawaii.

Acknowledgments.—We thank R. Bartlett, P. Bily, R. Crombie, F. Duvall, B. Farm, and E. Nishibayashi for assistance in collecting frogs, R. Crombie and J. Lynch for providing identifications of the species, and M. Fall and A. Koehler for providing comments on the manuscript.

Specimens Examined—*E. coqui*: HI: Hawaii Is.: NE of Huina Rd., Kurtistown (USNM 518648–64); Ka'iulani St., Hilo (BPBM 13296–97); Nahoa Rd., Leilani Estates, Puna District (BPBM 13751–52); Lava Tree State Park (BPBM 13753–54; Holualoa (BPBM 13750); Maui: Kapalua Bay Hotel, Kapalua (BPBM 13457); Kokomo Rd., Kokomo (BPBM 13459); Huelo (BPBM 13460). *E. martinicensis*: HI: Maui: Pea Place, Oma'opio (BPBM 13291); Kokomo Rd., Kokomo (BPBM 13292–95). *E. planirostris*: HI: Hawaii Is.: Auina Rd., Pahoa (USNM 518665–703, 518707–20, BPBM 13298–319); Kealakai St., Pana'ewa (USNM 518704–06, BPBM 13355); Oahu: Kaimalolo Rd., Waiahole (BPBM 13724–13729).

Unvouchered Records—*Eleutherodactylus* sp. (either *E. coqui* or *E. martinicensis*). HI: Maui: Hyatt Hotel, Ka'anapali; Lower Honoapi'ilani Hwy., Napili; Maui Inter-continental Hotel, Wailea; High St., Wailuku. *E. planirostris*. HI: Hawaii Is.: University of Hawaii Agriculture Experimental Station off Stainback Hwy.

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