RANGE, HABITAT, AND ECOLOGY OF THE WEKIU BUG (*NYSIUS WEKIUICOLA*), A RARE INSECT SPECIES UNIQUE TO MAUNA KEA, HAWAI'I ISLAND

FINAL REPORT

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EXECUTIVE SUMMARY

The Hawaii Biological Survey of the Bishop Museum was contracted by the Office of Mauna Kea Management (OMKM) to assess the distribution and habitat use of the wēkiu bug (*Nysius wekiuicola* Ashlock, and Gagné), endemic to Mauna Kea. This project arose after a preliminary study conducted by the Smithsonian Institution found relatively high numbers of wēkiu bugs on Pu‘u Hau Kea in June 2001, in contrast to other similar studies which had indicated population declines. Because of these findings, OMKM was interested in obtaining further information regarding the distribution and status of wēkiu bugs in the alpine zone of Mauna Kea.

The three major objectives of this study were to 1) survey for the presence or absence of wēkiu bugs at the summits of various pu‘u’s (cinder cones) located in the alpine zone of Mauna Kea, 2) determine the elevational distribution of wēkiu bugs on Mauna Kea, and 3) assess whether different pitfall trapping methods used in earlier Bishop Museum surveys provide comparable data in regard to wēkiu bug capture rates.

Wēkiu bug surveys for this study occurred in April and May 2002, with additional sampling of Pu‘u Hau Kea in September 2002. The current study assessed the presence or absence of wēkiu bugs in the alpine zone of Mauna Kea as a whole, and provided valuable new information that will help better conserve and manage this rare species.

Wēkiu bugs were infrequently collected, occurring preferentially along the upper rim areas of suitable cinder cones within the alpine zone of Mauna Kea. Evidence for the rarity of wēkiu bugs is demonstrated by the fact that despite 398 total trap days of effort during this study, only 47 wēkiu bugs were captured. Wēkiu bugs were found at lower elevations than previously recorded, being present in pitfall traps, although in low numbers, to elevations as low as 11,715 ft (3,572 m). A pronounced pattern was observed of wēkiu bugs becoming increasingly more common in pitfall traps as elevations increased, with the greatest numbers captured on Pu‘u Hau Kea. Substrate types were also determined to be of critical importance in assessing whether a particular habitat was suitable or not for wēkiu bugs.

Bishop Museum wēkiu bug studies conducted in the early 1980s have been implicated by some for the demise and current rarity of the wēkiu bug. On the contrary, our findings indicate there is no evidence that ethylene glycol trapping in the early 1980s was responsible for this decline, nor is there is any quantitative evidence available to actually show there has been a decline or increase in the population. This is because: 1) valid population studies have not been conducted, 2) methodologies used in the 1982 study with one exception have not been used since that time and, 3) past sampling measured wēkiu bug foraging activity. Because there are no reliable data comparable to the 1982 study, and because valid population studies are not being currently conducted, any conclusions that wēkiu bug populations are currently increasing or decreasing are invalid.

Although much controversy has been generated recently over whether wēkiu bug populations are increasing or decreasing, alternatives exist that could provide quantitative information regarding the population status of this species. Wēkiu bugs collected in the 1982 study could be compared to wēkiu bugs preserved from the more recent studies conducted since 1997. This would provide quantitative information as to whether the wēkiu bug populations have actually declined. Molecular markers could be used to quantitatively state whether wēkiu bugs have undergone a genetic bottleneck, and also examine gene flow between the core populations around the high observatory summit areas and smaller outlying populations in the lower alpine zone of Mauna Kea, such as at Pu‘u Makanaka.

To further understand the entire range of potential habitats that can be utilized by this species, it is recommended that wēkiu bug surveys be continued in the outlying alpine zone areas of Mauna Kea that have not yet been sampled. Although further testing of pitfall trap methodology is warranted, our study has shown that shrimp pitfall traps have several major drawbacks, with 56% mortality recorded during this study compared to 55% recorded in previous Bishop Museum studies. This clearly cannot be considered a non-lethal sampling methodology. Additionally, large predators such as lycosid (wolf) spiders consume items within these traps, and thus traps with negative wēkiu bug results may not necessarily have had zero wēkiu bugs within them. Thus, it is concluded that because both native and alien insects cannot escape from ethylene glycol traps, they are a better measure of wēkiu bug presence.

INTRODUCTION

The Hawaii Biological Survey of the Bishop Museum was contracted by the Office of Mauna Kea Management (OMKM) to assess the distribution and habitat use of the wēkiu bug (*Nysius wekiuicola* Ashlock and Gagné), which is endemic to Mauna Kea. This project arose after a preliminary study conducted by the Smithsonian Institution (Polhemus 2001) found relatively high numbers of wēkiu bugs on Pu‘u Hau Kea in June 2001 (see Appendix 1 for a copy of this report), in contrast to other similar studies that had indicated population declines. Because of these findings, OMKM was interested in obtaining further information regarding the distribution and status of wēkiu bugs in the alpine zone of Mauna Kea.

The three major objectives of this study were to 1) survey for the presence or absence of wēkiu bugs at the summits of various pu‘u’s (cinder cones) located in the alpine zone of Mauna Kea, 2) determine the elevational distribution of wēkiu bugs on Mauna Kea, and 3) assess whether different pitfall trapping methods used in earlier Bishop Museum studies provide comparable data in regard to wēkiu bug captures.

Wēkiu bug surveys for this study occurred in April and May 2002, with additional sampling on Pu‘u Hau Kea in September 2002. Sampling in the alpine zone of Mauna Kea in April/May 2002 was coordinated with Pacific Analytics (Pacific Analytics 2002) wēkiu bug monitoring in the summit area. Our study used identical collecting techniques for the shrimp pitfall traps, and were conducted in nearly the same time frame. Previous Bishop Museum wēkiu bug studies were concentrated directly around the astronomical observatories (Gagné and Howarth 1982, Howarth and Stone 1982). Howarth et al. (1999) also examined areas in the Mauna Kea Science Reserve. Because it is such a vast area, little previous information was available regarding the overall elevational range and distribution of the wēkiu bug throughout the entire alpine zone of Mauna Kea. The current study assessed the presence or absence of wēkiu bugs throughout the alpine zone, and provided valuable new information that will assist in conserving and managing this rare species.

Areas surveyed during this study included Pu‘u Mākanaka, Pu‘u Māhoe, Pu‘u Ala, Pu‘u Poepoe, Pu‘u Keonehehe‘e and adjacent unnamed cones, and several unnamed cones near the VLBA (Very Long Baseline Array) facility. To assess the effectiveness of various trapping methods on wēkiu bug capture rates, Pu‘u Hau Kea was sampled in both July 2001 by Polhemus (2001) and again by our team in September 2002.

STUDY AREA

At 13,796 ft (4,206 m), the dormant Mauna Kea volcano is the highest mountain in the Hawaiian archipelago. Mauna Kea was glaciated as recently as 9,100 years ago, with extensive glaciation occurring within the past 300,000 years (Porter 1979 a, b, c; Wolfe 1997). The most recent glacial period, called the late Makanapa, was at its maximum about 30,000 years ago before the glaciers disappeared entirely approximately 9,100 years ago. The largest extent of the ice cap on Mauna Kea was 50–58 mi^2 (130-150 km^2), with ice depths as much as 558 ft (170 m) thick. Evidence exists of at least two volcanic eruptions taking place underneath the Mauna Kea ice cap, with the tephra cones of Pu‘u Waiau and Pu‘u Poliahu being composed of hyaloclastite, which forms only during subaqueous deposition (Porter 1979c). This Pleistocene glaciation and corresponding cold climate depressed ecological zones further downslope from the summit of Mauna Kea then seen at present, and undoubtedly influenced populations and habitats of both the wēkiu bug and its presumed sister taxon, the Mauna Loa alpine ‘a‘ā bug (*Nysius aa*) (Polhemus 1998).

The study area encompassed portions of the alpine zone of the Mauna Kea volcano, including both the Mauna Kea Science Reserve (MKSR) and the Mauna Kea Ice Age Natural Area Reserve (NAR). For the purposes of this study, cinder cones are defined as non-vegetated, dormant volcanic cones in the alpine zone above 10,500 ft (3,200 m). Elevations sampled during the current study ranged from a maximum of 13,441 ft (4,098 m) at Pu‘u Hau Kea to a low of 11,300 ft (3,445 m) at Pu‘u Keonehehe‘e. The study area was divided into two general geographic sections east and west of the Mauna Kea observatories access road. Unless otherwise stated, pu‘u names were derived from USGS topographic quad maps. The NAD 83 datum was used for recording GPS locations. Altitudes were determined using a combination of USGS 7.5 minute topographic quad maps and a handheld Suunto altimeter calibrated daily at Hale Pohaku.


Pu‘u Hau Kea, 30 April 2002

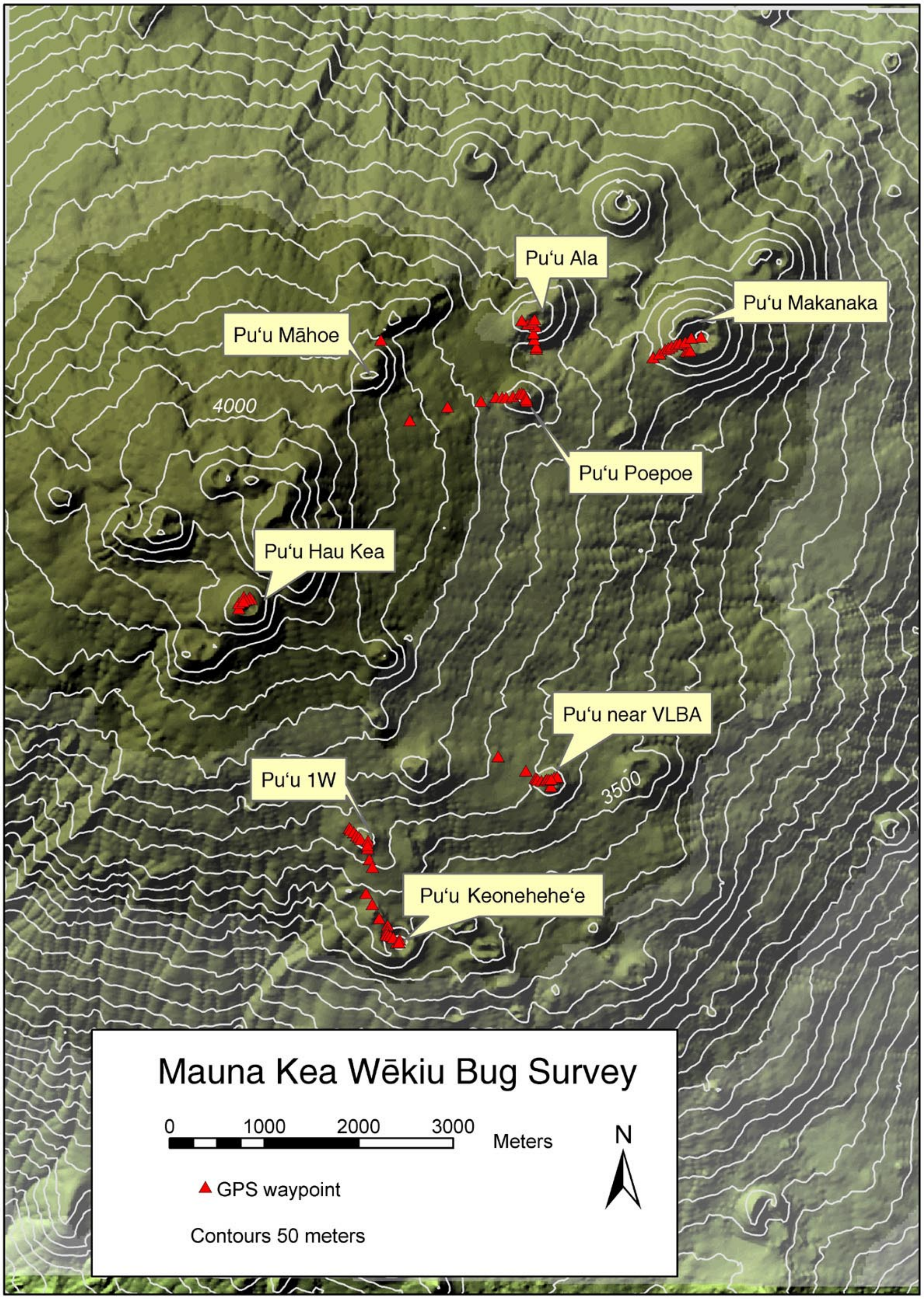


Figure 1. Overall study area and sampling sites and GPS waypoints at sample sites.

