Reintroduction of a Native Hawaiian Bee, *Hylaeus anthracinus* (F. Smith) (Hymenoptera: Colletidae), to Part of its Former Range

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Abstract. The endangered endemic coastal bee *Hylaeus anthracinus* (F. Smith) (Colletidae) is currently restricted to a few populations on each island from Oahu to Hawaii, which are mostly near the shoreline and vulnerable to extirpation due to environmental change or alien species incursion. At the same time, the species is absent from some sites where it formerly occurred that have once again become suitable due to habitat restoration. To increase the number of populations and test translocation as a method for *Hylaeus* conservation, bees were captured at high-density sites in South Kohala, Hawaii island and released at three sites in South Kona at Puuhonua o Honaunau National Historic Park. Follow-up monitoring indicated that they successfully established at the highest-quality site with a diverse array of native plants following a single release of 100 bees, but failed to survive at two sites with high abundance of bigheaded ants (*Pheidole megacephala*) even after a second release. This study may serve as a model for re-establishing not only *Hylaeus* but other native insects that have been lost from large parts of their range.

Key words: conservation, translocation, restoration, coastal habitat

Translocation and reintroduction from captive-bred populations are common methods in the conservation of rare plants but are relatively rare for insects. It has been used with only a few taxa: butterflies in Europe and the United States (e.g., Wynhoff 1998, Linders and Lewis 2013, Kuussaari et al. 2015), the American burying beetle (Mckenna-Foster et al. 2016), and wetas in New Zealand (reviewed by Watts et al. 2008). Unsuccessful attempts have also been made to establish new populations of the rare damselfly *Megalagrion xanthomelas* Sélys-Longchamps in Hawaii (Preston et al. 2007). Despite the recent increased focus on bee conservation, there appears to have been only one attempt to restore bee populations through translocation, the apparently unsuccessful movement of *Bombus subterraneus* (L.) from Sweden to England (Gammans 2020).

Bees are represented in the native Hawaiian fauna solely by the yellow-faced bees, *Hylaeus*. A single group of 63 species, all derived from a single ancestral colonist, occurs in the islands (Daly and Magnacca 2003, Magnacca and Danforth 2006). The great entomologist R.C.L. Perkins described them as “almost the most ubiquitous of any Hawaiian insects” and added that “Many of the species of *Nesoprosopis* [= *Hylaeus*] are extraordinarily abundant and I doubt whether any species is really rare” (Perkins 1913). Just over 100 years later, at least half of the species are extremely rare, even accounting for those that have abundant habitat but are rarely collected, and many are threatened with extinction or possibly already extinct (Magnacca 2007).

Hylaeus anthracinus (F. Smith) is one of seven native bee species listed as endangered in 2016 (U.S. Fish and Wildlife Service 2016). Specimens from the 1890s to the 1930s in the Bishop Museum and other collections show that it was formerly widespread and abundant along the coasts of all islands from Oahu to Hawaii, but is currently restricted to a few relictual populations. The species occurs in three genetically distinct island clades that probably represent cryptic species: Oahu + Molokai, Maui + Kahoolawe, and Hawaii (the Lanai population has not been sampled; Magnacca and Brown 2010). It is unique among the endangered *Hylaeus* species in that the Hawaii population can still be found in relatively large numbers at a few sites in North Kona and South Kohala (Magnacca and King 2013). Along several stretches of coastline, hundreds of bees may be found around a single flowering tree, higher densities than even the most common species occur at. Nevertheless, they are restricted to a narrow strip of strand vegetation no more than 20 m wide, nesting in holes in shoreline coral rubble and hollow stems such as those of *Scaevola taccada* (Graham and King 2016), and are highly vulnerable to extirpation by ant invasion (Magnacca and King 2013). For example, since 2013, *Hylaeus* have been eliminated from approximately 1 km of coastline north of Kaloko-Honokohau National Historical Park due to the dramatic expansion of bigheaded ants (*Pheidole megacephala* [Fabricius]) following road construction (pers. obs.).

