AN ARTHROPOD ASSESSMENT WITHIN SELECTED AREAS OF THE MAUNA KEA SCIENCE RESERVE

FINAL REPORT

Prepared for

**THE UNIVERSITY OF HAWAI'I
INSTITUTE FOR ASTRONOMY**

7 May 1999

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II. EXECUTIVE SUMMARY

The Mauna Kea Science Reserve (MKSR) is located on the summit of the tallest mountain in Hawai‘i, (13,795 feet). The upper reaches of this extinct shield volcano are the site of a unique natural environment, and also the site of one of the world's foremost astronomical observatories. The agency charged with management of both the environment and the observatory complex is the Institute for Astronomy (IFA), an affiliate of the University of Hawai‘i.

Over the last 20 years, the IFA has been concerned with the status of rare plants and animals found on or near the summit of Mauna Kea. Among these concerns is a special interest in the arthropod community. The IFA has established a program to gather the information necessary for protection and management of resident arthropod species, including the Wekiu bug and lycosid spiders. This report presents the results of a study of the Mauna Kea arthropod community that took place in 1997-98.

Six core tasks were assigned to this study: (1) a comparison of current Wekiu bug trap capture rates to those found in the 1982 Bishop Museum summit arthropod assessment, (2) an assessment of the seasonal fluctuations of Wekiu bug populations,
(3) identification of Wekiu bug habitat within the buffer zone of the MKSR,
(4) a comparison of Wekiu bug occurrence between the summit and buffer areas,
(5) a comparison of arthropod diversity between summit and buffer areas, and
(6) development of management recommendations for the MKSR to preserve and protect resident arthropod populations.

We present the results and discuss the implications of the findings, for each of the five study tasks. We also furnish and discuss recommendations for management of the MKSR to preserve and protect resident arthropod populations. Maps, figures, and tables are included for clarity of understanding. We also provide a list of the literature cited in the report.

Field work began April 1997 with the development and testing a new pitfall trap designed for effectiveness in capturing Wekiu bugs, survival of Wekiu bugs, and comparability to traps used in the 1982 study. After two reconnaissance trips in June and

July1997, a sampling plan was statistically designed to adequately sample all areas of interest, and to allow for valid comparisons to the 1982 study. Sampling began in August 1997 at the summit areas of Pu'u Wekiu and Pu'u Hauoki and ended in September 1998 with a final reconnaissance and sampling of buffer areas.

Significantly fewer Wekiu bugs were captured in the 1997-98 pitfall study than during the 1982 study, corroborating incidental observations that the bug has declined. Furthermore, there was strong evidence that the Wekiu bug capture rate during the 1982 study was significantly greater than the Wekiu bug capture rate during the 1997-98 study. Lycosid spiders were also less abundant, but the difference was not significant, observational data suggest that its population is comparable to its 1982 level. The endemic moth, *Agrotis* sp., appears to have expanded its range within the MKSR since 1982.

There was little significant seasonal variation in the number of traps that captured Wekiu bugs. Trap captures were always much lower on Pu'u Wekiu relative to Wekiu bug trap captures on Pu'u Hauoki. Seasonal peaks occurred in May and July but were not significant. No Wekiu bugs were seen or captured during the January trapping. Lycosid spider activity did not vary significantly with season.

Several "Type 2" (Scoria slopes) and "Type 5" (Talus deposits) areas were located in the buffer zone of the MKSR. Potentially suitable habitat was noted at the lower boundary of the MKSR, at about 11,800 feet. We recommend that these areas be further sampled to determine the lower limits of the Wekiu bugs. Several prospective sampling sites within the "buffer zone" were determined in consultation with the IfA.

Only six Wekiu bugs were seen during the survey of the buffer zone areas. All were in "Type 2" habitat. There was convincing evidence that Wekiu bugs are more likely to occur in the summit area than in the sampled buffer areas. The odds of finding a Wekiu bug in a summit area pitfall trap was estimated to be 4 times greater than finding a Wekiu bug in a buffer area pitfall trap. The lycosid wolf spider was widespread but not abundant. A few were seen or trapped in every area sampled. There was no evidence that lycosid spiders are more likely to occur in the summit area than in the sampled buffer areas.

The average capture rate of Wekiu bugs in disturbed areas was 0.27 bugs per 3 day sampling period. The average capture rate of Wekiu bugs in undisturbed areas was 0.11 bugs per 3 day sampling period. There was strong evidence that the Wekiu bug capture rate in disturbed areas was greater than the capture rate in undisturbed areas. The odds of finding a Wekiu bug disturbed habitat was estimated to be 2.7 times greater than finding a Wekiu bug in an undisturbed habitat. However, the foraging area of the Wekiu bug is unknown, and it is possible that the bug survives in less disturbed areas and forages on disturbed substrates.

Species richness in the buffer zone areas was similar to that found in the summit area. A few species were exclusively found in one or the other of the two areas. The species richness of the summit area did not appear to be diminished by the presence of observatory structures. The quantity of aeolian waifs (the lowland arthropods carried up the mountain on wind) was also comparable in both the summit and buffer areas. This wind-borne material provides the major food resource for the resident animals.

Several species never before collected were found within the MKSR. Two small non-native spiders have invaded the MKSR since 1982. One is a sheet web spider from Europe, *Lepthyphantes tenuis*, which may be competing with the native sheet-web spiders. The other, *Meriola arcifera*, is a hunting spider that doesn't build a web but actively hunts on the ground. It may be having a negative effect on the Wekiu bug population.

The changes in the biotic community within the MKSR since the 1982 study indicate that active management of the habitat should be initiated. A comprehensive monitoring program is strongly recommended to track changes over time and to provide the necessary information to develop appropriate management practices to protect the natural systems. The major elements of a monitoring program are described. Other management recommendations include development and implementation of protocols to minimize introduction of non-native species; to minimize disturbance of habitats; to control dust; to collect and contain waste; to restrict access to sensitive areas; to limit skiing and playing in snow; and to expand public outreach and educational programs.

III. INTRODUCTION

After a series of observational reports listing invertebrates collected from the summit areas of the highest volcanoes in Hawai‘i (Guppy 1897, Bryan 1916, Bryan 1923, 1926, Swezey and Williams 1932, Wentworth et al. 1935, Beardsley 1966, Gagne 1971), the existence of a resident community of native Hawaiian arthropods living near the Summit of Mauna Kea on the Island of Hawai‘i was identified in 1980 (Howarth and Montgomery 1980). The resident species seemed to be able to cope with the stressful environments above 4,000 m (ca. 13,000 ft.). One long-legged, black, nearly wingless true bug, of the genus *Nysius* received substantial interest and was given the common name "Wekiu bug", *wekiu* being Hawaiian for summit or highest (Mull and Mull 1980). The Wekiu bug was one of several species new to science that were collected from the Mauna Kea summit area.

The discovery of this high-elevation, resident arthropod community generated considerable interest among biologists because of the scientific value of comparative studies in ecology, ethology, physiology, and morphology between high elevation aeolian organisms and their lowland relatives (Mull and Mull 1980, Papp 1981, Anonymous 1981, Gagne and Howarth 1982, Howarth and Stone 1982, Edwards 1987, Dumand and Montgomery 1991). Additionally, the discovery raised concerns about the impact of telescope construction in the summit area within the Mauna Kea Science Reserve (MKSR) to this newly described native ecosystem (Mull 1980).