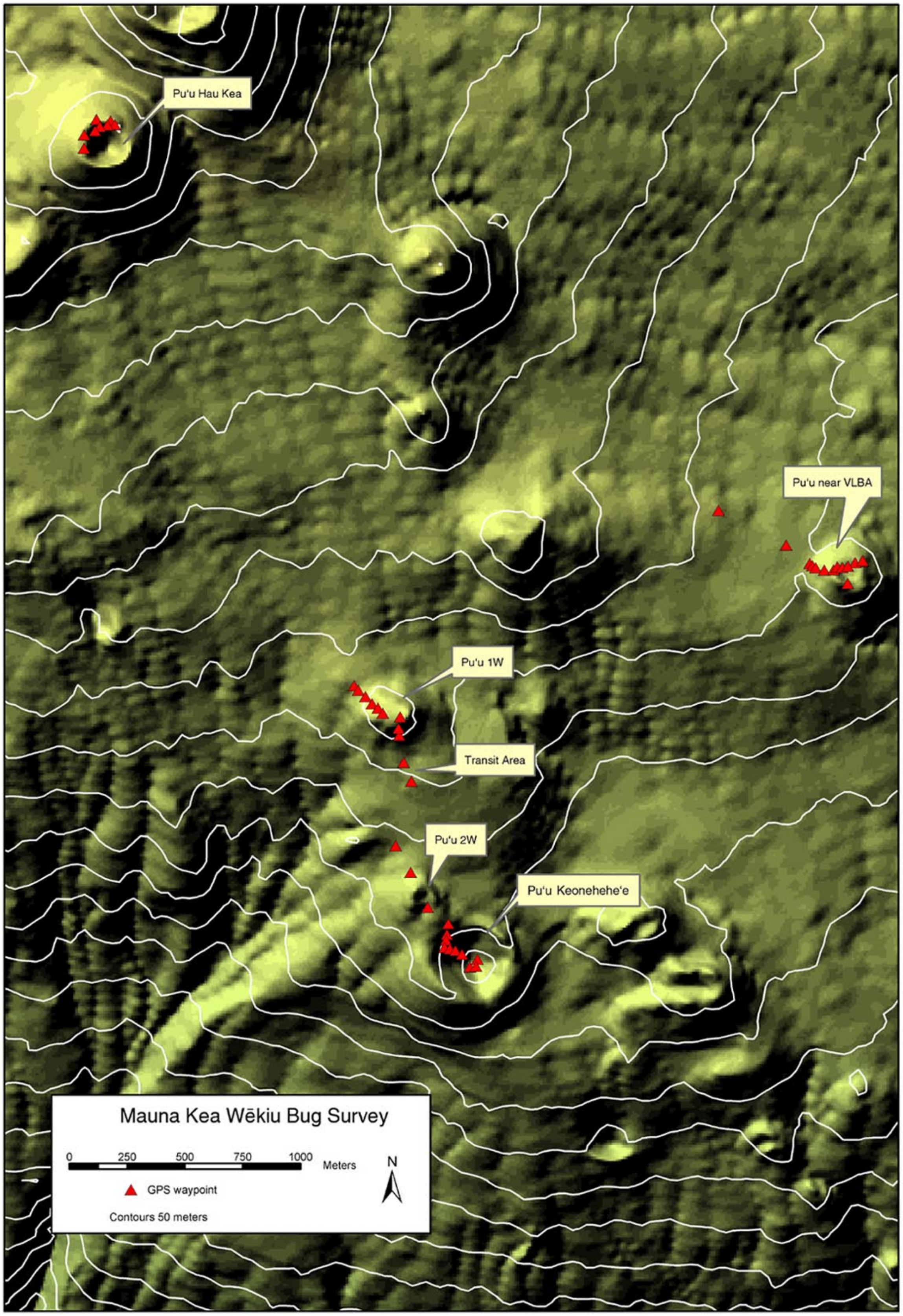


Figure 2. Western and lower portion of study area and GPS waypoints at sample sites.

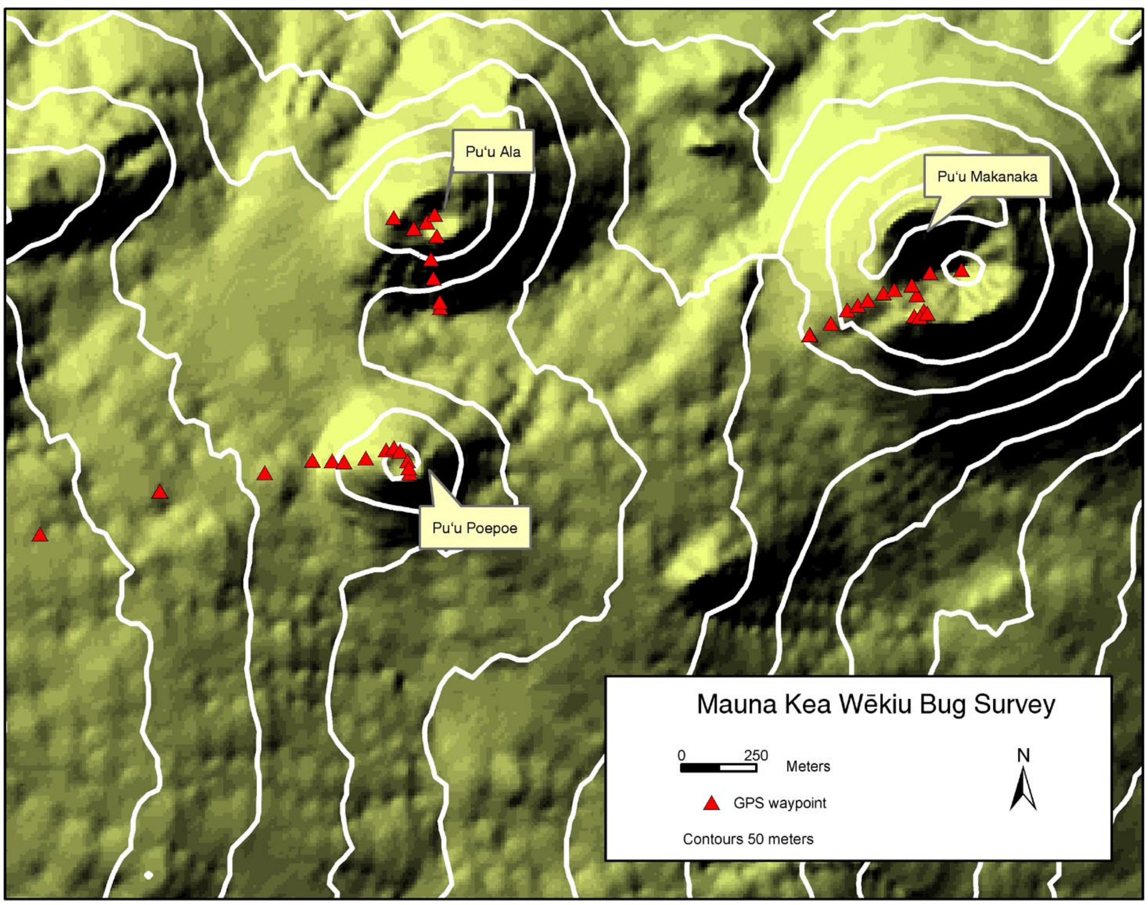


Figure 3. Close-up of eastern alpine cones sampled during this study and GPS waypoints at sample sites.

Eastern Study Area

GPS coordinates for each individual trap located in this portion of the study area are shown in Table 1. The eastern portion of the study area included the outlying cinder cones to the northeast of the main observatories, as well as an unnamed cone near the VLBA observatory. Sampling occurred from 22 April to 1 May 2002. These remote areas were accessed via hiking, with visual observations being conducted along the way and during rest breaks that are mandatory when working at such high elevations. Because of the high stress to researchers from carrying large numbers of pitfall traps, bait, and sufficient water to fill all the traps, trap placement was concentrated on the slopes closest to the access points, generally the western facing slope of each remote cinder cone surveyed. Future studies may also want to assess the eastern slopes of the cinder cones, especially if helicopter or other access can be arranged.

Sampling the outer cones involved placing a line of shrimp pitfall traps starting at the base of each cinder cone and evenly spacing the traps up to the cone rim and down into the bottom of the crater. Nine traps were set on Puʻu Ala, which had larger substrates than the finer ash generally found at cones in the vicinity of Puʻu Makanaka. Fifteen traps were then placed on the Puʻu Makanaka cone, starting on the western slope and continuing as a transect up the steep slope of the cinder cone and into the crater bottom. Puʻu Poepoe was next sampled; the lower 50% of this cone's slopes were covered with large basaltic boulders, with the remaining upper half covered with a finer red cinder/ash. Finally, to ensure all habitats were sampled, three shrimp pitfall traps were placed in the valley floor between Puʻu Māhoe and Puʻu Poepoe. Substrates in the valley floor area differed greatly from substrates found on cones within the alpine zone. Instead of red, cindery fist-sized cobbles intermixed with gravels, the valley floor substrate consisted of glacial flour in a large boulder field area with some flat gray slate-like 3–10 in (7–25 cm) rocks. Additionally, while digging pitfall traps in the valley floor area between Puʻu Māhoe and Puʻu Poepoe we encountered a nine-inch (23 cm) layer of this slate-like cobble deeply embedded in a fine layer of tightly packed, light colored sand.

Thirteen shrimp pitfall traps were placed in and around an unnamed puʻu near the VLBA observatory; at 11,700 ft (3,567 m) this was the lowest elevation surveyed in the eastern portion of the study area. Substrate findings similar to those seen in the area between Puʻu Māhoe and Puʻu Poepoe were observed when sampling the valley floor area at the unnamed puʻu near the VLBA observatory. This unnamed puʻu had an

Table 1. Eastern study area shrimp pitfall trap GPS locations during wēkiu bug surveys conducted from 22 April–1 May 2002.

Cinder Cone	Trap #	Trap Elevation	GPS Coordinates
Pu‘u Ala	1	12,030 ft	19°50'20.5"N, 155°26'37.3"W
Pu‘u Ala	2	12,070 ft	19°50'21.2"N, 155°26'37.4"W
Pu‘u Ala	3	12,170 ft	19°50'23.7"N, 155°26'38.1"W
Pu‘u Ala	4	12,270 ft	19°50'25.8"N, 155°26'38.4"W
Pu‘u Ala	5	12,390 ft	19°50'28.3"N, 155°26'37.8"W
Pu‘u Ala	6	12,370 ft	19°50'29.1"N, 155°26'40.5"W
Pu‘u Ala	7	12,350 ft	19°50'29.8"N, 155°26'39.0"W
Pu‘u Ala	8	12,320 ft	19°50'30.6"N, 155°26'38.1"W
Pu‘u Ala	9	12,410 ft	19°50'30.3"N, 155°26'42.8"W
Pu‘u Makanaka	1	11,890 ft	19°50'18.2"N, 155°25'54.8"W
Pu‘u Makanaka	2	11,920 ft	19°50'19.4"N, 155°25'52.4"W
Pu‘u Makanaka	3	12,030 ft	19°50'20.9"N, 155°25'50.5"W
Pu‘u Makanaka	4	12,080 ft	19°50'21.4"N, 155°25'49.3"W
Pu‘u Makanaka	5	12,120 ft	19°50'22.0"N, 155°25'48.2"W
Pu‘u Makanaka	6	12,170 ft	19°50'22.8"N, 155°25'46.4"W
Pu‘u Makanaka	7	12,140 ft	19°50'23.2"N, 155°25'45.2"W
Pu‘u Makanaka	8	12,170 ft	19°50'23.7"N, 155°25'43.2"W
Pu‘u Makanaka	9	12,050 ft	19°50'25.0"N, 155°25'41.1"W
Pu‘u Makanaka	10	11,980 ft	19°50'25.5"N, 155°25'37.4"W
Pu‘u Makanaka	11	12,140 ft	19°50'22.7"N, 155°25'42.6"W
Pu‘u Makanaka	12	12,220 ft	19°50'20.9"N, 155°25'41.7"W
Pu‘u Makanaka	13	12,230 ft	19°50'20.3"N, 155°25'42.8"W
Pu‘u Makanaka	14	12,230 ft	19°50'20.2"N, 155°25'42.2"W
Pu‘u Makanaka	15	12,230 ft	19°50'20.7"N, 155°25'41.3"W
Pu‘u Poepoe	1	12,290 ft	19°50'03.7"N, 155°26'51.1"W
Pu‘u Poepoe	2	12,350 ft	19°50'03.7"N, 155°26'49.5"W
Pu‘u Poepoe	3	12,400 ft	19°50'03.6"N, 155°26'48.1"W
Pu‘u Poepoe	4	12,500 ft	19°50'04.0"N, 155°26'45.6"W
Pu‘u Poepoe	5	12,560 ft	19°50'04.9"N, 155°26'43.3"W
Pu‘u Poepoe	6	12,580 ft	19°50'05.2"N, 155°26'42.4"W
Pu‘u Poepoe	7	12,560 ft	19°50'04.8"N, 155°26'41.7"W
Pu‘u Poepoe	8	12,510 ft	19°50'03.8"N, 155°26'40.8"W
Pu‘u Poepoe	9	12,540 ft	19°50'03.0"N, 155°26'40.7"W
Pu‘u Poepoe	10	12,560 ft	19°50'02.5"N, 155°26'40.6"W
Pu‘u Poepoe (valley floor)[1]	11	12,350 ft	19°50'02.2"N, 155°26'57.2"W
Pu‘u Poepoe (valley floor)[1]	12	12,440 ft	19°50'00.1"N, 155°27'09.2"W
Pu‘u Poepoe (valley floor)[1]	13	12,640 ft	19°49'55.3"N, 155°27'22.9"W
Unnamed Pu‘u near VLBA	1	11,700 ft	19°47'52.7"N, 155°27'35.4"W
Unnamed Pu‘u near VLBA	2	11,710 ft	19°47'52.4"N, 155°26'35.0"W
Unnamed Pu‘u near VLBA	3	11,715 ft	19°47'52.1"N, 155°26'34.5"W
Unnamed Pu‘u near VLBA	4	11,750 ft	19°47'51.8"N, 155°26'33.2"W
Unnamed Pu‘u near VLBA	5	11,770 ft	19°47'51.9"N, 155°26'31.8"W
Unnamed Pu‘u near VLBA	6	11,780 ft	19°47'50.0"N, 155°26'29.7"W