The relative fragility of even these apparently robust populations underscores the necessity of establishing *Hylaeus anthracinus* as widely as possible throughout its former range in order to ensure continued survival of the species. The impending listing of it and other *Hylaeus* as endangered added urgency at the time this study was conducted, as a translocation involving *H. anthracinus* could serve as a model for other species with similar conservation needs but with smaller wild populations. To this end, I selected Puuhonua O Honaunau National Historical Park (PUHO) as the site for a reintroduction attempt. Collections by Perkins from adjacent Kealakekua Bay (Perkins 1899) indicate that it formerly occurred in the area. As part of the National Park system, it is a protected site that includes native outplantings for restoration and receives active management. The area is noteworthy because it contains a good diversity of native plants (see Methods below), yet is approximately 30 and 60 km from the nearest extant populations to the north and south respectively, so that natural dispersal is unlikely. Based on available floral resources, it appears to be the only site even potentially suitable for *Hylaeus* habitation along the Kona coast between Kailua and Milolii, a span of 50 km. In addition to the primary goal of establishing a new population of *H. anthracinus*, this project aimed to test the effects of habitat composition and number of released individuals on establishment success by releasing bees at different microsites at PUHO.

Methods

Release sites. Three sites were selected for release based on availability of potential host flowers (Fig. 1). They were intended to represent a gradient of quality and abundance of flowers, nest site availability, and presence of ants. Starting from the south, site 1 is a small restoration area containing a number of native plants planted by the park, with relatively high diversity (Table 1). Both coral rocks on the shoreline and twigs are abundant for nesting. The restoration planting area and adjacent high-quality habitat is approximately 50 m square, bounded on the

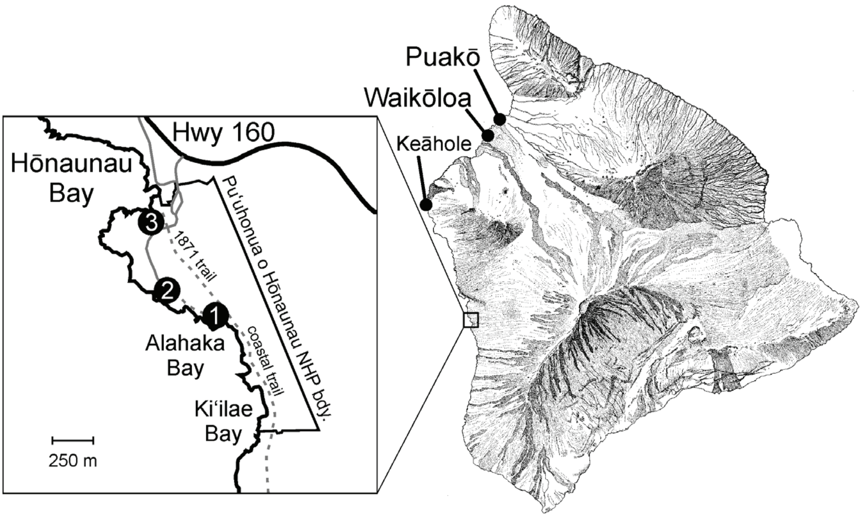

Figure 1. Map of the source sites in South Kohala and North Kona, and release sites at PUHO (inset).

Table 1. Distribution of potential flower resource plants at the three release sites. *Indicates alien species.

Species	Family	Site 1	Site 2	Site 3
Cordia subcordata	Boraginaceae	X		
Capparis sandwichiana	Capparaceae	X		
Ipomoea pes-caprae	Convolvulaceae	X		
Jacquemontia ovalifolia	Convolvulaceae	X		
Sesbania tomentosa	Fabaceae	X	X	
Scaevola taccada	Goodeniaceae	X	X	X
Vitex rotundifolia	Lamiaceae		X	
Sida fallax	Malvaceae	X		
Waltheria indica	Malvaceae	X	X	X
Pandanus tectorius	Pandanaceae	X		
Myoporum sandwicense	Scrophulariaceae		X	
*Cocos nucifera**	Arecaceae	X	X	X
*Heliotropium foertherianum**	Boraginaceae	X		
*Prosopis pallida**	Fabaceae		X	
*Tephrosia purpurea**	Fabaceae	X	X	
*Thespesia populnea**	Malvaceae	X		
*Morinda citrifolia**	Rubiaceae		X	X