In 1982 the Institute for Astronomy (IFA) funded a team of scientists to conduct an assessment of the arthropod fauna and aeolian ecosystems near the summit of Mauna Kea (Howarth and Stone 1982). The scientific team collected a large number of arthropod species. At least eleven of these species were native to Hawai‘i and do not occur outside of the Hawaiian island chain. Enough information was gathered about two endemic species, the Wekiu bug and a lycosid spider (Lycosa sp.), to draw distribution maps. A large number of species captured were considered transient, aeolian waifs, blown upslope by the daily mountain winds. These latter species were thought to be a food source for the resident species.

Since the 1982 study, several biologists have collected arthropods from the summit of Mauna Kea. However, no organized, systematic sampling has occurred, and little information was available about the distribution of the species that were thought to be restricted to the summit area. Concurrent with its mission of astronomical exploration and research, the IFA recognizes a responsibility for the protection of native flora and fauna and the maintenance of native biological integrity within the MKSR. The IFA has initiated a program to gather the information necessary for effective and efficient management of the MKSR, and thereby help fulfill management goals by supplying the scientific justification for natural resource management activity.

In order to determine the current status of resident arthropod species within the MKSR, the IFA contracted for a new study of the summit area. Six core tasks were included in the 1997 IFA *Request for Proposals* (*RfP*). These tasks were as follows:

Task 1. For all areas included in the Bishop Museum study, assess current arthropod capture rates relative to those found in the 1982 study.

Task 2. Within a representative subset of these areas, investigate seasonal fluctuations in Wekiu bug populations and, where feasible, other arthropod populations.

Task 3. Identify areas of promising Wekiu habitat in the "buffer zone" areas (i.e., that part of the MKSR outside those areas identified for possible telescope development in the Complex Development Plan).

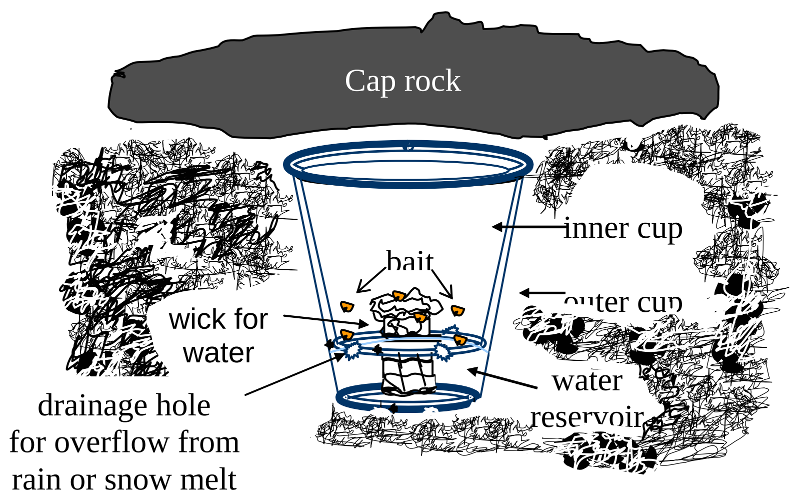
Task 4. To the extent feasible, replicate the 1982 Bishop Museum study in a sample of promising Wekiu habitat within the buffer zone areas.

Task 5. Use data from Tasks 1 and 4 to compare arthropod diversity within the 1982 Bishop Museum study area with that in the selected buffer zone areas.

Task 6. Based on Tasks 1 through 5, recommend an arthropod management plan for the telescope development areas.

Field work began in April 1997 with the testing of new trap designs. The 1982 Bishop Museum study employed traps that killed all specimens collected. The best approach to the study of rare and sensitive invertebrate species is nondestructive sampling. Live capture and release is the best method for measuring Wekiu bug activity rates. This method assures that the research procedures have minimal effect on the rare summit-resident arthropod of the MKSR.

In an effort to reduce the impact of sampling on Wekiu bugs, three different live traps were designed and tested for effectiveness in capturing Wekiu bugs, survival of the trapped Wekiu bugs, and comparability to traps used in the 1982 study. After testing, a modified pitfall trap was selected as the most efficient design comparable to traps used in the 1982 study (Figure III-1). Further modifications, including the addition of a water reservoir, were made to the new pitfall trap design to increase Wekiu bug survival.



Wekiu bug Pit Fall Trap

Figure III-1

After two reconnaissance trips in June and July, 1997, a sampling plan was statistically designed to adequately sample all areas of interest, and to allow for valid comparisons to the 1982 study. Sampling began in August, 1997, at the summit areas of Pu‘u Wekiu and Pu‘u Hau‘Oki and ended in September, 1998, with a final reconnaissance and sampling of buffer areas.

A total of 44 days (179 person days) were spent in the field for sampling and reconnaissance. Several more person days were spent in the laboratory sorting and identifying specimens. Preliminary reports for each task were submitted to the IFA. In March, 1999, principal investigators Frank Howarth and Greg Brenner met with Robert McLaren of the IFA and George Atta of Group 70 to discuss management strategies for the protection of summit-dwelling arthropod species.

This document represents the final report of all activities undertaken in 1997-98 to assess the status of arthropods occurring within the MKSR.

IV. TASK 1. A COMPARISON OF 1982 AND 1997-98 ARTHROPOD CAPTURE RATES

Task 1 of the IFA *Request for Proposals* (*RfP*) asked for a comparison of current arthropod capture rates to those found in the 1982 study. While there is interest in the capture rates for all arthropods within the MKSR, quantitative analysis was limited to the Wekiu bug, *Nysius wekiuicola*, the only arthropod for which enough historic information was available for comparison. Other resident arthropods captured in pitfall traps within the MKSR occurred in small numbers, making inferences about their capture rates impossible.

Questions Of Interest:

1. Is there a difference between 1982 and 1997-98 Wekiu bug capture rates in the areas sampled during the 1982 Bishop Museum arthropod assessment of the MKSR? What is the trend?

2. Is there a difference between 1982 and 1997-98 captures of arthropods other than the Wekiu bug in the areas sampled during the 1982 Bishop Museum arthropod assessment of the MKSR?

Methods:

Field Methodology:

The methods are described in detail in Appendix A: Documentation of Methodology. The traps were set along transects as follows.

Wekiu Crater Transects (Map 1):

1) Summit Ridge: 5 traps placed along the ridge.
2) Inner Crater Talus Slopes: 5 traps placed about 1/3 the distance down the slope longitudinally along the slope.
3) Col: 5 traps placed along the col from the road to the summit ridge.
4) Upper Crater Floor: 5 traps placed across surface of the upper crater floor.

Hau‘Oki Crater Transects (Map 2):

1) Crater Floor: 5 traps placed at random across the crater floor.
2) Undisturbed Inner Slope: A vertical transect on undisturbed talus slope with 5 traps.
3) Disturbed Inner Slope: A vertical transect on disturbed talus slope with 5 traps.
4) Outer North Slope: 5 traps placed longitudinally across the outer north slope of Hau‘Oki crater.
5) Outer East Slope: 5 traps placed longitudinally across the outer east slope of Hau‘Oki crater.

North Slope Road (Map 3):

1) Talus: 5 traps were placed in zones of gently sloping talus selected at random.
2) Blocky Lava: 5 traps were placed in zones of blocky lava selected at random. Blocky lava was medium- to large-sized (10-40 cm) rocks in a mosaic of volcanic substrates.
3) Periglacial Pavement: 5 traps were placed in zones of periglacial pavement selected at random.
4) Ashy Periglacial Pavement: 5 traps were placed in zones of ashy periglacial pavement selected at random.
5) Caves: Traps were placed in 5 shelter caves selected at random.