[1]These traps located in “valley floor” area adjacent and not within the cinder cone proper

Table 1 (cont.). Eastern study area shrimp pitfall trap GPS locations during wēkiu bug surveys conducted in April-May 2002.

Cinder Cone	Trap #	Trap Elevation	GPS Coordinates
Unnamed Pu‘u near VLBA	7	11,770 ft	19°47'52.3"N, 155°26'31.3"W
Unnamed Pu‘u near VLBA	8	11,750 ft	19°47'52.2"N, 155°26'30.6"W
Unnamed Pu‘u near VLBA	9	11,740 ft	19°47'52.4"N, 155°26'29.7"W
Unnamed Pu‘u near VLBA	10	11,750 ft	19°47'52.9"N, 155°26'28.7"W
Unnamed Pu‘u near VLBA	11	11,770 ft	19°47'53.2"N, 155°26'27.5"W
Unnamed Pu‘u near VLBA[1]	12	11,710 ft	19°47'55.2"N, 155°26'38.9"W
Unnamed Pu‘u near VLBA[1]	13	11,820 ft	19°48'00.0"N, 155°26'49.1"W
Total Shrimp Pitfall Traps	50		

[1]These traps located in “valley floor” area adjacent and not within the cinder cone proper

approximate 50% red ash color and 50% black ash color on its outer flanks. Our transect up and into this cone sampled both types of substrate.

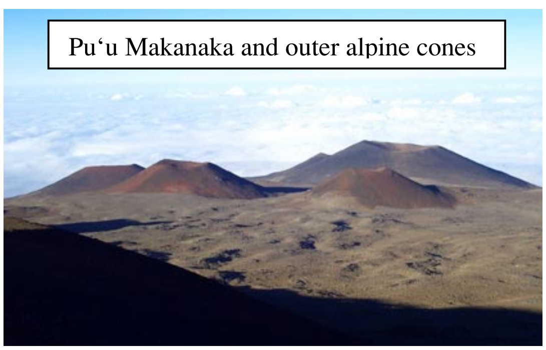
Western Study Area

A total of 25 shrimp pitfall traps, built and emplaced according to protocols discussed in the Methods section, were set along a transect running roughly north to south, from 19°47'34.6"N, 155°27'42.8"W to 19°46'55.3"N, 155°27'25.0"W, at elevations from 12,100 ft (3,689 m) to 11,300 ft (3,445 m), during April 2002 (Table 2). The lower end of the western study area defines the lower end of the alpine zone in the Mauna Kea Ice Age NAR, while Pu‘u Hau Kea defines the upper end.

The northern terminus of the trapline lay on the northern slope of an unnamed cone centered on 19°47'31.5"N, 155°27'39.2"W, with a maximum elevation of approximately 12,100 feet; this cinder cone is not presently named on USGS topographic quads, but is adjacent to the glacial moraine. For the present study this cone was coded as Unnamed Pu‘u 1W. Ten shrimp pitfall traps were set in a north to south line across Unnamed Pu‘u 1W, with 4 shrimp pitfall traps on the north outer slope, 4 on the relatively flat summit area, and 2 on the south outer slope (Table 2). The shrimp pitfall trapline then continued south through a col consisting of broken rock exposures and ashy plains, which was referred to as the "Transit Area". Three traps were set here, at elevations from 11,850 ft (3,613 m) to 11,600 ft (3,537 m). The trapline then skirted a small but locally prominent reddish cone, centered on 19°47'03.6"N, 155°27'31.4"W, referred to in the present study as Unnamed Pu‘u 2W. Two traps were placed here, one on the outer northeast slope at 11,600 ft (3,537 m), the other in the small interior crater at 11,550 ft (3,521 m).

The southern terminus of the trapline consisted of 10 traps set in the very large, cinder-sloped crater of Pu‘u Keonehehe‘e. Seven of these traps were set on the south facing inner slope of this crater at elevations between 11,600 ft (3,537 m), and 11,350 ft (3,460 m), 2 traps were set amid the reddish rocks of the crater floor at 11,300 ft (3,445 m), and 1 trap was set on the east facing inner slope of the crater at 11,350 ft (3,460 m). The trapline for the lower study area was emplaced on 22 April 2002, checked and rebaited on 25 April 2002, and checked again with cups removed on 28 April 2002.

In addition, a comparative test of pitfall trapping efficiency between shrimp pitfall traps and ethylene glycol traps occurred at Pu‘u Hau Kea, the highest elevation site on Mauna Kea examined during this study. Traps on Pu‘u Hau Kea were placed around the uppermost portion of the northern slope on the rim, and on the inside slopes in windy areas receiving large amounts of aeolian drift.


Pu‘u Makanaka and outer alpine cones


Pu‘u Makanaka Interior


Collecting on snowpack

Table 2. Western study area shrimp and ethylene glycol pitfall trap GPS locations (using NAD 83) during wēkiu bug surveys conducted in April-May 2002.

Cinder Cone	Trap #	Trap Elevation	GPS Coordinates	Trap Type
Puʻu Hau Kea (	1	13,422 ft	19°48'49.6"N, 155°28'24.1"W	shrimp and ethylene glycol
Puʻu Hau Kea	2	13,432 ft	19°48'51.5"N, 155°28'24.1"W	shrimp and ethylene glycol
Puʻu Hau Kea	3	13,437 ft	19°48'53.7"N, 155°28'22.3"W	shrimp and ethylene glycol
Puʻu Hau Kea	4	13,441 ft	19°48'53.5"N, 155°28'20.2"W	shrimp and ethylene glycol
Puʻu Hau Kea	5	13,411 ft	19°48'53.0"N, 155°28'19.6"W	shrimp and ethylene glycol
Puʻu Hau Kea	6	13,402 ft	19°48'52.9"N, 155°28'20.7"W	shrimp and ethylene glycol
Puʻu Hau Kea	7	13,403 ft	19°48'52.7"N, 155°28'21.8"W	shrimp and ethylene glycol
Puʻu Hau Kea	8	13,407 ft	19°48'52.1"N, 155°28'22.5"W	shrimp and ethylene glycol
Unnamed Puʻu 1W[1]	1	11,750 ft	19°47'34.6"N, 155°27'42.8"W	shrimp pitfall
Unnamed Puʻu 1W[1]	2	11,800 ft	19°47'34.0"N, 155°27'42.2"W	shrimp pitfall
Unnamed Puʻu 1W[1]	3	11,850 ft	19°47'34.0"N, 155°27'41.6"W	shrimp pitfall
Unnamed Puʻu 1W[1]	4	11,950 ft	19°47'33.1"N, 155°27'41.1"W	shrimp pitfall
Unnamed Puʻu 1W[1]	5	12,000 ft	19°47'32.1"N, 155°27'40.1"W	shrimp pitfall
Unnamed Puʻu 1W[1]	6	11,950 ft	19°47'31.5"N, 155°27'39.2"W	shrimp pitfall
Unnamed Puʻu 1W[1]	7	12,000 ft	19°47'30.8"N, 155°27'38.5"W	shrimp pitfall
Unnamed Puʻu 1W[1]	8	12,100 ft	19°47'30.3"N, 155°27'35.9"W	shrimp pitfall
Unnamed Puʻu 1W[1]	9	11,950 ft	19°47'28.7"N, 155°27'36.1"W	shrimp pitfall
Unnamed Puʻu 1W[1]	10	11,900 ft	19°47'27.7"N, 155°27'36.0"W	shrimp pitfall
Transit Area[2]	11	11,850 ft	19°47'23.9"N, 155°27'35.3"W	shrimp pitfall
Transit Area[2]	12	11,750 ft	19°47'21.3"N, 155°27'34.1"W	shrimp pitfall
Transit Area[2]	13	11,600 ft	19°47'12.2"N, 155°27'36.3"W	shrimp pitfall
Unnamed Puʻu 2W[3]	14	11,600 ft	19°47'08.5"N, 155°27'34.0"W	shrimp pitfall
Unnamed Puʻu 2W[3]	15	11,550 ft	19°47'03.6"N, 155°27'31.4"W	shrimp pitfall
Puʻu Keonehehe'e	16	11,600 ft	19°47'01.3"N, 155°27'28.3"W	shrimp pitfall
Puʻu Keonehehe'e	17	11,550 ft	19°46'59.8"N, 155°27'28.5"W	shrimp pitfall
Puʻu Keonehehe'e	18	11,525 ft	19°46'59.0"N, 155°27'28.6"W	shrimp pitfall
Puʻu Keonehehe'e	19	11,500 ft	19°46'58.0"N, 155°27'28.8"W	shrimp pitfall
Puʻu Keonehehe'e	20	11,450 ft	19°46'57.8"N, 155°27'28.0"W	shrimp pitfall
Puʻu Keonehehe'e	21	11,400 ft	19°46'57.6"N, 155°27'27.2"W	shrimp pitfall
Puʻu Keonehehe'e	22	11,350 ft	19°46'57.1"N, 155°27'26.2"W	shrimp pitfall
Puʻu Keonehehe'e	23	11,300 ft	19°46'56.4"N, 155°27'23.9"W	shrimp pitfall
Puʻu Keonehehe'e	24	11,300 ft	19°46'55.4"N, 155°27'24.1"W	shrimp pitfall
Puʻu Keonehehe'e	25	11,350 ft	19°46'55.3"N, 155°27'25.0"W	shrimp pitfall
Total Shrimp Pitfall Traps	33			

[1]Unnamed Puʻu near Puʻu Keonehehe'e centered at 19°47'31.5"N, 155°27'39.2"W; [2]These traps located in col area between Puʻu Keonehehe'e and unnamed Puʻu, and not within the cinder cone proper; [3]Unnamed small reddish cone adjacent to the rim of Puʻu Keonehehe'e

METHODS

Sampling methodology consisted of three techniques: visual surveys, baited shrimp pitfall traps, and ethylene glycol pitfall traps. Preliminary comparisons were made between trapping methods used during the original wēkiu bug study conducted by Howarth and Stone (1982), and more recent trapping methods devised by Howarth et al. (1999). All habitat and substrate types found in the Mauna Kea alpine zones (as defined by Howarth et al. 1999) were sampled during the current study. Sampling began on 22 April 2002 and continued through 1 May 2002. Sampling was discontinued on 1 May 2002 because heavy snows that started on 29 April (and continued through 30 April 2002) made conditions difficult for effective wēkiu bug trapping. Testing of pitfall trap efficiency occurred subsequently in September 2002.

The following sections describe the three sampling methods used during the current study. Individual pitfall trap locations were recorded with GPS (NAD 83 datum), as were locations where wēkiu bugs were visually observed during the study.