south by a lava flow, mauka (upslope) by alien vegetation, and by the ocean along the shore. To the north it grades into the same habitat found at site 2. Site 2, located approximately 200 m north of site 1, is also predominantly native but is of lower diversity, with a few outplanted *Sesbania tomentosa*. It is part of a relatively homogenous section of coastal vegetation, approximately 280 m long and 30 m wide between the ocean and mauka alien vegetation, and the site is not differentiated except for the presence of the *Sesbania*. Coral rock is smaller here but twigs are present for nesting. Both of these sites are adjacent to the coastal trail, and some plants in the trail corridor (especially naupaka, *Scaevola taccada*) are trimmed periodically for trail maintenance. Site 3 is a further 450 m north in the royal grounds compound of the park; it is relatively sparsely vegetated compared to the other two, with only the weakly-favored flower *Waltheria indica* in addition to *Scaevola taccada* (Graham and King 2016), coconut palms, and large areas of lava rock and sand. Only twigs of *Scaevola* are present for nest habitat. Species present at the sites are listed in Table 1.

All sites were previously checked visually for the presence of yellow crazy ants (*Anoplolepis gracilipes*) and Argentine ants (*Linepithema humile*), which almost inevitably exclude *Hylaeus* when they occur at moderate to high densities (Magnacca and King 2013), but due to logistics and permitting, were not surveyed for other species until the first release (big-headed ants, *Pheidole megacephala*, were noted to be conspicuously present at site 3 in the visual survey). Ten ant baits, consisting of a mixture of corn syrup and salmon pate cat food, were set out on cards along trails at each site approximately 5 m apart. These were left out for approximately 1 hour before being checked for ants, which were collected to be identified later.

Translocation. *Hylaeus anthracinus* were sourced from the Puako and Waikoloa areas, adjacent to the Fairmont Orchid and Hilton Waikoloa hotels respectively (Fig. 1). For the second release, an additional group was taken from Keahole Point (see Results). *Hylaeus anthracinus* were caught with a net around flowering tree heliotrope (*Heliotropium foertherianum* [=*Tournefortia argentea*]), where the greatest number can typically be found, and transferred to 9-dram plastic snap-cap vials. Thirty to 50 bees were placed in each vial, and the vials kept in an insulated bag with an ice pack to prevent overheating. Non-native bees were excluded as much as possible, and any accidentally let into the vials were removed and killed while they were cold-stunned. The alien bees *Ceratina arizonensis* Cockerell, *C. dentipes* Friese, *C. smaragdula* (Fabricius), *Lasioglossum impavidum* (Sandhouse), and *L. imbrex* Gibbs are widespread along the Kona coast and had already been collected at or immediately adjacent to PUHO, so there was no concern about importing new species to the area (Magnacca and King 2013). The honeybee *Apis mellifera* L., a potential competitor for floral resources, is also widespread throughout the region, including the release sites. Bees were transported to PUHO and released the same day, within five hours of the first collection.

The first collection and translocation was made January 15, 2015. Flowering at this time was generally low. At Puako, only four heliotrope trees had adequate bees to collect from (about 100 or more visible at a time), and the sex ratio was approximately equal. At Waikoloa, several trees were in full bloom with many hundreds of bees around them, but were heavily male-biased; bees were caught and males selectively released until at most a 2:1 male:female ratio was achieved. Overall, 100 bees were collected from Puako and 135 from Waikoloa. Capture of this

Figure 2. Left: *Hylaeus* nest in coral rubble at site 1, with cellophane-like lining covering a round hole in the rock. Right: Female *H. anthracinus* concentrating nectar on a flower bud of ilima (*Sida fallax*).

quantity did not result in any obviously diminished number of bees around the trees. One hundred bees were released at site 1, 85 at site 2, and 50 at site 3. Bees released onto the ground or leaves were active but usually unable to fly immediately due to being cooled; they warmed up and took flight within a few minutes. After flying off they were not observed at the release sites during informal surveys of approximately 20–30 minutes.