The traps on Pu‘u Wekiu were set along the same transects used in the 1982 study, and in some cases, set in the same location. All were set in sites comparable to the specific sites used in the 1982 study. Because of the construction of the Keck and Subaru telescopes on Pu‘u Hau‘Oki, it was not possible to duplicate the 1982 transects exactly. However, transect 3 above (“Hau‘Oki Disturbed Inner Slope”) was approximately along the same transect into the crater used in the 1982 study. Also, transect 4 (“Hau‘Oki Outer North Slope”) was in a comparable location and habitat to a few traps set there in 1982. The other transects on Pu‘u Hau‘Oki were chosen in an attempt to investigate the effects of recent disturbance on arthropod abundance.

Statistical Methodology:

Log-linear Poisson regression was used to model the relationship between the rate of Wekiu bug captures and the year the captures were made. Year, locality, and disturbance were tested for statistical significance as indicator explanatory variables in the regression model. The year indicator variable represented the 1982 and 1997-98 studies; the locality indicator variable represented 7 localities. Localities not sampled during both studies were not included. The disturbance indicator variable represented relatively disturbed and undisturbed localities.

Results:

A full model with all interactions was tested first, and non-significant explanatory variables were eliminated step-wise from the model. The final model was:

$$\text{Log}(\mu) = \beta_0 + \beta_1 \text{ year} + \beta_2 \text{ locality} + \beta_3 \text{ disturbance}$$

Regression Summary:

Coefficients	Value	Std. Error	t value
(Intercept)	3.41	0.044	76.80
year	-6.64	0.38	-17.32
locality1	-0.44	0.076	-5.81
locality2	0.098	0.03	3.19
locality3	-0.82	0.03	-23.86
locality4	-0.21	0.04	-4.99
locality5	0.05	0.01	3.36
locality6	-0.21	0.03	-7.24
locality7	0.29	0.0	38.94
disturbed	1.12	0.45	2.50

Deviance Residuals:

Min	1Q	Median	3Q	Max
-21.20893	-0.8559877	-0.3044401	-0.08634431	32.87128

Null Deviance: 14057.1 on 202 degrees of freedom
Residual Deviance: 3211.176 on 193 degrees of freedom

Over all localities, the average capture rate of Wekiu bugs during the 1982 study was 60 bugs per 3 days of sampling. The average capture rate of Wekiu bugs during the 1997-98 study was 0.16 bugs per 3 days of sampling (Table III-1). There was strong evidence that the Wekiu bug capture rate during the 1982 study was significantly greater than the Wekiu bug capture rate during the 1997-98 study (p-value < 0.0001).

The capture rates for 3 days of sampling in various localities are presented in Table III-1 along with standardized 3 day capture rates of the 1982 study for comparison. While the capture rates were significantly lower for each locality during the 1997-98 study, it is interesting to note the relative ranks of localities for each year. In 1982, the upper crater of Pu‘u Wekiu had the greatest Wekiu bug capture rate. This locality fell dramatically to the 6th ranked locality in 1997-98. All other localities held their approximate relative rank.

Locality	1982	1982 rank	1997-98	1997-98 rank
WEKIU UPPER CRATER BOTTOM	644.48	1	0.07	6
WEKIU SUMMIT RIDGE	225.04	2	0.23	2
HAU‘OKI INNER TALUS SLOPES	105.61	3	0.36	1
HAU‘OKI OUTER S-E SLOPE	92.25	4	0.17	3
BOTTOM OF HAU‘OKI CRATER	44.48	5	0.14	4
WEKIU COL TRAIL	35.24	6	0.05	7
HAU‘OKI OUTER N SLOPE	10.92	7	0.13	5
WEKIU NORTH RIDGE	6.55	8	0.00	9
NORTH PLATEAU	2.85	9	0.04	8
MEAN 3-DAY CAPTURE RATES	60.09		0.16	

Table III-1. 1982 and 1997-98 3 day capture rates for the Wekiu bug. Table III-1 displays the standardized 3 day capture rate for Wekiu bugs in pitfall traps for the 1982 and 1997-98 studies. The table also contains the rank of the locality for Wekiu bug capture rate for each study.

There was strong evidence that the Wekiu bug capture rate in disturbed areas was greater than the capture rate in undisturbed areas (p-value < 0.0005). For a discussion of this result see Chapter VII. Task 4 (Page 26).

Discussion:

Significantly fewer Wekiu bugs were captured in the 1997-98 pitfall study than during the 1982 study. The cause of the difference could be due to any of several factors. For example, live traps were in place for only three days in 1997-98, compared to death traps set for more than three weeks in 1982. Because of the shorter period they are in place, live traps are less likely to reflect arthropod response to variations in weather. Additionally, live traps may not have been as attractive as death traps to animals that make their living scavenging on recently dead or dying animals. Although our tests showed that the Wekiu bug could not escape once inside the trap, other trapped arthropods may have escaped from the live traps, thus reducing the total catch. Furthermore, the 1982 study was conducted during a period of exceptional snowfall that may have favored Wekiu bug activity. A change in the Wekiu bug population due to climate, introduced species, or habitat disturbance is difficult to determine without more frequent monitoring.

Several factors can affect pitfall trap capture rates. First, the rim of the trap can create a barrier to foraging insects. To prevent this from happening, pitfall traps were carefully buried so that their rims were flush with or even a little below the surface. In periglacial environments, such as on Mauna Kea, frost can push the trap upwards, or wind, rain, and frost can remove surface material surrounding the trap. These processes can expose the rim and compromise trap effectiveness. A cap rock was used to minimize this problem, and the condition of each trap was noted for additional disturbance information when visited for capture counting and release. No trap during this study experienced significant disturbance.

Second, the size of the trap can affect the capture rate. Size is usually considered to be the average diameter, because it is the trap width that is presented to an approaching insect. Baits may offset the size effect, because the range of attractiveness of the bait is thought to be more important than trap size. In both the 1982 and 1997-98 studies, the traps were baited with shrimp or fish paste.

Third, captured animals can attract or repel additional animals approaching a trap. Thus, the length of time the trap is left in place may affect the capture rate. Leaving traps open for several weeks during the 1982 study allowed for a buildup of dead insects in the traps, which may have been an additional attractant to scavenging Wekiu bugs.

It is important to note that pitfall traps measure activity rates of foraging animals. Although for many insect species the percentage of the population that are foraging may be roughly constant over time, in general the size of animal populations can only be determined from additional studies such as mark-and-recapture experiments.

The 1982 study captured a sufficient number of lycosid spiders to determine spatial distribution information on the summit. Capture rates in the 1997-1998 study were lower, but this seems most likely due to the shorter times that the traps were in place. The behavior of lycosid spiders suggests that a higher percentage of traps would contain spiders the longer the traps were in place. Once trapped, some lycosid spiders may escape the traps if they attached silk drag-lines as they fell into the trap. Observational data collected during the 1997-1998 study suggest that the lycosid spider population is comparable to what it was in 1982.

The endemic moth, *Agrotis* sp. has expanded its range since 1982, perhaps resulting from the different climatic conditions or additional food. The 1982 trap data and direct observations suggested that the moth larvae were most common on blocky lava substrates and that they fed on lichens. In the current study, we captured a few larvae in traps on the summit ridges far from blocky substrate and known lichen growths. On the summit, the larvae were feeding on dead arthropod remains, and in the buffer area, we found them feeding on the skin of a mummified sheep.