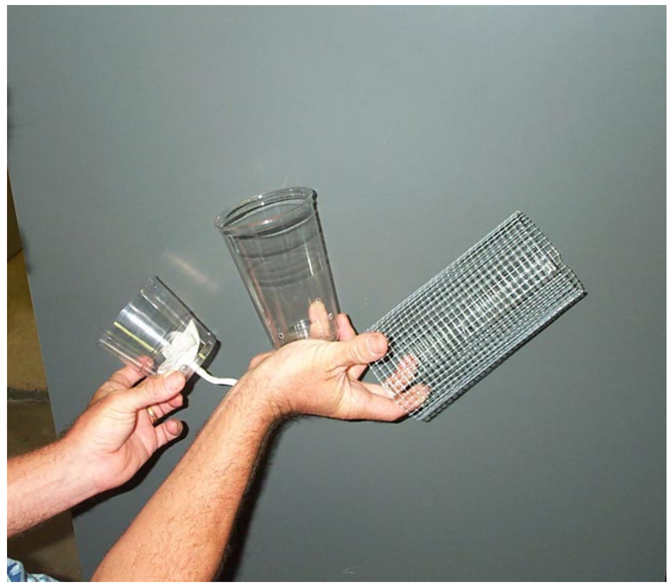
Visual Surveys

This method primarily involved turning over rocks and visually assessing the presence or absence of wēkiu bugs. GPS recordings were made at sites where wēkiu bugs were observed, along with notes on substrate and aeolian drift present. Although not the primary sampling method, visual observations provided valuable presence/absence data regarding the distribution of wēkiu bugs throughout the study area. Qualitative observations on the amount of aeolian drift available for wēkiu bugs as prey were also made during visual observations, and when searching for locations to place pitfall traps. Researchers also conducted visual searches and randomly turned over rocks during the long hikes required to access the outer alpine areas of Mauna Kea.

Shrimp Pitfall Traps

Shrimp pitfall traps were similar to those used in the Howarth et al. (1999) study, and consisted of two differently sized, clear plastic Solo® Big Drink cups inserted into a fine-wire mesh cage constructed to protect the plastic cups from the surrounding rocks. Our shrimp pitfall trap design was identical to pitfall traps used by Pacific Analytics (2002) during summit area monitoring they conducted at approximately the same time as our study. The protective wire mesh cage measured 7 in (17.8 cm) high and 3.5 in (8.9 cm) in diameter. The outer cup contained a 20 ounce (590 ml) Solo® TN20 cup with four drainage holes placed one inch above the cup's bottom to provide drainage for the water reservoir. Next, a 16-ounce (473 ml) Solo® TP16 cup was cut to 3 in (7.6 cm) in height, and a 0.25 in (0.64 cm) hole was made in the bottom center of the cup.

Once a suitable area was found, the wire cage was buried flush and level with the ground. If necessary, fine ash was added around the rim of the pitfall trap to maximize the percent of the rim flush with the substrate. One coffee filter was placed in the hole of the smaller plastic cup to serve as wick to keep the rehydrated shrimp pieces from drying out. Three to four small pebbles were placed inside the smaller inner plastic cup, then several (3-4) small pieces of previously dried shrimp (that had been rehydrated overnight) were placed on top of the rocks inside the smaller inner cup, and a 1 in (2.5 cm) layer of Lee Kum Kee® shrimp paste was applied inside the inner rim of this smaller cup, and also on top of some of the rocks in the bottom of the cup. Next, water was poured up to the drainage holes of the larger plastic cup and the coffee filter was checked to ensure that water was being wicked up to keep the shrimp from drying. A nearby rock that would serve as cap for the shrimp trap also had some shrimp paste applied to the bottom side, and this rock was then placed over the buried trap. Traps were marked and numbered with fluorescent irrigation flag marker and GPS recordings were taken at each individual trap location.



Shrimp pitfall traps were checked and the smaller insert Solo® cups were replaced when the traps were rebaited. The small plastic insert cups had to be replaced after three days because windblown dust would scratch the inner surface of the plastic cup, providing wēkiu bugs the necessary traction to escape. However, attempts were made to make the traps attractive enough so wēkiu bugs would stay if the sandblasting and grit caused the inside of the plastic cups to became abraded. We did this by providing shelter (rocks), food (shrimp/shrimp paste), and thermal protection (digging the traps in deeply).

Shrimp pitfall traps ran for three nights before being disturbed and checked for wēkiu bugs. Moisture of shrimp baits was noted, along with the amount of water remaining in the larger plastic cup. All live wēkiu bugs were recorded and released, with all dead wēkiu bugs preserved in 95% ethanol for future research.

Additionally, notes were made on other arthropods found in the traps, especially the large lycosid spider and the smaller introduced spiders. After checking for wēkiu bugs and lycosids, traps were rebaited and water levels were checked and refilled.

Ethylene Glycol Pitfall Traps

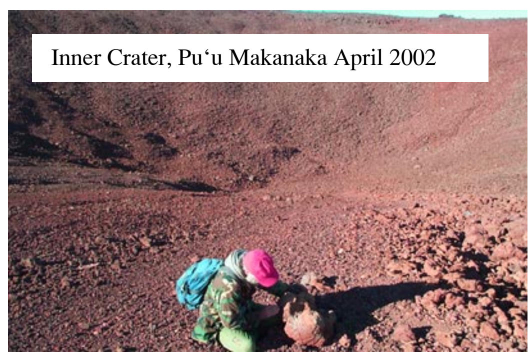
These pitfall traps were substantially similar to traps used during the original Howarth and Stone (1982) study. Traps were constructed from 3.5 in (8.9 cm) long, 0.25 in (0.64 cm) diameter gray PVC piping, with an inner diameter of 2 and 7/8 in (7.3 cm) into which a 5 oz (140 ml) clear, plastic medical sampler cup could be firmly inserted. The traps were buried in the desired sample substrate, with the top rim of the PVC pipe flush with the ground. If necessary, fine ash was added around the rim of the pitfall trap to maximize the percent of the rim flush with the substrate. One inch of ethylene glycol was then poured into plastic medical cup placed in the pitfall trap, and an approximate 1 in (2.5 cm) layer of Lee Kum Kee® shrimp paste was applied to the upper most portion of the inserted plastic cup. As an additional attractant, shrimp paste was applied to the underside of a nearby rock large enough to cover the pitfall trap, and the rock was then placed as a cap over the trap. Traps were then marked and numbered with fluorescent irrigation flag marker and GPS recordings were taken at each individual trap location. Ethylene glycol traps ran for three nights prior to removal, with all arthropods collected within these traps preserved in ethanol and transported to the Bishop Museum.

Protocol for Testing Comparative Shrimp and Ethylene Glycol Pitfall Trap Efficiency

At a meeting held at the Bishop Museum on 19 March 2002 with representatives from the Hawaii Biological Survey, University of Hawaii, U.S. Fish and Wildlife Service, Hawaii Natural Areas Reserve System, and Pacific Analytics in attendance, it was agreed that it was important to test the efficiency of two different types of pitfall traps that had been used for wēkiu bug surveys. The main question of interest was "is there a significant difference in capture rate between the shrimp pitfall traps developed and used in the 1998 survey and the ethylene glycol traps used during the 1982 study"? At this meeting it was agreed that the comparison would be done in suitable habitat on Puʻu Hau Kea, which was known to have a large population of wēkiu bugs (Polhemus 2001).

The following protocol was used for this test of pitfall trapping efficiency. To ensure a large enough sample size of collected wēkiu bugs, optimal areas (Howarth and Stone 1982, Polhemus 2001) were sampled in and around the upper rim of Puʻu Hau Kea. Eight shrimp pitfall and eight ethylene glycol traps were set in a pairwise fashion in windblown areas near the upper rim of Puʻu Hau Kea. An area of suitable wēkiu bug habitat with similar substrate characteristics and exposure was located, and two trap positions about four meters apart were randomly selected. A coin toss then determined which trap type was set in each position; i.e., the coin toss determined the position of one trap type, then the different trap type was set at the other position.

Notes on trap placement, substrate type, temperature, etc., were recorded on standard data forms. Baiting then followed the protocols used for each pitfall trap type as described in the previous section. Each pitfall trap was set as flush as possible with the substrate surface, and if necessary fine ash was added next to the trap rim to maximize the percent of the rim flush with the substrate. Each trap pair was set at least 30 m apart. After the traps were set, additional areas were inspected visually as a qualitative measure of bug activity. Seeing numerous active bugs on the surface (matching the 1982 observations) or not seeing any bugs in several man-hours of search (matching the 1998 situation) aided in assessing the trap results.


Inner Crater, Puʻu Makanaka April 2002

The next day after the traps were set, each ethylene glycol trap was carefully checked but not removed or disturbed to assess trap effectiveness. If an obvious difference in catch had been noted, (e.g., hundreds of wēkiu bugs observed in the ethylene glycol traps), then both types of pitfall traps would have then been pulled to preclude excessive wēkiu bug mortality. To ensure standardized sampling with previous pitfall trapping, both pairs of traps were then left undisturbed until after they had been in place for three nights.

RESULTS

The study period included 14 field days in April, May, and September 2002. A total of 47 wēkiu bugs were collected during 398 total trap days of both shrimp pitfall and ethylene glycol trapping (Table 3). One individual wēkiu bug was observed in visual surveys at Pu‘u Māhoe during the April/May 2002 portion of the study, while two wēkiu bugs were collected or observed during visual surveys in September 2002 on Pu‘u Hau Kea. An additional two wēkiu bugs were observed near shrimp paste on the caprock at Pu‘u Hau Kea (Table 4) during the pitfall trapping efficiency test in September 2002. Table 3 summarizes trap locations by cinder cone, elevation, numbers of wēkiu bugs either observed or collected, and sampling effort or the amount of trap days for each sampled cinder cone. Total trap days are defined as the number of nights each shrimp or ethylene glycol pitfall trap was running.

One of the most significant findings of this study was the collection of one wēkiu bug at the unnamed Pu‘u near the VLBA observatory, at 11,715 ft (3,572 m) elevation. This is the lowest elevation that wēkiu bugs have yet been collected or observed from, and indicates their elevational distribution on Mauna Kea is considerably wider than previously reported. Another low elevation record of an individual wēkiu bug came from 11,920 ft (3,634 m) at the Pu‘u Makanaka cinder cone. Even though wēkiu bugs were recovered these from lower elevations, they were uncommon there, with only one specimen taken from each cone during a total 95 aggregate trap days at the two cones (Table 3). Excluding Pu‘u Hau Kea, which is known to have some of the highest wēkiu bug capture rates on the mountain (Polhemus 2001), and Pu‘u Poepoe, low numbers of wēkiu bugs were collected throughout the eastern and western portions of the study area. Of the cinder cone alpine areas examined that were away from the core wēkiu bug habitat (the summit area where the astronomical observatories are located), the greatest wēkiu bug pitfall trap captures during this study were obtained at Pu‘u Poepoe. However, the wēkiu bugs at Pu‘u Poepoe were found only within a narrow band of elevation ranging from 12,500–12,580 ft (3,811–3,835 m).

Wēkiu bugs were found to be concentrated near the rims of all alpine cinder cones sampled in this study, similar to the situation reported on Pu‘u Hau Kea by Polhemus (2001). As noted previously, traps for wēkiu bugs were set as a transect starting at the base of each cinder cone with traps being evenly spaced going up, over, and into the bottom of each cone. An examination of wēkiu bug catch rates along these elevational transects is of great interest because of the broad range of habitats sampled. With only one exception, the insects were captured near the inner and outer rim of each cone, generally within approximately 150 ft (50 m) vertical elevation of each individual cinder cone lip (Table 5). Puʻu Makanaka was the one notable exception. An individual wēkiu bug was collected at pitfall Trap #2, which was the second to lowest in the transect of 15 pitfall traps up this large cinder cone.

At Puʻu Ala and the unnamed Puʻu near the VLBA observatory, shrimp pitfall traps were rebaited and allowed to run for longer times than in other sampled areas (Table 7). No additional wēkiu bugs were collected in either of these cinder cones after rebaiting. Two possibilities may explain this observed lack of additional captures after rebaiting. First, weather deteriorated during the last few days of the study in late April, and the snow and freezing rain may have led to reduced wēkiu bug activity. The other plausible explanation is that these two cinder cones contain only marginal wēkiu bug habitat, and thus have low numbers of these insects in these areas as reflected by the low total numbers captured in the traps.

Table 3. Summary of sample effort and results of Mauna Kea cinder cones surveyed for Wēkiu bugs using both shrimp pitfall and ethylene glycol pitfall traps in April/May 2002, and September 2002.