To check for establishment, the release sites were monitored quarterly for a year (the last was delayed from January to March 2016). Each time, a five-minute count of *H. anthracinus* was conducted at the sole large *Heliotropium* tree at site 1, and targeted searches for approximately one hour were done at other flowering plants to determine presence and relative abundance of bees. Evidence of nesting was also noted. Targeted searches were conducted at sites 2 and 3 for at least 30 minutes. After the failure to establish at sites 2 and 3 in the second release (see Results), the area between sites 1 and 2 was also included in targeted searches beginning July 2016 in order to determine how far up the coast the bees had spread from site 1.

Results

Hylaeus anthracinus was found at site 1 during all of the four post-release monitoring checks, through 14 months after release. Cloudy weather prevented reliable time counts in April and October 2015; in July 2015 and in March 2016, five-minute counts at a large *Heliotropium* were 107 and 41 respectively. *Hylaeus* were frequently seen on *Sida fallax* and *Scaevola taccada*, and occasionally on *Jacquemontia ovalifolia*. A nest of the characteristic *Hylaeus* type (Michener 2000) was observed in a large piece of coral rock, indicating that reproduction was taking place (Fig. 2). National Park Service staff subsequently observed *H. anthracinus* in November 2017 and March 2018, confirming that the population remains established (M. Hayes, pers. comm.).

Because no bees were recovered at sites 2 and 3 in the first monitoring, a second release was conducted on April 16, 2015. Bees were in similar abundance at Waikoloa and 100 bees were collected there. At Puako they were more widespread than in January but less dense, so bees were instead collected from the vicinity of the Natural Energy Laboratory of Hawaii (NELHA) at Keahole Point. Only 20 were obtained there due to the high male:female ratio and the need to reach the release site in sufficient time. The 100 from Waikoloa were released at site 2, and the 20 from Keahole released at site 3.

Hylaeus were never recovered at sites 2 and 3, despite the second release at each. Ant surveys conducted in conjunction with the first release found very high numbers of bigheaded ants (*Pheidole megacephala*) at all baits at these two sites (>100 individuals per bait), but not at site 1, where only low numbers (<10 individuals per bait) of three other ants were found (*Ochetellus glaber* [Mayr], *Tapinoma melanocephalum* [Fabricius], and *Tetramorium insolens* [F. Smith]). However, in July and October, *Hylaeus* were observed as far as 150 m northwest of the site 1 release, about halfway to site 2.

Discussion

This is the first example of successful insect translocation in Hawaii for conservation purposes. With *Hylaeus* and other species under continuing threat from invasive species and habitat destruction, this can be a useful tool for re-establishing species that have disappeared from large parts of their original range but where suitable areas now exist again.

Part of the design of this experiment was to test the number of individuals needed for establishment by releasing different numbers at each site, and the habitat quality required. Studies of releases for biocontrol suggest a minimum of 100 individuals to have a good likelihood of success where the species' biology is largely unknown (Grevstad 1999, Fauvergue et al. 2012), which is relatively small for an insect but nevertheless would be difficult to obtain for rare species such as most of the native *Hylaeus*. Unfortunately, it was not possible to test if smaller numbers would succeed because they were only able to establish at site 1, which has both the highest native floral diversity and is the only one free of *Pheidole* ants. While *Hylaeus* can sometimes coexist with low levels of *Pheidole* (Magnacca and King 2013), the high density found at sites 2 and 3 would overwhelm any number of released bees. The presence of *Hylaeus* halfway between sites 1 and 2 means that some of those released at site 2 may have contributed to the population by moving down the coast, rather than solely expansion of the site 1 population. The effective number released and ultimately established may therefore be higher than the 100 released at site 1. The northernmost spot where *H. anthracinus* were observed is close to the southernmost area where *Pheidole* is readily observed on the ground and vegetation, suggesting that ants limit the distribution of *H. anthracinus*. During the second release in April, *Pheidole* were observed attacking and pinning down *Hylaeus* rendered flightless by cold within seconds of them emerging from a vial at site 3 (Fig. 3). Although the bees were able to fly away after being freed, the high density of ants likely prevented them from establishing in the area.