V. TASK 2. AN ASSESSMENT OF ARTHROPOD SEASONAL FLUCTUATION

Task 2 required an investigation into the seasonal fluctuations, over one full year, of the population of the Wekiu bug, *Nysius wekiuicola*, in a representative subset of the areas assessed for arthropods in the 1982 Bishop Museum study. The *RfP* also targeted for investigation, where feasible, the seasonal fluctuations of other arthropod populations. The field assessments were to include at a minimum, the late spring, early summer, and one winter/early spring snow melt. Four sampling periods were subsequently identified for assessment of seasonal fluctuations of arthropod activity. These sampling periods were summer melt, fall drought, winter melt, and spring melt.

We hypothesized that the seasonal activity of arthropods resident within the MKSR is influenced by weather factors, such as the amount of snow, moisture, and wind. While is it difficult to assess the direct impact of these factors on arthropod activity, changes that occur seasonally may be correlated with weather factors.

While there is interest in the seasonal activity of all arthropods within the MKSR, the study was limited to the Wekiu bug, *Nysius wekiuicola*, and the resident lycosid spider, *Lycosa* sp. The other resident arthropods captured in pitfall traps within the MKSR occured in small numbers, making inferences about their activity difficult. Future studies should use sampling methodologies designed specifically for these other species.

Questions Of Interest:

1. Does Wekiu bug activity change seasonally?

2. Does the activity of lycosid spiders change seasonally?

3. Is there a correlation between the amount of snow and/or moisture and arthropod activity within the MKSR?

4. Is activity during the period of Fall drought different than that in other seasons?

5. Can any of the differences found in arthropod activity be attributed to Fall drought conditions?

6. Is there a trend in the population of Wekiu bug or in arthropod activity since the1982 Bishop Museum study?

Methods:

Field Methodology:

The methods are described in detail in Appendix A: Documentation of Methodology. Sampling was restricted to the summit areas, excluding the North Plateau. Transect design was similar to that discussed in Task 1, but repeated over time. Sampling was conducted in May and August of 1997 and January, April, July, and September of 1998.

Statistical Methodology:

Seasonal fluctuations were investigated using statistical tools developed for binomial (presence/absence) responses (Ramsey and Schafer 1997). The analysis of data composed of binomial responses (proportions) requires statistical tools different from normal distribution tools such as t-tests, analysis of variance, or least-squares regression. We tested differences between seasons of proportions of traps with Wekiu bugs. Statistical analysis of binomial responses leads to conclusions about population proportions and probabilities, which may be stated as inferences about odds ratios, such as the relative odds of a Wekiu bug occurring in a particular habitat.

Results for Task 2 were reported in a time series graph to better illustrate seasonal variation in Wekiu bug activity. This type of reporting will be useful when comparisons are made to future sampling results.

Results:

The total number of Wekiu bugs captured varied only marginally with season (Figure V-1). The proportion of traps with Wekiu bugs on Pu‘u Wekiu during the 1997-98 study was not significantly different across all seasons (p-values > 0.27). On Pu‘u Hau‘Oki, there was a significant difference in the proportion of traps with Wekiu bugs only between the May, 1997 and August, 1997 seasons (p-value = 0.0025). No other seasonal differences were statistically significant. Trap captures on Pu‘u Wekiu was very low compared to Pu‘u Hau‘Oki, never exceeding more than 3 bugs. On Pu‘u Hau‘Oki the number of Wekiu bugs captured was much larger in the May, 1997 and July, 1998 sampling periods than any other period.

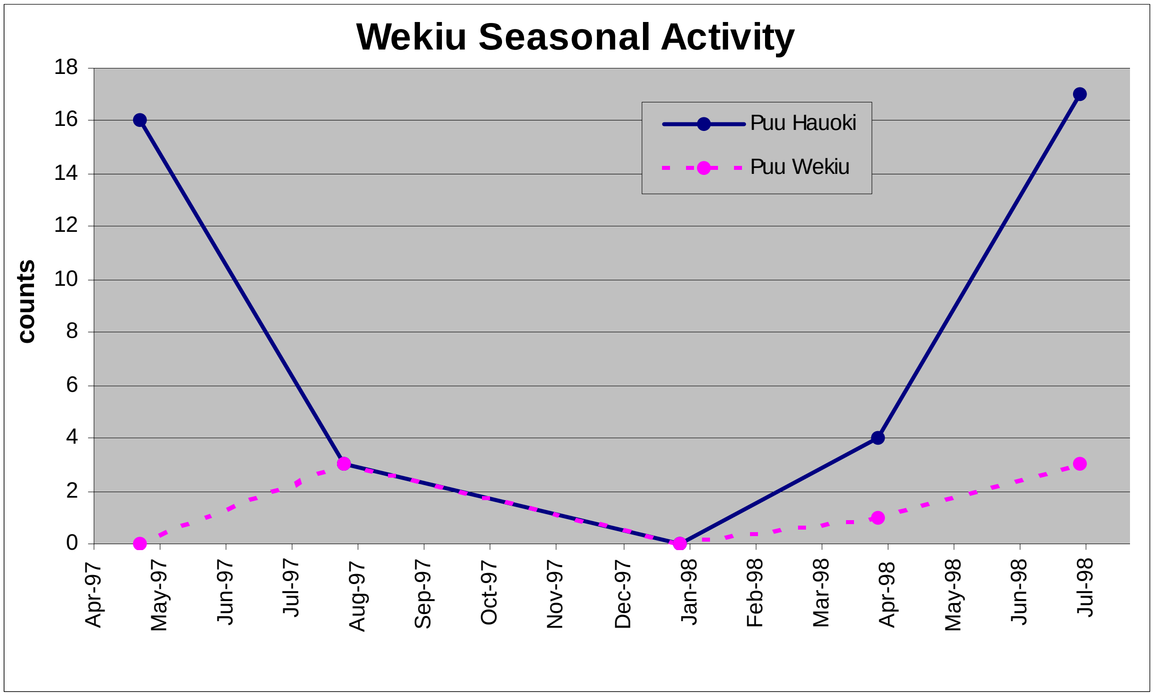


Figure V-1. Wekiu Bug Seasonal Activity. The graph shows the number of Wekiu bugs captured in Pu‘u Wekiu and Pu‘u Hau‘Oki for five sampling periods in 1997 and 1998.

Lycosid spider activity did not vary significantly with season (p-values > 0.13) (Figure V-2). When snow was present, May 1997 and January 1998, lycosids were not active. Peak lycosid activity was not associated with peak Wekiu bug activity. Peak captures of the two species did not occur on the same sampling dates, nor was a significant lag period detected.