Cinder Cone	Highest Elevation	Total Traps	Wēkiu bugs in traps	Wēkiu bugs observed only	Trap Dates	Total Trap Days[3]
Puʻu Hau Kea	13,441 ft	16	9	4	17-20 Sept	48
Puʻu Māhoe	13,154 ft	-	n/a	1	24 Apr	-
Puʻu Poepoe	12,679 ft	10	33	0	26-29 Apr	30
Puʻu Ala	12,610 ft	9	3	0	24 Apr-May 1	63
Puʻu Makanaka	12,414 ft	15	1	0	22-24 Apr	30
Unnamed Puʻu 1W[1]	12,100 ft	10	0	0	22-28 Apr	60
Unnamed Puʻu near VLBA	11,920 ft	13	1	0	25-30 Apr	65
Transit Area[2]	11,850 ft	3	0	0	22-28 Apr	30
Puʻu Keonehehe'e	11,600 ft	10	0	0	22-28 Apr	60
Unnamed Puʻu 2W[3]	11,600 ft	2	0	0	22-28 Apr	12
Totals		88	47	5		398

[1]Located at 19°47'34.6"N, 155°27'42.8"W; [2]Located at 19°47'52.7"N, 155°26'35.4"W; [3]Located at 19°47'08.5"N 155°27'34.0"W; [3]Trap days = total nights x total traps per cinder cone

Ethylene Glycol versus Shrimp Pitfall Trapping Test

The results of the test between shrimp pitfall traps and ethylene glycol traps on Puʻu Hau Kea in September 2002 were statistically even (Table 4), with 4 wēkiu bugs collected in the ethylene glycol pitfall traps versus

5 collected in the shrimp pitfall traps. Statistical tests are obviously not needed to conclude there were no significant differences in wēkiu bug catch rates between these two types of traps. By contrast, far greater numbers of wēkiu bugs were captured in June 2001, with 473 wēkiu bugs (Polhemus 2001) collected on Pu'u Hau Kea in exactly the same trapping localities as compared to nine wēkiu bugs in September 2002, and with 8 fewer traps than used during the present study. During the preliminary June 2001 Polhemus study, only ethylene glycol traps were used. Seasonal abiotic factors such as air temperature, humidity, soil moisture, and substrate temperature were quite different in September 2002 than in June 2001, and undoubtedly influenced wēkiu bug activity and likely accounted for the wide disparity in results between 2001 and 2002 on Pu'u Hau Kea. Additionally, a massive aeolian drift event of the small seed bug *Nysius palor* Ashlock from the lower grasslands into the Mauna Kea alpine zones may have also had some influence on wēkiu bug activity (see Discussion section).

Table 4. Summary of results of Pu'u Hau Kea paired ethylene glycol and shrimp pitfall traps for each trap used during surveys for wēkiu bugs during September 2002.

Trap Type	Trap #	# wēkiu bugs collected in trap	# wēkiu bugs observed on caprock[1]	wēkiu Mortality (shrimp traps)
Ethylene Glycol	1 A	0	0	n/a
Shrimp Pitfall	1 B	0	1	0
Ethylene Glycol	2 A	0	0	n/a
Shrimp Pitfall	2 B	0	1	0
Ethylene Glycol	3 A	0	0	n/a
Shrimp Pitfall	3 B	1	0	1
Ethylene Glycol	4 A	1	0	n/a
Shrimp Pitfall	4 B	1	0	1
Ethylene Glycol	5 A	2	0	n/a
Shrimp Pitfall	5 B	0	0	0
Ethylene Glycol	6 A	0	0	n/a
Shrimp Pitfall	6 B	0	0	0
Ethylene Glycol	7 A	0	0	n/a
Shrimp Pitfall	7 B	0	0	0
Ethylene Glycol	8 A	1	0	n/a
Shrimp Pitfall	8 B	3	0	0
Total Glycol		4	0	n/a
Total Shrimp		5	2	2

[1] Wēkiu bugs not collected within trap, but observed near underneath caprock near shrimp paste

Wēkiu Bug and Mortality and Daily Catch Rates in Pitfall Traps

Although originally designed to prevent wēkiu bug mortality during sampling, shrimp pitfall traps did not prove to be an effective method for the live capture and release of wēkiu bugs. Twenty-four of 43 insects captured in such traps during this study were found dead or dying, for a mortality rate of 56% (Table 5). Mortality appeared to be primarily caused when wēkiu bugs became stuck to the shrimp paste in the interior cup section of these shrimp pitfall traps. During the wet and moist conditions brought on by snow or rain, the Kum Lum Lee® shrimp paste becomes wet and sticky, so that wēkiu bugs become ensnared and weakened, subsequently dying from exposure to low night-time temperatures. Those wēkiu bugs that remain alive in the shrimp pitfall traps are generally found in the shelter of the small gravel or pebbles placed in the bottom of the plastic cups.

Table 5. Complete results, including wēkiu bug mortalities, of shrimp pitfall trap results for each trap that captured wēkiu bugs during April-May 2002, and September 2002 (see Table 1 for each trap GPS coordinates). Only traps collecting wēkiu bugs were included in this table.

Cinder Cone	Trap #	Trap Elevation	Trap Run Dates[1]	# wēkiu collected	wēkiu mortality
Pu‘u Hau Kea	3B	13,437 ft	17-20 Sept	1	1
Pu‘u Hau Kea	4B	13,441 ft	17-20 Sept	1	1
Pu‘u Hau Kea	8B	13,407 ft	17-20 Sept	3	0
Pu‘u Ala	4	12,270 ft	24-27 Apr	1	1
Pu‘u Ala	5	12,390 ft	24-27 Apr	1	0
Pu‘u Ala	7	12,350 ft	24-27 Apr	1	0
Pu‘u Makanaka	2	11,920 ft	22-24 Apr	1	0
Pu‘u Poepoe	4	12,500 ft	26-29 Apr	4	3
Pu‘u Poepoe	5	12,560 ft	26-29 Apr	9	5
Pu‘u Poepoe	6	12,580 ft	26-29 Apr	8	2
Pu‘u Poepoe	7	12,560 ft	26-29 Apr	3	3
Pu‘u Poepoe	8	12,510 ft	26-29 Apr	6	6
Pu‘u Poepoe	9	12,540 ft	26-29 Apr	2	1
Pu‘u Poepoe	10	12,560 ft	26-29 Apr	1	1
Unnamed Pu‘u near VLBA	3	11,715 ft	25-28 Apr	1	0
Totals				43	24

[1]This date indicates the total time a trap had run when the first wēkiu bug was caught, although traps ran longer, no additional wēkiu bugs were captured in the traps.

With the exception of Pu‘u Poepoe, daily wēkiu bug capture rates using a three-day standardized average were low for all cinder cones examined during this study. When only cinder cones with wēkiu bugs present were averaged (Table 6 and Table 7), the three-day capture rate ranged from 0.04 to 2.5 wēkiu bugs/trap using shrimp pitfall traps. In June 2001, by contrast, a capture rate of 47.3 wēkiu bugs/trap for four days of trapping was obtained at the summit of Pu‘u Hau Kea (Polhemus 2001). The trap results observed on Pu‘u Hau Kea for September 2002 are likely a result of seasonal differences due to changes in abiotic factors such as increased temperatures and decreased soil moisture, or perhaps the mass windblown migration of *Nysius palor*. Overall, a pattern of an increasing wēkiu bug capture as elevation increases was apparent during this study (Table 6), particularly when the high wēkiu bug captures from Pu‘u Hau Kea in June 2001 (Polhemus 2001) were taken into account.

Table 6. Summary of mean wēkiu bugs/trap for three days of trapping using shrimp pitfall traps, all other pu’us had 0 wēkiu bugs.

Cinder Cone	Maximum Elevation	Mean # trap/3 days	Std. Dev.
Pu‘u Hau Kea – June 2001[1]	13,441 ft	47.3	58.6
Pu‘u Hau Kea – September 2002	13,441 ft	0.63	1.1
Pu‘u Poepoe – April 2002	12,679 ft	2.5	3.3
Pu‘u Ala – April 2002	12,610 ft	0.17	0.38
Pu‘u Makanaka[2]- April 2002	12,414 ft	0.07	0.28
Unnamed Pu‘u near VLBA[3]- April 2002	11,920 ft	0.04	0.19

[1]Ethylene glycol traps used for four days[2]Traps on Pu‘u Makanaka ran for two nights instead of three; [3]Traps ran for 5 nights instead of 6

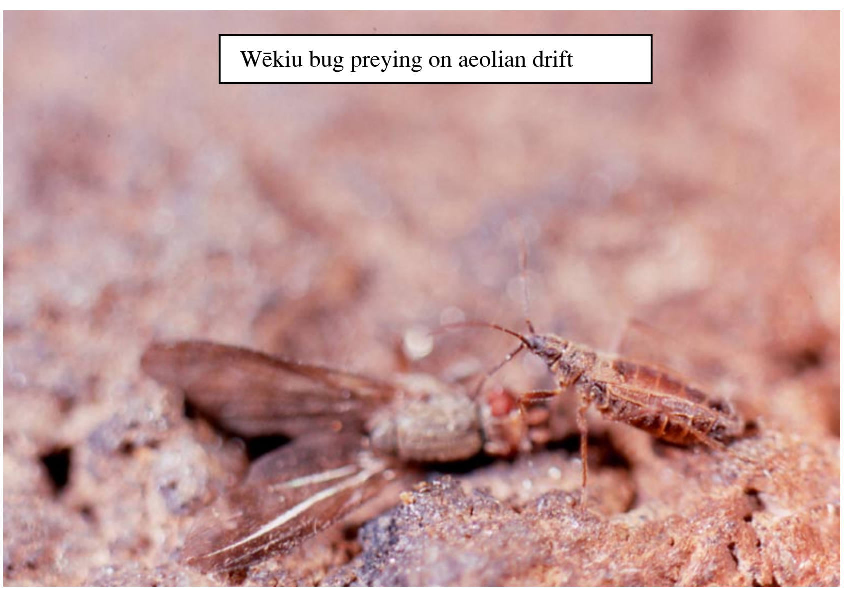


Table 7. Total wēkiu bug numbers in each shrimp pitfall trap for every three days.

Pu‘u Hau Kea	17-20 Sept
Trap 1	0
Trap 2	0
Trap 3	1
Trap 4	1
Trap 5	0
Trap 6	0
Trap 7	0
Trap 8	3
Totals:	5

Pu‘u Ala	24-27 Apr	27 Apr-1 May
Trap 1	0	0
Trap 2	0	0
Trap 3	0	0
Trap 4	1	0
Trap 5	1	0
Trap 6	0	0
Trap 7	1	0
Trap 8	0	0
Trap 9	0	0
Totals:	3	0

Unnamed Pu‘u near VLBA	25-28 Apr	28-30 Apr
Trap 1	0	0
Trap 2	0	0
Trap 3	1	0
Trap 4	0	0
Trap 5	0	0
Trap 6	0	0
Trap 7	0	0
Trap 8	0	0
Trap 9	0	0
Trap 10	0	0
Trap 11	0	0
Trap 12	0	0
Trap 13	0	0
Totals	1	0

Pu‘u Poepoe	26-29 Apr
Trap 1	0
Trap 2	0
Trap 3	0
Trap 4	4
Trap 5	9
Trap 6	8
Trap 7	3
Trap 8	6
Trap 9	2
Trap 10	1
Trap 11	0
Trap 12	0
Trap 13	0
Totals:	33

Pu‘u Makanaka	Apr 22-24
Trap 1	0
Trap 2	1
Trap 3	0
Trap 4	0
Trap 5	0
Trap 6	0
Trap 7	0
Trap 8	0
Trap 9	0
Trap 10	0
Trap 11	0
Trap 12	0
Trap 13	0
Trap 14	0
Trap 15	0

Lygaeidae Relatives of Wēkiu Bugs

Of particular concern in evaluating the pitfall trapping comparisons conducted on Pu‘u Hau Kea were the large numbers of *Nysius palor* blown onto the summit area of Mauna Kea during September 2002. It was therefore of interest to ascertain the source areas for these itinerant aeolian seed eating lygaeids, which presumably came from lower elevations on the mountain. To address this, surveys were undertaken of lygaeid assemblages at varying elevations on Mauna Kea during September and October 2002.