Due to the confounding presence of *Pheidole*, the effect of floral diversity also could not be adequately assessed. Site 3 has relatively low vegetation quality and it was always unlikely they would establish there, but site 2 is little different vegetatively from the areas where bees have successfully established just to the south. The source sites have low diversity overall, but are dominated by a mix of *Scaevola taccada* and *Heliotropium foertherianum*. The latter supports extremely high numbers of *Hylaeus anthracinus* visitors, but is uncommon at PUHO.

The life history of *H. anthracinus* and other native bees is poorly studied, and seasonal differences between the January and April releases that may have affected survivorship are unknown. A study on

Figure 3. A newly released *Hylaeus* being attacked by *Pheidole megacephala* almost immediately after being released at site 3.

Oahu found *H. anthracinus* most active between May and September at one site and relatively continuous from July through December at another (data was not recorded earlier in the year; Graham 2018). However, Oahu data may not be applicable to Hawaii, and flowering at dry coastal sites is often highly variable from year to year depending on rainfall. Although conditions appeared the same at the source sites both times, some of those that had large numbers in January had few in April and vice versa.

The only other attempt at bee translocation, involving *Bombus subterraneus*, does not appear to have been successful (Gammans 2020). The lack of establishment may have been due in part to the relatively small number released – due to limitations on collecting at the source and the need to screen for diseases and parasites, only an average of 40 queens were released per year (Brown et al. 2017, Gammans 2020). While this added up to over 200 over the five years of the project, it may not have been enough to create a critical population size in the relatively large habitat. In the case of *H. anthracinus* here, disease and parasite screening was unnecessary given the close distance and lack of other *Hylaeus* species at the release site (alien bees, particularly honeybees, may spread pathogens but their impact is poorly understood in Hawaii), and the released bees were confined to a very small area due to the presence of high densities of ants to the north and lack of habitat on all other sides.

For *Hylaeus* in particular, this technique may have limited application. *Hylaeus anthracinus* on Hawaii is unusual in being present in very high densities at sites in North Kona and South Kohala, allowing for removal of 100–200 individuals without significantly impacting local populations. There are additional sites available on Hawaii available for restoring *H. anthracinus*, such as Manuka Natural Area Reserve, Punaluu, and Kawa Bay. Many of these are relatively small, but each would provide additional backup against catastrophic loss of the source sites. Other island populations are widely divergent genetically, and probably represent cryptic species (Magnacca and Brown 2010). The Oahu population occurs in moderate numbers at some sites but far below those of Hawaii, while the Maui taxon is very rare. All other Hawaiian *Hylaeus* species—even those considered relatively common—are either rare or widely dispersed, making collecting large numbers impractical. If it is possible to rear them in captivity as halictid bees can be (Batra 1964, 1968; Stockhammer 1966; May and Stockhammer 1968; Michener and Brothers 1971), then collection of a much smaller number might be possible.

The technique of direct release for reintroduction may be more useful for other native insects such as the endemic *Drosophila*. For some species, removal of feral pigs and other plant conservation measures have allowed their host plants to recover such that they may be able to sustain viable populations again, but the nearest existing population is too far away to naturally disperse. For example, the distinctive hammerhead *D. heteroneura* (Perkins) has been extirpated from most of its former range across Hawaii island except a small portion of South Kona (Foote 2000), probably due to a combination of the introduction of the western yellowjacket, *Vespula pensylvanica* (Saussure), and decline of its primary host plant, *Clermontia hawaiiensis* (Foote and Carson 1995). Extensive regeneration of the related *Clermontia montis-loa* over the past 20 years in areas fenced off from pigs (Three Mountain Alliance 2007) at elevations where *Vespula* is rare may provide areas for reintroduction of this endangered *Drosophila*. The endemic *Drosophila* can also be lab-reared in large numbers in one or two generations starting from only a few individuals (Kaneshiro 2006), allowing for small number of wild-collected individuals but a large number released to the new site.

With large uncertainty in the future distribution of suitable native habitat due to climate change and new invasive species introductions, it is likely that reintroductions such as these will be increasingly necessarily in the future. As plant communities are restored in formerly degraded areas or shift to new distributions, it is important to restore the insect community as well to preserve ecosystem functions and conserve species, particularly pollinators such as *Hylaeus*.

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