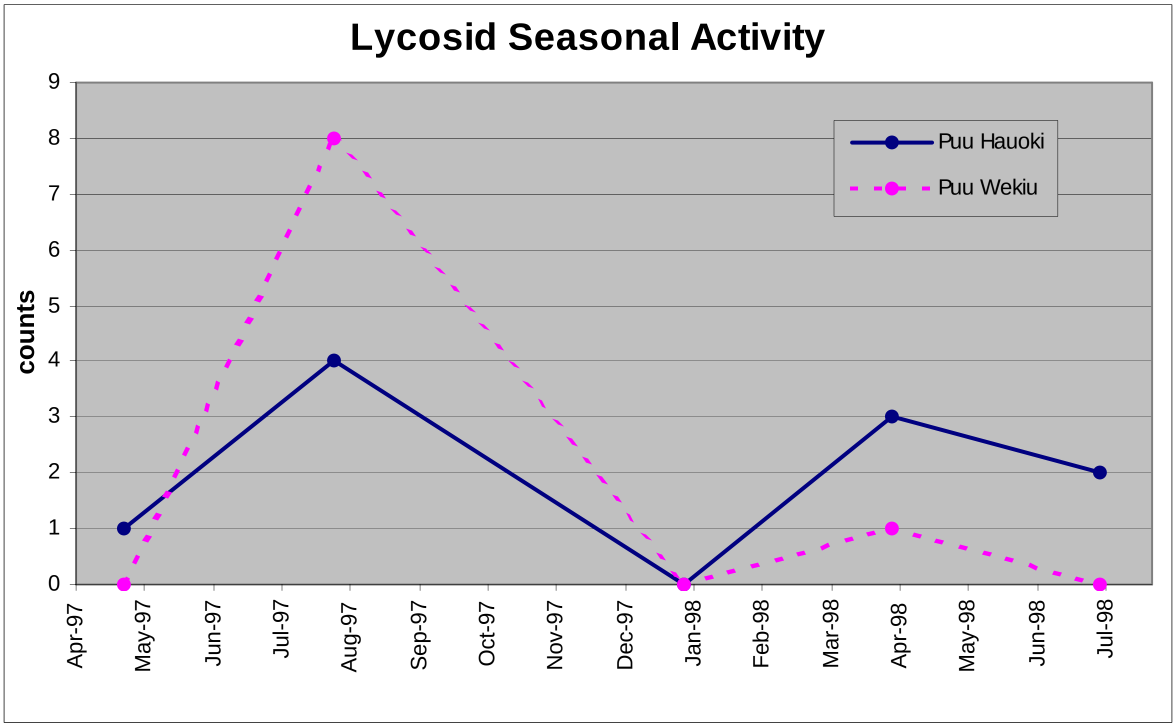


Table V-2. Lycosid Seasonal Activity. The graph shows the number of lycosid captured in Pu‘u Wekiu and Pu‘u Hau‘Oki for five sampling periods in 1997 and 1998.

Discussion:

The capture rate of Wekiu bugs did not vary significantly with season. It is difficult to detect seasonal trends with a limited number of sampling dates and low capture rates. We collected data for only five sampling periods, which was insufficient to detect seasonal or other long-term population changes. Many insect populations exhibit abundance cycles over long periods of time. These long-term cycles can mask seasonal population changes.

The seasonal trends for both the Wekiu bugs and lycosid spiders may be associated with activity of aeolian prey species, or with substrate temperature. The abundance of aeolian prey species was quantified, and substrate temperature was not measured. During the January sampling period, the water reservoirs in most traps froze, and the number of all arthropods captured was low. Possibly the bait also froze or remained fresh and less attractive to scavenging arthropods. That is, arthropods may have been present but were not as attracted to the traps as when the temperatures were warmer.

Inactive lycosid spiders were found within their silken nests beneath large rocks frequently during cold periods, and occasionally at other seasons. This may indicate that they avoid harsh climatic conditions by seeking and remaining in sheltered habitats. The contemporaneous presence of different age classes of spiders during most of the sampling periods may indicate that reproduction is not synchronized with the seasons.

A hypothesis generated from 1982 study was that Wekiu bugs are adapted to exploit the margins of melting snow patches, and therefore, their activity and populations should be expected to be strongly correlated with seasonal and climatic events. The current study did not find evidence to support that hypothesis. The peak of Wekiu bug activity occurred in May 1997. At this time melting snowfields were present. Wekiu bug activity also reached a similar peak in July 1998, a time when no snow was present at the summit of Mauna Kea, and reached a low in January 1998, when snow was present. This evidence suggests that some factor other than the presence of snow may be influencing Wekiu bug activity. However, the conflicting results may reflect differences in the magnitude of snowfall during the two studies.

The 1982 study was conducted in the summer months. Snowfall had been heavy, and large patches still occurred on the summit throughout the entire sampling period. Further, 1982 followed several years of greater than average snowfall. Snowfall on Mauna Kea has been relatively light since about 1990, and the 1997-98-winter season was one of the lightest snowfall years in recent memory. Either no snow or only ephemeral patches were present during the 1997-1998 study. In the winter of 1982, most of the known Wekiu bug habitat near the summit was under a meter or more of snow. It is likely that the bugs were inactive when their habitat was snow-covered, but they emerged as the snow retreated and the substrate warmed. Thus in both the 1982 and 1997-1998 studies the bugs were active during the warmer spring and summer months. The current study found only suggestive evidence that they were less active during the both colder winter and drier autumn periods.

The life history of the Wekiu bug is poorly documented. We hypothesize that their development is slow in the cold Mauna Kea climate, and that the animals may be long-lived. All age classes of individuals, as well as mating pairs, were relatively abundant during the 1982 study, which was conducted in the summer months. Only adults, including a few mating pairs, were found during the May 1997 reconnaissance survey. Both nymphs and adults were found in the summer and fall sampling of this study, but the numbers were too low to compare age distributions with those of the earlier study.

The small numbers of Wekiu bugs found during this study did not allow us to make further observations on their activity or biology in the field. In the laboratory, we found that Wekiu bug nymphs would feed on small flies(Mull pers. com.). Wekiu bugs are sucking insects and can feed only upon live or recently deceased prey.

It is important to note that this survey measured arthropod activity, and the results cannot be used as a measure of the population size. It is unfortunate that in this study we failed to find a local population of bugs with the activity we found on both Pu‘u Wekiu and Pu‘u Hau‘Oki in 1982. We had hoped to conduct mark-recapture experiments to determine the proportion of active/inactive bugs, and thereby determine relative population size. In a mark-recapture study, the insects are captured, marked with a nontoxic marker, and released. The proportion of marked to unmarked individuals caught subsequently can be used to determine a number of biological traits, including dispersal ability, longevity, and population size.

A long-term monitoring program would be useful in characterizing Wekiu bug life history. A comprehensive monitoring program, with repeated sampling over many seasons and years, would yield the information necessary to determine seasonal and long-term trends in Wekiu bug activity. Properly designed, a monitoring program would also supply new information about the impact of management, construction, and restoration activities.

VI. TASK 3. IDENTIFICATION OF PROMISING WEKIU "BUFFER ZONE" HABITAT

Task 3 required a reconnaissance of the "buffer zone" areas; that is, the part of the MKSR outside of those areas identified for possible telescope development in the Complex Development Plan. The reconnaissance helped us identify locations of suitable Wekiu bug substrates for detailed sampling. Potential Wekiu bug habitats were visually assessed along preplanned routes throughout the MKSR. The results of the reconnaissance were presented to the IFA, and specific localities were selected for comparisons to the summit area of Mauna Kea, as required in Task 4.

Question of Interest:

1. What is the distribution of promising Wekiu bug habitat in the "buffer zone" areas within the Mauna Kea Science Reserve?

Methods:

Two substrates types were specified in the *RfP* for assessment: "Type 2", (tephra ridges and slopes with scoria or lapilli deposits), and "Type 5", (talus slopes and highly fractured rock outcrops). These two substrate types were hypothesized to be the most suitable Wekiu bug habitats. Factors that might affect the suitability of these substrates for Wekiu bugs were noted. These factors include slope, size of the area, grain size, porosity, moisture content, presence of other arthropods, aeolian food resources, and elevation. In spite of the relatively dry weather, moisture was present at most sites, especially within the sandy ash layers.