GPS readings (NAD 83 datum) for each collecting site are as follows:

- Pu‘u Ko‘ohi, 6,300 ft (1,920 m), 5 October, 2002, 19°44'44.1"N, 155°30'11.4"W
- Hale Pohaku, 9000 ft (2,744 m), 18-19 September 2002, 19°45'30.5"N, 155°27'21.1"W
- Mauna Kea summit road, 10,000 ft (3,049 m), 18 September 2002, 19°46'13.6"N, 155°27'33.2"W
- Mauna Kea, summit road, 10,200 ft (3,110 m); 18 September 2002, 19°46'15.3"N, 155°27'09.9"W
- Mauna Kea summit road, 11,500 ft. (3,500 m), 17 September 2002, 19°47'44.5"N, 155°29'03.1"W These results are provided in Table 8.

Although *Nysius palor* was found in all areas of Mauna Kea surveyed, it was much less common in the zone from Hale Pohaku at 9,000 ft (2,744 m) to the top of the subalpine shrubland at 11,500 ft (3,500 m). By contrast, this seedbug was common at the lower elevation Pu‘u Ko‘ohi (6,300 ft/1,920 m), and was most common at the summit of Pu’u Hau Kea at 13,441 ft (4,098 m).


Nysius palor congregation on Pu‘u Hau Kea

Extremely high densities of *Nysius palor*, were found throughout Mauna Kea alpine zones during the pitfall trapping test in September 2002. It is difficult to quantify how abundant *N. palor* was around the summit area, but Hawaii Biological Survey staff working on the Pu‘u Hau Kea summit in September 2002 were covered with a thick layer of these insects and at times breathing was difficult because of their high densities. *Nysius palor* were so abundant they often flew into researchers’ eyes, at times causing vision problems, and generally rendering work on the summit of Pu‘u Hau Kea uncomfortable, especially in areas sheltered from the wind. Although less common than *N. palor*, the introduced *Geocoris pallens* Stål was also abundant around the summit area. Evidence of the abundance of the larger (compared to *Nysius palor*) *Geocoris pallens* was the frequent discomfort caused when this species' sharp rostrum would probe the skin of researchers while on the summit of Pu'u Hau Kea. No similar massive aeolian drift events for these two seedbug species were observed during sampling of Mauna Kea alpine zones in either July 2001 or April/May 2002 (Howarth and Stone 1982, Howarth et al. 1999, Polhemus 2001).

Table 8. Lygaeidae wēkiu bug relatives collected or observed during surveys conducted in April, May, and September-October 2002.

Taxon	Pu'u Ko'ohi - 6300 ft	Hale Pohaku – 9000 ft	Mauna Kea Summit Road – 10,000-10,200 ft	Mauna Kea Summit Road – 11,200 ft	Mauna Kea Summit Road – 13,441 ft	Host Plant
Heteroptera						
Lygaeidae						
Geocoris pallens Stål				X	X	uncommon on *Hypocaeris radicata*, uncommon on rocks and cinders
Nysius coenosulus Stål	X	X	X	X		*Chamaesyce olowaluana, Chenopodium oahuense,* uncommon on *Geranium cuneatum*
Nysius communis Usinger	X					*Bidens menziesii*
Nysius kinbergi Usinger	X		X			*Gnaphalium sandwicensium*
Nysius lichenicola Ashlock			X			1 specimen only, on *Dubautia ciliolata*
Nysius nemorivagus White	X					*Bidens menziesii*
Nysius palor Ashlock	X	X	X	X	X	common on rocks and cinders, *Gnaphalium sandwicensium*, *Sophora chrysophylla*, Dubautia ciliolata, *Geranium cuneatum*, *Hypochaeris radicata*
Nesius (Icteronysius) ochriasis mauliceps (Usinger)		X				*Sophora chrysophylla*
Nysius terrestris Usinger	X	X				*Chamaesyce olowaluana, Chenopodium oahuense*
Miridae						
Lygys elisus Van Duzee	X					*Gnaphalium sandwicensium*
Taylorilygus apicalis (Fieber)	X					*Bidens menziesii*
Rhopalidae						
Liorhyssus hyalinus (Fabricius)	X					*Chamaesyce olowaluana*

These bugs appear to be aeolian drift from lower elevations. For example, green and wet conditions in the lower Hawaii Belt Road area (4,000 ft and higher elevations) had led to vigorous grass growth, providing an ample food source after years of drought. This in turn led to a large pulse of aeolian drift around the Mauna Kea alpine zones that primarily included *Nysius palor*. Within three days, a layer of these dead insects ranging from 0.25-0.5 in (0.6-1.3 cm) in depth accumulated underneath some of the pitfall traps, providing a significant potential food source for wēkiu bugs.

DISCUSSION

Habitat Use and Ecological Implications

Based on 398 trap days and the sampling of 10 discrete cinder cone areas during this study, we conclude that wēkiu bugs are infrequently collected except in localized areas of Mauna Kea. In general, wēkiu bugs are restricted to the rims and inner craters of each alpine cone where they occur and, with only one exception, were found within 150 ft (50 m) of the peak elevation of each cone. Additionally, seasonality (weather, abiotic factors, substrate moisture) appears to play an important role in wēkiu bug catch rates, with fewer captures on Pu'u Hau Kea in September 2002 as than in June 2001.

Previous studies (Howarth and Stone 1982, Howarth et al. 1999) have found the most favored wēkiu bug habitat included tephra ridges and slopes with scoria or lapilli deposits, and talus slopes and highly fractured rock substrates (Type 2 and Type 5 habitats, respectively, in Howarth et al. 1999). Howarth et al. (1999) found evidence that wēkiu bugs were more likely to occur on the highest summit cones than on those in the lower, outlying alpine zone areas such as at Pu'u Makanaka. The results of the current study confirm these findings, and also provide substantial information regarding the preference of wēkiu bugs for the highest rim regions of each cinder cone where they occur.

Along with the upper elevation cinder cone rim areas facing prevailing winds, substrate characteristics are one of the most important factors influencing wēkiu bug distribution. Howarth and Stone (1982) found that wēkiu bugs were most common in loose cinders and tephra rocks where the interstitial spaces were large enough to allow the insects to migrate downward in times of inclement weather or nighttime to find moisture and shelter. An examination of the substrate characteristics from areas with the greatest wēkiu bug captures during this study corroborate these findings. Pu'u Poepoe and Pu'u Hau Kea were the two cinder cones with the greatest wēkiu bug captures during this study; they exhibited similar substrates, and wēkiu bugs were concentrated along the highest crater rim areas. For example, Trap 5 on Pu'u Poepoe, which captured 9 wēkiu bugs, was located at the very summit towards the outer edge of the crater, and was in a windy and exposed area. Substrate at Trap 5 at the surface consisted of mostly small cobbles 1.5-2.5 inches (4-6 cm) in diameter. This cobble layer was 4-5 in (10 cm) thick and overlaid a fine reddish ash; the cinders in this area were noted to be loose and have airspaces between them.

Pu'u Hau Kea substrates are also of great importance to understanding wēkiu bug habitat requirements because of the very high number of captures from the Polhemus (2001) study with the Polhemus Trap 6 set at the outer rim having 148 wēkiu bug captures (Trap 6 in the Polhemus study corresponds to the identical location of Trap 2 in the current study). Substrate conditions at Trap 6 (Polhemus 2001), which lies in an area of periglacial pavement, consisted of 70% gravels (0.5-1 inch/1.3-2.5 cm) and 30% cobbles (1-4 inches/2.5-10 cm) at the surface, loosely packed. Two inches down, the substrate consisted of 50% sand and 25% gravels and 25% cobbles, with the sand dry until at four inches (10.2 cm) in depth where the sand became moist. The traps that contained the greatest numbers of wēkiu bugs at both Pu'u Hau Kea and Pu'u Poepoe have similarities in that gravels and small cobbles were predominant and loosely packed. Either larger and smaller surface substrates seem to be unsuitable as prime wēkiu bug habitat, and both prime habitat areas were within 20 ft (6 m) of the peak elevation of the cinder cone.

The high densities of the lygaeid seed bug *Nysius palor* may have been one of several confounding factors impacting the trapping efficiency test on the summit of Pu'u Hau Kea in September 2002. Massive aeolian drift events of seedbugs have also occurred in other Hawaiian alpine areas such as in Haleakalā National Park (Beardsley 1966) so this was not a unique event. It is possible that wēkiu bugs were satiated from the large amounts of freshly dead *N. palor* that covered both the tops and bottoms of the cinder substrate at the cinder cone summit, or abiotic factors such as decreased soil moisture may have also affected activity. Wēkiu bugs have physogastric abdomens that expand when full (Ashlock and Gagné 1983). Thus, it was possible to observe that the two wēkiu bugs found on the summit of Pu'u Hau Kea by SLM during visual surveys (one adult and one immature) in fact did have extended abdomens, indicating they had recently eaten; they were also collected around a large pile of dead and dying *N. palor*. Although this evidence is only anecdotal, it is possible that few wēkiu bugs in September 2002 were collected because they were completely satiated, and had little reason to forage in the pitfall traps when great amounts of freshly dead *N. palor* were available. More research is needed to determine the causality of these observed seasonal fluctuations in wēkiu bug activity.

Surface temperatures were measured and provided additional data regarding the tolerance of wēkiu bugs to elevated summer temperatures. These temperatures ranged from a low of 32-40 °F (0-4 °C) during the snows in late April 2002, to much higher, 106°F (41.1 °C), in September 2002, and this may have been a major factor limiting wēkiu bug activity during April. During a period of snow and cold weather no wēkiu bug recaptures were made in the only two traplines, Pu‘u Ala and the unnamed Pu‘u near the VLBA observatory, that were rebaited in this study (Table 7). Although cold weather was most likely the factor limiting wēkiu bug activity and any recaptures in traps that were rebaited in the spring of 2002, it is also apparent that wēkiu bugs are quite hardy and can withstand a broad range of climatic variables. Mid-day surface temperatures in September 2002 at Pu‘u Hau Kea were recorded up to 106 °F (41.1 °C) at Trap 5, a trap that collected 2 wēkiu bugs, and subsurface temperatures 3 in (7.6 cm) down into the substrate were recorded at 75 °F (24 °C) at Trap 5. It is known that antifreeze properties found in the blood of wēkiu bugs (Duman and Montgomery 1991) allow them to inhabit the alpine zone of Mauna Kea.

Our finding that wēkiu bugs are active in areas with elevated temperatures directly contradicts the previously unsubstantiated claim also mentioned by Brenner (2002: 5) that "Wēkiu bugs are very sensitive to heat and will die within minutes if held in one's hand". We tested this hypothesis by holding a wēkiu bug in one of the author's hands (SLM) for over one hour in a room at 70 °F (21 °C). Next, the same wēkiu bug was placed in a snap-cap vial in the warm pants pocket of SLM for over 6 hours.

Comparisons to Pacific Analytics Quarterly Monitoring

Sampling the alpine zone of Mauna Kea in April/May 2002 was coordinated with Pacific Analytics (Pacific Analytics 2002a) wēkiu bug monitoring. Our study used identical collecting techniques for the shrimp pitfall traps, and both studies were conducted within days of each other. Reported results from Pacific Analytics (2002) indicated that an average of 0.03 wēkiu bugs/3 days were captured at Pu‘u Wēkiu, while 10.26 wēkiu bugs/3 days were captured at Pu‘u Hau Oki for the month of May 2002. A careful examination of Pacific Analytics data as reported on page 14 of the June 2002 quarterly report (Pacific Analytics 2002) indicates a statistical error was made when these densities were calculated. There were actually 8 total trap periods (as reported on page 13, first sentence of this Pacific Analytics report), but only 7 trap periods were used to calculate average numbers on Table 3 of that report, because one sampling period was missed because of bad weather. The correct average wēkiu bug catch rate on Puʻu Hau Oki for the month of May should be calculated as follows:

$$\frac{\text{359 wēkiu bugs/8 three-day trap periods}}{\text{5 traps}} = \text{8.98 wēkiu bugs/3 trap–days on Puʻu Hau Oki}$$

Because only one wēkiu bug was captured on Puʻu Wēkiu for the entire month of May by Pacific Analytics (2002), the calculation for wēkiu bugs per 3–day captures in May 2002 was not affected by this statistical error. Although wēkiu bug captures were generally low during the current Bishop Museum study, Puʻu Poepoe exhibited a capture rate of 2.5 wēkiu bugs per 3–days in April 2002, which is biologically similar to the corrected catch rate from Puʻu Hau Oki of 9.0 wēkiu bugs per 3–days of trapping throughout May 2002. However, as wēkiu bugs were not being marked after being released during monitoring by Pacific Analytics, it is not valid to conclude anything other than maximum capture rates/3 days. This is because all captures (except for mortalities) could have been collected in previous sampling periods. Unfortunately, no mortality data are provided by Pacific Analytics, so there is the possibility that virtually all later captures were recaptured wēkiu bugs.

We also have concerns with Puʻu Wēkiu being used as a control site in the Pacific Analytics study. By definition, a control site is an undisturbed area comparable to the experimental area in question. Puʻu Wēkiu currently is highly disturbed by the hiking trails that have greatly compacted the soil around the crater rim, especially where the Pacific Analytics (2002) pitfall traps are placed. This impacted soil disturbance is obvious and can be seen from great distances. The area of impacted soil in the hiking trail around the rim of Puʻu Wēkiu is a relatively new development, and had not yet occurred during the first Howarth and Stone (1982) study. Previous studies (Howarth and Stone 1982, Gagné and Howarth 1982, Howarth et al. 1999), and the current study have provided data showing the importance of the upper cinder cone rim areas as wēkiu bug habitat. It is scientifically impossible to use one disturbed control area (Puʻu Wēkiu), compare it to another disturbed area (Puʻu Hau Oki) and be able to draw any valid conclusions. Puʻu Hau Kea is the obvious and logical choice as a control area, in that it lies at a similar elevation, and has had much less disturbance when compared to any other summit cone. However, Pu‘u Hau Kea should be treated with great care because it is currently the last major unimpacted summit cone, and disturbance on this cone should be kept to a minimum.

However, these errors are inconsequential when compared to the misleading statement by Pacific Analytics (2002: 32) “The wēkiu bug population has apparently increased since 1998”. As stated in Howarth et al. (1999: 20) pitfall trapping methods similar to those currently employed by Pacific Analytics measure arthropod **activity** and “... cannot be used as a measure of the population size”. This statement is extremely significant with respect to the Pacific Analytics report (2002) and renders any statements about population size invalid for two major reasons: 1) sampling was being done with replacements, (i.e., wēkiu bugs were released back into the environment) and 2) no mark-recapture or any other standardized population measuring analysis was being done. Because of the methods employed by both our study and the Pacific Analytics study, it can only be said that wēkiu bugs were more active on certain dates, in certain areas, or more captures were made in traps. An examination of Pacific Analytics data from May 2002 indicates that only wēkiu bug activity, and presence or absence, is being measured via their methodology. For example, at Pu‘u Hau Oki during the sampling period of 21-24 May 2002, 194 adult wēkiu bugs were captured while only 11 adults had been captured in the previous sampling period from 18-21 May 2002. Clearly the adult wēkiu bugs captured on 24 May 2002 did not result from spontaneous generation because the immature stage of the wēkiu bug requires at least several months or more to become adults. Instead, these captures were simply inactive adult wēkiu bugs that resided in the immediate area of those pitfall traps prior to the 24 May sampling period. For whatever reason, a variety of factors made the wēkiu bugs very active during the 24 May trapping period, but this in no way allows any estimation of population size, or increasing or decreasing population levels; it simply tells us the bugs were present and very active on that particular trapping date. It is invalid to compare population sizes found in the Howarth et al. (1999) study as compared to the Pacific Analytics (2002) study because neither study assessed populations, as Howarth et al. (1999) explicitly stated.

It is also statistically invalid for Pacific Analytics (2002) to compare arthropod trap rates between the 1982 Bishop Museum study (Howarth and Stone 1982) and the recent 2002 monitoring being conducted by Pacific Analytics (2002: 32). This is because the trapping protocols used during the 1982 study and more recent studies were different. The traps ran for several months in 1982, and the amount of dead insects accumulating in the traps during this nearly two-month period became an additional wēkiu bug attractant that was not present when traps are rebaited and emptied every three days, as was the protocol for more recent studies.

Ethylene Glycol Traps versus Shrimp Traps

Although there recently has been considerable controversy raised about the use of ethylene glycol traps during previous Bishop Museum wēkiu bug studies (Loos 2002), no published peer-reviewed scientific research has been found presenting evidence that rare Heteroptera can be over-collected. However, it is known that other more rare Hawaiian insects are resistant to intensive collecting. For example, Englund (2001) found that a native damselfly (*Megalagrion xanthomelas* Sélys-Longchamps) population restricted to 100 m of stream at Tripler Army Medical Center, O‘ahu suffered no ill-effects when substantial numbers (approximately 30%) of adults and immatures were transferred out of the watershed to a remote relocation site. This native Hawaiian damselfly population is orders of magnitude smaller than that of the wēkiu bug, inhabiting only 100 m of stream, far smaller than the area of habitat occupied by wēkiu bugs on Mauna Kea.

We found a 56% mortality rate for wēkiu bugs in the shrimp pitfall traps, which is nearly identical to the 55% wēkiu bug mortality found by Brenner et al. (1999: 5) when using these same traps. Although Pacific Analytics (2002: 4), stated “Nondestructive sampling is the best approach to monitoring rare and sensitive invertebrate species. Special live-traps were developed and tested during the 1997-1998 MKSR arthropod assessment…”, this was based on a trapping system that has a 55% mortality rate. Clearly, mortalities this high are not “nondestructive”, and the fact that the present Bishop Museum study obtained nearly identical mortality rates from these same shrimp pitfall traps further corroborates this.

Also, obtaining quantitative, comparable results with non-destructive shrimp pitfall traps appears to be problematic for the reasons that will be outlined below, especially when mark-recapture or other populations estimates are not used in conjunction with these traps. Pacific Analytics (2002: 4) stated that “nondestructive sampling is the best approach to monitoring rare and sensitive invertebrate species…”. This assumption may be wrong, even though on the surface it seems to be intuitively correct. The trapping areas consist of low numbers of small traps placed in large cones (> 100 ha) in alpine areas of Mauna Kea. For these pitfall trap transects to have caused a purported decline in wēkiu bugs, trapping efficiencies would have to be higher than that recorded for any other Heteropteran (true bug) control system known to exist. This is so because these traps likely impact only a small area of several hundred square meters, which is unlikely to measurably impact a potentially far larger overall wēkiu bug population throughout an individual cinder cone. Furthermore, there has never been simultaneous sampling of all cinder cones during any one wēkiu bug study. Because of this, it is difficult to imagine a scenario by which trapping conducted in either 1982 or June 2001, in relatively small portions of the large summit cone area of Mauna Kea, would have any measurable, long-term impacts on wēkiu bug populations as a whole.

Nondestructive sampling can also give biased results simply because the insect has the potential to 'walk out' of the trap. We observed many *Nysius palor* actively walk out of the shrimp pitfall traps during sampling on Pu'u Hau Kea in September 2002. This was especially pronounced in windblown areas of the rim (prime wēkiu bug habitats) where a fine grit often abraded the plastic cups providing a firmer grip for *Nysius palor* to escape. Climbing out of the shrimp pitfall traps has not yet been observed for wēkiu bugs captured in the field, but it is notable that we captured far fewer wēkiu bugs as compared to the many thousands of *Nysius palor* collected in September 2002, despite the demonstrated ability of the latter to exit the traps.

During dry periods the Lee Kum Kee® shrimp paste used in the pitfall traps would desicate and harden allowing the *Nysius palor* to walk out of the traps. Wēkiu bugs were prone to sticking to the sides of the shrimp pitfall traps when snow and rain made the paste sticky instead of a dry, hard surface. Not only did we observe a 56% mortality in the shrimp pitfall traps, but retaining wēkiu bugs in pitfall traps was likely directly influenced by the weather. Either they would stick to the shrimp paste (and die), or wēkiu bugs would have a hard surface on which they could crawl out and escape from the traps.

Large numbers of native lycosid (wolf) spiders were also collected in shrimp pitfall traps during spring 2002 sampling. We found evidence that these spiders had eaten wēkiu bugs and other arthropods in some of the traps. The spiders were observed to easily enter and exit the shrimp pitfall traps. This could lead to an under-reporting of the true numbers of wēkiu bugs in the traps, since the absence of lycosids when we checked the shrimp pitfall traps did not mean these spiders had not been in the trap,

Mauna Kea Wolf Spider

consumed their meal, and then left. In fact, there was ample evidence that lycosid spiders did exactly this. We commonly found legs and other lycosid spider parts in shrimp pitfall traps, indicating that at least two lycosid spiders had been in the trap, with one being eaten and the other spider leaving the trap. This was never a problem in the ethylene glycol traps, where the insects are not able to escape once in the pitfall trap, as mortalities are 100% in ethylene glycol traps.

CONCLUSIONS

Wēkiu bugs were infrequently collected during this study, and they were preferentially found along the upper rim area of each cinder cone they inhabit within the alpine zone of Mauna Kea. Despite 398 total trap-days of effort during this study, only 47 wēkiu bugs were captured. Wēkiu bugs were found at lower elevations than previously recorded, and were present in pitfall traps although they were only captured in low numbers, to elevations as low as 11,715 ft (3,572 m). A pronounced pattern was observed of wēkiu bugs becoming increasingly more common in pitfall traps as elevations increased, with the greatest numbers captured on Pu'u Hau Kea. At a maximum elevation of 13,441 ft (4098 m), Pu'u Hau Kea is the fourth highest cinder cone on the summit of Mauna Kea, and the only unimpacted (as defined by the lack of observatories and major foot trails) summit area cone. Seasonal differences related to a wide variety of factors such as substrate moisture, temperature, prey availability, and weather likely influence wēkiu bug activity and hence also capture rates. Substrate types are also of critical importance in determining if a particular habitat is suitable or not for wēkiu bugs. Both high and low temperatures appear to influence wēkiu bug activity, but field observations indicate some wēkiu bugs were active even when rock surface temperatures in midday were recorded up to 106 °F (41.1 °C) during this study.

Wēkiu bug and dead ladybug beetle

Suitable aeolian habitats used by the wēkiu bug and similarly flightless Mauna Loa alpine ‘a‘ā bug (*Nysius aa* Polhemus) are likely to be much more limited in total area on the Mauna Kea volcano than on Mauna Loa. Mauna Loa, being a shield volcano, has greater total areas above 11,715 ft (3,572 m) elevation, the lowest area where wēkiu bugs have been found. The gently sloping shield shape of Mauna Loa provides a more favorable thermal regime than do the steeper slopes of Mauna Kea that would be expected to have a greater thermal variance as evidenced by snowpacks lasting longer in the deep ‘a‘ā cracks of Mauna Loa. Finally, the younger substrate on Mauna Loa, with extensive ‘a‘ā flows, provides a larger area of suitable substrates than on Mauna Kea. In contrast, Mauna Kea appears to have islands of suitable habitat within a sea of compacted and unsuitable periglacial fine ash and dust. Furthermore, glacial scouring has scraped away some of the suitable cinder cone substrates and increased the amount of fine substrates on Mauna Kea, further restricting wēkiu bug habitats.

Bishop Museum wēkiu bug studies conducted in the early 1980s (Howarth and Stone 1982) have been blamed for the demise and current rarity of the wēkiu bug by some (e.g., Loos 2002). On the contrary, our findings indicate there is no evidence that ethylene glycol trapping in the early 1980s was responsible for this decline, nor is there is any quantitative evidence available to actually show there has been a decline or increase in the population. This is because: 1) statistically valid population studies have not been conducted; 2) methodologies used in the 1982 study with one exception (Polhemus 2001) have not been used since that time; and 3) past sampling measured only wēkiu bug foraging activity. Although traps ran for only four days, the Polhemus (2001) study is the only one that used quite similar methodology to the 1982 Bishop Museum study, and took place in the unimpacted Pu‘u Hau Kea crater area. Although the Polhemus (2001) study only ran 4 days as compared to several months for the 1982 study, wēkiu bug captures at 47.3 bugs/4 days of trapping in Pu‘u Hau Kea were substantially similar to the findings of 60 to 90 bugs/3 days of trapping in some unimpacted areas during the Howarth and Stone (1982) study. It should be noted that these high 1982 numbers were found on the then unimpacted Pu‘u Wēkiu ridge and crater area (90 bugs/3 days of trapping), while the 60 bugs/3 days of trapping occurred on the Mauna Kea summit area. All other areas surveyed during the 1982 study had substantially lower wēkiu bug captures (Howarth and Stone 1982). Because there are no reliable and comparable data to the 1982 study, and because population studies are not being conducted by Pacific Analytics (2002), the conclusion by Pacific Analytics that wēkiu bug populations are currently increasing is also unsupportable because of insufficient and non-comparable sampling data.