Results:

A total of eight cones were surveyed and about 16 kilometers of transects were traversed (Map 4). Several Type 2 and Type 5 habitats were located (Table VI-1), and these larger and more accessible of these areas were selected for Task 4 sampling (Table IV-2). No Wekiu bugs were observed during the Task 3 reconnaissance. Lycosid spiders and noctuid moths were relatively common, as were linyphiid and clubionid spiders.

Table VI-1. Potential Wekiu bug habitats (i.e., Type 1 and Type 2) within the buffer areas of the Mauna Kea Science Reserve.

Talus Habitats:

1. **North Slope:** An accessible area of talus habitat lies near the end of the road along the north base of Pu‘u Hau‘Oki and Pu‘u Kea. This habitat is composed of two areas about 300 meters apart more or less connected by a series of discontinuous islands of talus on blocky lava outcrops. These blocky ridges are narrowly separated by an irregular patchwork of periglacial pavements. The first talus area is on the ridge from Pu‘u Kea, and the second area is downslope from the first area and west of Pu‘u Mahoe. It was not possible to measure the size of the talus habitat directly, but the two areas probably total about 20 hectares of which about 25% is suitable habitat. The blocky lava flow continues eastward downslope about 2 kilometers, but the outcrops of talus are relatively small and modified by glaciers.

2. **South Slope:** A relatively large area of good talus habitat occurs between the Summit Road and Pu‘u Lilinoe. The talus habitat connects with broken lava habitat on the south face of Pu‘u Wekiu and continues downslope nearly to the access road to the VLBA facility. The total area of the blocky outcrop is about 29 hectares of which between 40 to 50% appear to be suitable talus habitat. Blocky lava flows and glacial till make up the remaining substrate. The talus habitat also connects with the excellent scoria (cinder) habitat on Pu‘u Lilinoe.

3. **West Slope:** The south facing cliff of the northwest lava plateau has many small but good patches of talus along nearly its entire length from Pu‘u Poliahu west to near the edge of the Science Reserve. Crevices in the blocky lava increase the connectivity among these patches. About one half of the upper part lies within the Ice Age NAR and outside the study area. The talus near the upper end connects with the scoria habitat on the northwest slope of Pu‘u Poliahu. The cliff is 10 to 30 meters high and about 1.5 kilometers long. Most of the habitat is nearly vertical, and it was not possible to measure its area from the aerial photograph or map.

4. **Other Talus Deposits:** Smaller patches of talus habitat occur as islands in the blocky lava flows, especially on the northwest plateau, near the unnamed cone south of the VLBA facility, and on the slopes between the scoria cones. Some of these may be suitable, especially if interconnected by crevices in the broken lava. In many places, glaciers have modified these, and glacial till fills many of the cracks probably making them less suitable for the bug.

Scoria Habitats:

The scoria cones are described geologically (Wolfe and Morris 1996) as follows:

> "Scoria cones of Hawaiite or mugerite (unit 1c) and benmoreilte (unit 1bc) consist mostly of vesicular lapilli with lesser amounts of ash and bombs; agglutinated spatter occurs locally. Cones are generally dark gray to red where freshly exposed and yellowish brown where weathered; however, interiors that have been hydrothermally altered are grayish orange to yellowish and weakly cemented. Cones are locally mantled by unmapped fine-grained deposits of aeolian or tephra-fall origin."

1. **Puʻu Lilinoe:** The scoria habitat on Puʻu Lilinoe covers about 40 hectares. Greater than 50% of the surface is composed of fist-sized vesicular scoria and appears to represent good to excellent habitat for the Wekiu bug. The scoria on the northern and western outer slopes is larger and is probably better habitat than the eastern and southern outer slopes.

2. **Puʻu Mahoe:** The outer slopes of the more accessible southern portion of this cone have deep deposits of fist-sized scoria and appear excellent for Wekiu bug habitat. The southern-most crater also contains excellent habitat. Approximately 50% of the remaining surface of Puʻu Mahoe also appears to be good to excellent bug habitat, but the more northern portion is too remote for efficient sampling. The total area of the cone is about 62 hectares.

3. **"VLBA Cone":** The unnamed cone south of the VLBA facility is composed of finer material with a shallow surface layer of larger scoria. The total area of scoria covers about 32.5 hectares. The cone itself is relatively small and steep, but a large area of scoria continues downslope between deposits of glacial moraines. There is a breached crater and many blocky lava outcrops at the summit. About 40% of the steeper main cone is promising bug habitat, especially the lower portion of the east slope and portions of the summit ridge.

4. **"Southeast Boundary Cone**:" The unnamed cone along the southeast boundary of the reserve is composed of a very loose deposit of fist-size scoria with scattered blocks deposited by the glacier. The floor of the summit crater is an undisturbed periglacial pavement of scoria and glacial blocks on moist sandy ash. Most of the cone appears to be excellent Wekiu bug habitat, and the site would be a good location to test the lower limit of bug distribution within the Science Reserve. The total area is 18 hectares of which about half are within the Science Reserve.

5. **Puʻu Poliahu:** Most of Puʻu Pollahu cinder cone is composed of weathered yellowish sandy ash with rocky outcrops and a thin surface layer of scoria. These ashy deposits are generally poor Wekiu bug habitat. The total area is about 112 hectares. On the lower northwest outer slopes is a deep deposit of fist-size scoria which appears to be excellent habitat, but it is a small area, about 4 hectares in extent. The scoria connects with the valley bottom of periglacial pavement made up of fallen scoria and weathered tephra. The pavement habitat is fair and covers about 3.4 hectares.

6. **"Lilinoe Iki":** This small (about 15 hectares) unnamed cone between Puʻu Lilinoe and the VLBA facility has more compact scoria than on Puʻu Lilinoe, but deep deposits of loose scoria occur in patches as solifluction lobes. About 50% of the cone is promising Wekiu bug habitat. The summit has no crater and the subsurface sandy ash layer on the narrow summit ridge is dry. However, lycosid and linyphiid spiders were seen on the slopes and summit area.

7. **"West Boundary Cone":** The large cinder cone downstope and west of Puʻu Pohaku is unnamed. Most of the slopes are too remote and steep to safely survey, but large areas appear to be promising Wekiu bug habitat. There are accessible promising areas on the upper slope, but they are still remote by foot. The total area is estimated to be about 150 hectares, of which more one half (the lower slopes) has an unknown composition. Up to 50 hectares may be suitable Wekiu bug habitat. Approximately 25 hectares of the eastern slopes between the blocky lava flows below Puʻu Pohaku and the rim of the crater is covered with a loose fine tephra deposit that is probably not suitable for Wekiu bugs. However, it may harbor other species, as it is one of the largest areas of this habitat type on the mountain.

8. **Puʻu Makanaka:** Puʻu Makanaka is one of the largest cinder cones on the mountain covering about 83 hectares. The west and southwest facing portions of the cone are composed largely of loose scoria, which is probably suitable bug habitat. The north facing slope appears to be covered with finer material and less suitable. The distinct crater covers just over 12 hectares. The summit rim and western half of the crater slope are covered mostly with ash, although numerous lava bombs and spatter deposits may provide refuge habitat. Most of the eastern half of the slope into the crater is composed of a loose deposit of large scoria blocks. This is a unique habitat type within the MKSR.

9. **Puʻu Poepoe:** A brief reconnaissance was made of this small cone, which covers about 24 hectares. The outer slopes are covered with sandy ash with scattered scoria channels. The small summit area and crater are covered with deposits of loose scoria, some of which appear to offer good bug habitat.

Because of their remoteness, the following cinder cones were not visited during this survey. From the aerial photographs, geologic maps, and inspection from a distance, they probably have significant scoria deposits and promising Wekiu bug habitat. However, they are at lower altitudes.

1. **Puʻu Hoaka:** Puʻu Hoaka is on the northeast boundary of the Science Reserve and north west of Puʻu Makanaka. The area could not be determined accurately from the aerial photographs, but it is approximately 30 hectares. The substrate type is unknown, but it is indicated to be a scoria cone on the geologic map, and its appearance from a distance suggests that it contains some good Wekiu habitat.

2. **Puʻu Ala:** Puʻu Ala is between Puʻu Makanaka and Puʻu Mahoe and covers about 68 hectares. We had good views of the western outer slopes during our transect across Puʻu Mahoe and believe the cone contains promising bug habitat. Also, according to the geologic map (Wolfe and Morris 1996), the north slope of Puʻu Ala consists of blocky lava.

3. **"Unnamed North Boundary Cone":** This is a small scoria cone downslope (north) of Puʻu Mahoe. It is remote, and its habitat characteristics are unknown, although like its neighbors, it possibly has suitable Wekiu bug habitat.

Other Habitats:

Other habitats seen in the buffer areas during the survey include blocky lava flows, aeolian deposits, glacial till, and moraines (Wolfe and Morris 1996). These often occur together in a mosaic or patchwork of ridges of lava flows interspersed with wind, water, or ice deposited material. The base substrate is usually blocky lava flows which occur as solid ridges of more massive flows of Hawaiite or the surface is more irregular and more 'a'a like. These flows nearly circle the summit cones being obscured by glacial till on the east. On the north slope they extend down to about 12,900 feet; on the west to 12,800 feet and the south to nearly 12,000 feet in places. The largest recognizable single flow is the northwest plateau, which covers about 270 hectares in area.

The lower slopes have been modified by the glacier, with the surface rocks either swept away or deposited in a jumble. Areas with glacially deposited material usually have the crevices filled with a fine-grained material. From our survey and confirmed by the maps (Wolfe and Morris 1996) and photographs, most of the east and north slopes between the scoria cones is covered with glacial till with large to small irregular boulders loosely held in a mixture of finer grained material. Because the pore spaces are mostly filled, the habitat appears poorly suited for the Wekiu bug, but there may be patches of suitable habitat there, or there may be important refuges. Some plants were widely scattered growing in crevices. During our reconnaissance, we saw several lycosid spiders, and they appeared to be locally common on this habitat.

Patches of smaller material usually are sorted by frost into layered size classes, and depending on degree of slope, these patches can creep downslope as solifluction lobes. These pavements of sorted material and lobes are characteristic of periglacial environments. Several small irregular gray colored areas are conspicuous on the aerial photographs of the northwest plateau. We planned our traverse to the west slope to inspect these as they possibly represented an unrecognized habitat type. However, they appear to be weathered fine-grained deposits similar in composition to sandy ash deposits elsewhere on the mountain. The largest gray area is about 1.2 hectares in size, and the total area covered is between three to four hectares.

Table VI-2. Wekiu bug habitats selected for intensive survey.

Talus Habitats:

1. North Slope near Puʻu Mahoe
2. South Slope near Puʻu Lilinoe
3. West Slope Near Puʻu Poliahu

Scoria Habitats:

1. Puʻu Lilinoe
2. Puʻu Mahoe
3. Northwest slope of Puʻu Poliahu

Discussion:

The type of substrate may dictate the presence of other parameters important for the bug. Hypothetically, slope provides arthropods the opportunity to move vertically within the substrate to find optimal microclimatic conditions. Larger pore spaces may allow greater range of movement and more hiding or resting spaces. Abundant, interconnected, interstitial spaces may allow the arthropods to migrate and exploit resources without being exposed to surface weather conditions and surface predators.

The presence of organic aeolian debris and moisture are necessary to support life in this stone desert. Generally, in spite of the dry weather, we found moist substrates at most sites, especially within the sandy ash layer below the surface scoria.

Except for one collection at 12,075 feet in Pu‘u Makanaka Crater, the Wekiu bug has been found only at summit areas above about 12,800 feet. Potentially suitable habitat was noted at the lower boundary of the MKSR, at about 11,800 feet. We recommended that these areas be sampled to determine the lower limits of the Wekiu bugs. The lycosid spider, noctuid moth, some species of linyphiid spiders, and the recently invading clubionid spider were found at many sites down to the reserve boundary. We did not observe any Wekiu bugs during this reconnaissance, but found one Wekiu bug in Pu‘u Makanaka Crater in September, 1998.

We recommended a range of sites within the buffer zone where Type 2 and Type 5 habitat were found, that could be used for summit area and buffer zone Wekiu bug capture rate comparisons. We consulted with the IFA to determine which of the sites would be sampled. Sites chosen for detailed sampling appear in Table VI-2.

VII. TASK 4. A COMPARISON OF WEKIU BUG OCCURRENCE BETWEEN SUMMIT AND BUFFER HABITATS

Task 4 called for an assessment of Wekiu bug habitats and arthropod populations in selected areas of the "buffer zone" areas within the MSKR, along with a comparison of the status of arthropod populations between the summit areas and buffer zone areas.

Questions of Interest:

1. Is there a difference between Wekiu bug activity and abundance in the summit area and surrounding selected "buffer areas" within the MKSR? How abundant are Wekiu bugs in selected "buffer areas"?

2. Is there a difference between lycosid spider activity and abundance in the summit area and surrounding selected "buffer areas" within the MKSR? How abundant are lycosid spiders in selected "buffer areas"?

3. Is there suitable habitat for native arthropods beyond the summit area in the MKSR?

An additional question of interest was added during the planning phase of the study.

4. Is there a difference between disturbed and undisturbed sites within the summit areas?

Methods:

Field Methods:

Promising Wekiu bug habitats were identified in Task 3, and prospective sampling sites within the buffer zone were determined in consultation with the IFA. The sites were sampled for arthropod presence and diversity in July and September, 1998. Two Type 2 habitats, (Pu‘u Mahoe and Pu‘u Lilinoe), and two Type 5 habitats, (talus deposits near the bases of these two cinder cones), were sampled using the same live pitfall trapping method used in the summit area. In addition, a visual reconnaissance was conducted in Type 2 and Type 5 habitats at the northwest base of Pu‘u Poliahu, the western slopes and summits of Pu‘u Poepoe, and Pu‘u Makanaka.

To improve the comparisons, trapping was conducted contemporaneously during the summer sampling period, 15-25 July, 1998, in the summit areas of Pu‘u Hau‘Oki

(Map 2), Wekiu Crater (Map 1), and buffer areas of North Slope Road (Map 3), Pu‘u Mahoe transects (Map 5), and Northwest Pu`u Kea Talus Ridge (Map 6). Inclement weather made some trap collecting impossible, and traps set along Wekiu col and summit ridge were retrieved after winds and fog subsided. These traps were open for 9 days, and trap catches were standardized accordingly. A visual survey of the talus and cinder areas on and near Pu‘u Lilinoe was conducted in July, 1998. Trapping in the buffer areas of Pu‘u Lilinoe (Map 7) and visual surveys of the base of Pu‘u Poliahu, the west slope, and Pu‘u Makanaka occurred during the fall sampling period, 24-27 September, 1998.

We planned to conduct the Wekiu bug assessment of the selected buffer zone and summit habitats during periods of snowmelt when we hypothesized the bugs to be active. However, the low snowfall of the 1997-98 season made that objective impossible to mattaineet.