FUTURE RESEARCH

To further understand the entire range of potential habitats that can be utilized by this species, it is recommended that wēkiu bug surveys be continued in the outlying alpine zone areas of Mauna Kea that have not yet been sampled. Although further testing of pitfall trap methodology is warranted, our study has shown that shrimp pitfall traps have several major drawbacks, with 56% mortality recorded during this study, and

55% recorded in previous Bishop Museum studies (Brenner et al. 1999). Additionally, large predators such as lycosid (wolf) spiders consume items within these traps, and thus traps with negative wēkiu bug results may not necessarily have had zero wēkiu bugs within them. We therefore conclude that because insects cannot escape from ethylene glycol traps, these traps are a better measure of wēkiu bug presence. Ethylene glycol traps also provide a better measure of the presence or absence of other species of interest, both native and harmful introduced species. The judicious use of ethylene glycol traps for determining the presence or absence of wēkiu bugs during surveys of Mauna Kea alpine areas would have no negative or measurable long-term impacts to wēkiu bugs. Although long-term monitoring with ethylene glycol traps is not currently recommended, these traps should not be ruled out for baseline wēkiu bug survey work, as they are much simpler, more effective, and easier to use. Ethylene glycol traps are considerably lighter to carry (i.e., no extra water for traps), and hence reduce the load and potential hazards for researchers hiking into remote, high elevation and high stress environments where white-outs are common. Ethylene glycol traps affect a small amount of potential habitat in relation to an inhabited overall area and would have low impacts when considering the amount of habitat found on each cinder cone in the alpine areas of Mauna Kea.

Although much controversy has been recently generated over whether wēkiu bug populations are increasing or decreasing, alternative studies could be conducted to provide quantitative information regarding the population status of this species. Wēkiu bugs collected in the 1982 study could be compared to wēkiu bugs preserved from the more recent Howarth et al. (1997-1998) study, the Polhemus (2001) study, and the present (2002) study. These data would provide valuable information as to whether the wēkiu bugs have actually declined. Several thousand wēkiu bugs have been preserved in alcohol at the Bishop Museum from the original Howarth and Stone (1982) study and these could be compared to preserved specimens from the more recent studies. Molecular markers would be used to determine whether wēkiu bugs have undergone a genetic bottleneck, and also examine gene flow between the core populations around the high observatory summit areas and smaller outlying populations in the lower alpine zone of Mauna Kea, such as at Pu‘u Makanaka. Molecular analysis would also provide insight into whether outlying wēkiu bug populations are separate, discrete population units, or that gene flow between the outer alpine zone areas is uncommon. Additional genetic comparisons to the much more common Mauna Loa alpine ‘a‘ā bug (*Nysius aa*), the presumed sister taxon to the wēkiu bug, would also provide insights into the current population status of both species. This type of genetic bottleneck study has previously been done with endangered silverswords in Hawai‘i (Friar et al. 1996).

Basic autecological studies, or studies on the ecology of the wēkiu bug need to be conducted, including determining where wēkiu bugs hide or rest when not foraging. This would include studies to determine the most favorable attributes of substrate, soil moisture, or slope required by wēkiu bugs. For example, mini-data loggers measuring environmental factors such as temperature or moisture levels could be set in the substrate in known, favorable wēkiu bug habitats at various depths within the cinders and at various elevations up the Pu‘u Hau Kea crater. These data loggers could run in conjunction with monitoring to determine substrate condition when wēkiu bugs are most active, and would not have to be constantly monitored but could be checked only occasionally to minimize impacts to Pu‘u Hau Kea. This could provide information on wēkiu bug seasonal movements in response to environmental changes. Studies are also needed to determine the size of wēkiu bug populations on the various Mauna Kea summit cones. Mark-recapture studies provide only a rough approximation of population size, and also depend strongly on the foraging behavior of the species of interest, and would likely be inadequate. Furthermore, with a documented 55–56% mortality rate, current trapping methods are neither safe nor efficient enough to use in a mark-recapture program. Thus, other more effective and innocuous wēkiu bug sampling methods need to be developed.


Sampling at Pu‘u Hau Kea Summit, 13,441 ft

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APPENDIX 1: 2001 D.A. POLHEMUS STUDY

A PRELIMINARY SURVEY OF WEKIU BUG POPULATIONS AT PUU HAU KEA, IN THE MAUNA KEA ICE AGE NATURAL AREA RESERVE, HAWAII ISLAND, HAWAII

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The wekiu bug, Nysius wekiuicola, is a flightless seed bug in the family Lygaeidae occurring in the alpine deserts surrounding the summit of Mauna Kea volcano on Hawaii island, Hawaii (Ashlock & Gagné, 1983; Polhemus, 1998). The ongoing construction of astronomy facilities on this mountain has raised concerns regarding possible degredation of wekiu bug habitat, and the consequent impact on long term population viability of the species as a whole. Although previous studies examined these questions in the Mauna Kea Science Reserve (Howarth & Stone, 1982; Howarth et al., 1999), none had assessed wekiu bug densities in the State of Hawaii's adjacent Mauna Kea Ice Age Natural Area Reserve, even though the latter represented the largest intact block of undisturbed alpine habitat near the summit of the mountain.

At the urging of Betsy Gagné and Bill Stormont State of Hawaii's Natural Area Reserves System (NARS), a set of pitfall traps was emplaced at Puu Hau Kea in the Mauna Kea Ice Age NAR in mid-June 2001 to obtain a preliminary estimate of wekiu bug densities and distributions. Given the low bug catches obtained by previous study teams in the late 1990s, it was considered unlikely that large numbers of bugs would be found. The results of the trapping at Puu Hau Kea, however, revealed this particular crater to harbor dense and actively reproducing populations of wekiu bugs, with a particular concentration on the rim and inner slopes. These results raise interesting questions regarding the apparent low population densities of wekiu bugs on adjacent Puu Wekiu (the highest cone on the mountain) and Puu Hauoki, indicating that reassessments of both construction impacts and previous survey methodologies may be in order.

Study Site

Puu Hau Kea is a large volcanic cone occupying the southwestern portion of the Mauna Kea summit area. The base of the cone is 13,200 feet on its northern and western sides, and approximately 13,000 feet on the southern and eastern sides, while the maximum spot elevation given for any point on the rim of the cone is 13,441 feet, as shown on the USGS "Mauna Kea, Hawaii" 7.5 minute topographic sheet. The cone had apparently never been previously surveyed by biologists, and the composition of its inner crater slopes was therefore uncertain. The current study revealed that nearly the entire cone, on both the inner crater and outer slopes, is composed of deep layers of cinder lying over a basal layer of moist, compacted ash (permafrost?), apparently representing a "Type 2" substrate as defined by Howarth et al. (1999). At a few points along the eastern wall of the inner crater there are limited exposures of fractured basaltic bedrock, and a few large boulders derived from such bedrock were also observed lying in the bottom of the crater; these latter areas appeared to represent a "Type 5" substrate as defined by Howarth et al. (1999). Both of these two types of substrate are considered to be highly suitable as wekiu bug habitat.

Methods

Between 14 and 18 June 2001, pitfall trapping was conducted at Puu Hau Kea to assess the presence and relative abundance of wekiu bugs (Nysius wekiuicola) at this site. The crater was ascended from the western side, starting from the old road that runs from the Mauna Kea summit area toward Lake Waiau, and a total of 10 pitfall traps were emplaced on the outer slopes, rim, and inner crater. The traps were set at approximately 10:00–11:30 hrs. on 14 June 2001 and retrieved at approximately 10:30–12:00 hrs. on 18 June 2001. The locations of these traps are given in Table 1 below.

Table 1: Locations of pitfall traps set at Puu Hau Kea, 14–18 June 2001

Trap #	Elevation	Lat./Long. (WGS 84 datum)	Slope	Snow
1	13,200 ft.	19°48'46.2"N, 155°28'30.6"W	outer slope	absent
2	13,250 ft.	19°48'48.4"N, 155°28'28.9"W	outer slope	absent
3	13,300 ft.	19°48'50.4"N, 155°28'27.1"W	outer slope	absent
4	13,350 ft.	19°48'50.8"N, 155°28'25.7"W	outer slope	absent
5	13,400 ft.	19°48'49.9"N, 155°28'24.7"W	rim	absent
6	13,400 ft.	19°48'51.5"N, 155°28'24.0"W	rim	absent
7	13,400 ft.	19°48'53.7"N, 155°28'22.2"W	rim	present
8	13,300 ft.	19°48'53.4"N, 155°28'20.3"W	inner crater	absent
9	13,350 ft.	19°48'53.7"N, 155°28'19.7"W	inner crater	present
10	13,250 ft.	19°48'53.1"N, 155°28'19.8"W	inner crater	present

The traps employed were "dead traps" similar to those used in the initial wekiu bug surveys in 1982 (Howarth & Stone, 1982). Each cup was approximately 5 inches tall and 3 inches in diameter, and was set into the substrate with its lip flush to ground level. The interior of rim of each cup was smeared with a layer of shrimp paste, and the bottom of each cup was filled approximately 0.5 inches deep with ethylene glycol. Cups were covered with large cap rocks, and their positions marked with small yellow plastic flags on wire poles. Latitudes and longitudes of the trap sites were taken with a Garman GPS 48 global positioning system. Trap elevations were determined with a pressure altimeter, calibrated to the USGS "Mauna Kea, Hawaii" topographic sheet.

The traps were allowed to run for 4 days, then retrieved and their contents analyzed. Trap holes were filled, and the ethylene glycol from the traps recovered in plastic containers and removed from the mountain. The trap sites were not permanently marked in any fashion, but can be relocated using the GPS coordinates given in Table 1, if this is desired for future studies.

Results

A total of 473 wekiu bugs were taken in these 10 traps, for a mean of 47.3 bugs per trap. The catch data from the individual traps is shown in Table 2.

Table 2: Capture data from 10 pitfall traps set at Puu Hau Kea, 14–18 June 2001

		# Wekiu Bugs		
Trap #	Slope	adults	immatures	Total
1	outer slope	0	1	1
2	outer slope	0	0	0
3	outer slope	1	2	3
4	outer slope	3	2	5
5	rim	1	1	2
6	rim	28	120	148
7	rim	19	96	115
8	inner crater	10	21	31
9	inner crater	15	108	123
10	inner crater	16	29	45
Totals		93	380	473

Among the 473 individual wekiu bugs captured, 93 specimens, or approximately 20 % of the total, were adults, some of them taken in copula. The 380 immature specimens captured included numerous examples of all 5 nymphal instars, indicating that recruitment was ongoing at this time of year, even given the near absence of snow, which remained only as small patches in a few particularly sheltered spots, following an unusual late season storm the previous week.

A rough analysis of spatial distribution of bugs on the crater shows the following pattern: outer slope = 9 individuals; crater rim = 265 individuals; inner crater = 189 individuals. Even in the absence of statistical analysis, this clearly indicates that the rim and inner crater areas represent habitat most suitable for wekiu bugs at Puu Hau Kea.

The combined catch from the 3 traps adjacent to small snow patches was 283 individuals, while that from the 7 traps in areas devoid of snow was 190 individuals, indicating that proximity to snow patches may enhance trapping success to some degree.

Discussion

A recent study of wekiu bug distribution and abundance in the Mauna Kea summit area conducted from April 1997 to September 1998 (Howarth et al. 1999) recorded a mean capture rate of only 0.16 bugs/trap over any given 3 day sampling period. These low capture rates are in marked contrast to the capture rates of 60 bugs/trap recorded in the 1982 study (Howarth & Stone, 1982), and the 47 bugs/trap recorded during the present study (the latter using a 4 day sampling period). Several factors may account for these disparities:

1.) Environmental disturbances associated with observatory construction, such as dust and surface alteration, may have depressed population densities of wekiu bugs on Puu Wekiu and other nearby cones sampled during the 1984 and 1999 studies, but not affected Puu Hau Kea, which was not sampled during those studies.

2.) The live trapping methods used in the study of Howarth et al. (1999) may have produced lower catch rates than the dead trapping methods used in the 1982 study and the present study.

3.) Recent weather patterns may have produced a seasonal regime in 2001 that was more favorable to wekiu bug reproduction and survival, producing higher capture rates during the present study than those recorded by Howarth et al. (1999), but more similar to those recorded in 1982.

Sorting among these hypotheses will not be a simple matter. The most important first step, however, would appear to be a series of trapping trials involving stations with mixed trap types set in the same general areas, to determine whether certain aspects of live or dead traps, such as the presence of ethylene glycol in the latter, produce higher capture rates in one trap type versus another. If it is shown that the live trapping data from the study of Howarth et al. are not comparable with dead trapping data taken in 1982 and during the current study, it will call into question conclusions drawn from comparative assessments of such data, in particular the perception that wekiu bug populations have experienced significant decline over the last two decades. Conversely, if the two trapping regimes are proven to generate comparable data, then the focus will shift to the potential effects that climate cycles and human disturbance may have had on wekiu bug population dynamics in the summit area over this same time span.

References

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