Statistical Analysis Methodology:

The data collected in Task 4 were binary (presence/absence) and required statistical procedures similar to those used in Task 2. Only the July 1998 trapping data were used in the statistical analysis. This is because both summit and buffer areas were sampled contemporaneously, allowing direct comparisons to be made.

Because habitat types (i.e. summit and buffer) were not assigned at random, the study design for Wekiu bugs and other arthropods in their habitats is called retrospective sampling of observational data. Calculation and reporting of odds is an appropriate analytical tool for this type of data. Fisher's Exact Test is a randomization test that computes the probability values for every permutation of the responses and gives the exact probability of the observed case to occur. This test provides inference about population parameters with random samples from binary observational sampling (Ramsey and Schafer 1997).

Statistical analysis of binary responses leads to conclusions about population proportions and probabilities, which may be stated as inferences about odds, such as the odds of a Wekiu bug occurring in a pitfall trap in a particular habitat. When the question becomes one of interpreting the difference between two habitats, the inference is properly reported as an odds ratio, For example, reporting the odds of finding a Wekiu bug in the summit area as some multiple of the odds of finding a Wekiu bug in the buffer areas. The odds ratio is the only statistic appropriate for comparing two groups of binary responses from observational studies.

Results:

Wekiu bug:

Only six Wekiu bugs were seen during the survey of the buffer zone areas; five were captured in 20 pitfall traps on Pu‘u Mahoe, and one was observed in Pu‘u Makanaka Crater. All were in Type 2 habitat. The lycosid spider was widespread but not abundant. A few were seen but rarely trapped in every area sampled. The endemic moth, *Agrotis* sp., was also widespread in the buffer zone, but was not as common as the lycosid spider. Other resident arthropod species were only rarely observed.

The number of traps in which a Wekiu bug occurred were tabulated for summit and buffer areas (Table VII-1).

Location	present	absent
Summit Area	14	26
Buffer Area	3	22

Table VII-1. Wekiu bug occurrence in pitfall traps
during the 15-25 July 1998 sampling period.

There was convincing evidence that Wekiu bugs are more likely to occur in the summit area than in the sampled buffer areas (p-value = 0.001). The odds of finding a Wekiu bug in a summit area pitfall trap was estimated to be 4.0 times greater than finding a Wekiu bug in a buffer area pitfall trap (95% C.I. 1.3 to 15.5).

Lycosid wolf spider:

The number of traps in which lycosid spiders occurred were tabulated for summit and buffer areas (Table VII-2).

Location	present	absent
Summit Area	2	38
Buffer Area	2	23

Table VII-2. Lycosid spider occurrence in pitfall traps during the 15-25 July 1998 sampling period.

There was no evidence that lycosid spiders are more likely to occur in the summit area than in the sampled buffer areas (p-value = 0.69).

Disturbed vs Undisturbed:

The average capture rate of Wekiu bugs in disturbed areas was 0.27 bugs per 3 day sampling period. The average capture rate of Wekiu bugs in apparently undisturbed areas was 0.11 bugs per 3 day sampling period. There was strong evidence that the Wekiu bug capture rate in disturbed areas was greater than the capture rate in undisturbed areas (p-value < 0.0005).

Location	present	absent
Disturbed	18	52
Undisturbed	9	71

Table VII-3. Wekiu bug occurrence in disturbed and undisturbed Pu‘u Hau‘Oki habitats during the 1997-98 study.

The odds of finding a Wekiu bug disturbed habitat was estimated to be 2.7 times greater than finding a Wekiu bug in an undisturbed habitat (95% C.I.: 1.1 to 6.6).

Discussion:

Wekiu bugs appear to be rare in the buffer zone surrounding the summit area. Only six Wekiu bugs were collected throughout all of the sampling periods from buffer areas, five from Pu‘u Mahoe and one from Pu‘u Makanaka. No other collectors have found Wekiu bugs below the immediate vicinity of the summit area (Ashlock and Gagne 1983). During the 1982 Bishop Museum study, the mean adult/trap/day capture rate ranged from 0.01 to 1.10 below 4,100 m (13,450 ft) but averaged 16.2 adults/trap/day above 4,100 m. In 1982, Wekiu bugs occurred in highest abundance above 4,100 m on Pu‘u Wekiu and Pu‘u Hau‘Oki, with capture rates as high as 95.22 adult bugs per 3 days of trapping in some localities.

The evidence does not support the hypothesis that substrate factors are more important to Wekiu bug distribution than elevation. Significantly fewer Wekiu bugs were collected in Type 2 and Type 5 habitats in the buffer areas than were collected in the same habitat types in the summit area.

It has been hypothesized that Wekiu bugs have some obligatory association with snow and/or permafrost (Ashlock and Gagne 1983). Retreating snow fields were thought to be a source of food for Wekiu bugs, which have been observed feeding on frozen insects that melt out of the margins of snow fields (Howarth and Montgomery 1980). Snow patches remaining after long snowy periods contain abundant trapped food, and these remnant patches survive in nearly identical areas each year. This makes the resource predictable for scavenging arthropods (Ashlock and Gagné 1983). Limited seasonal data collected during this study did not support this hypothesis, but snowfall during the current study was exceptionally low compared to 1982. Permafrost was believed be a source of moisture critical to the easily dehydrated Wekiu bug. Ashlock and Gagne (1983) pointed out that the abdomens of Wekiu bugs are physogastric (swollen) after feeding, and collapse on almost all dry-mounted museum specimens. An adequate supply of moisture may be necessary for Wekiu bug survival; however, no literature is available that suggested permafrost is restricted to summit areas.

Food resources probably do not account for the differences in Wekiu bug occurrences between summit and buffer areas. Arthropod species richness was approximately the same in summit areas and buffer areas, (see Task 5). In captivity, Wekiu bugs survive nicely when fed small flies (W.P. Mull pers. com.). Small flies (Phoridae, Muscidae, Sciaridae, Sepsidae, and Sphaeroceridae) were abundant in both areas. Further study is needed to determine the factors that limit Wekiu bugs to the summit area. Generally, these flies and other weak flying aeolian waifs, which are carried wind currents, may be more common near ridge crests and other areas where wind eddies tend to drop their particulate load. Snowfields chill and trap alighting insects and preserve these for foraging resident scavengers. In the absence of snow, wind-deposited insects can remain active on warm days and possibly avoid scavenging species such as the Wekiu bug.

Lycosid spiders appear to inhabit both summit and buffer areas. There was no statistically significant difference in lycosid occurrence between the areas, (Table VII-2). The capture rates were so low in both areas that statistical comparisons may not reveal true differences. Since lycosids generally feed on active prey, hypothetically they are not as tied to snow fields as the Wekiu bug is thought to be.

The current level of overall arthropod activity is significantly less than that measured in the 1982 Bishop Museum study. The cause of this decline in activity remains unknown. In 1982, and during brief visits in the few years following, Wekiu bugs could be easily observed on Pu‘u Wekiu. More recent observations found Wekiu bug activity in decline. Possible causes for the decline include changing weather patterns, habitat disturbances, presence of harmful alien species, and long-term population cycles.

In all but one case, arthropod activity on Pu‘u Hau‘Oki was greater than or equal to that found on Pu‘u Wekiu. Pu‘u Wekiu is supposedly less disturbed, although substrate disturbance was evident, apparently caused by the greatly increased foot traffic along the ridge and within the crater since the 1982 study. Trap capture rates for Wekiu bugs were significantly higher in disturbed areas than in undisturbed areas. The highest trap capture rates occurred in Pu‘u Hau‘Oki, where inner crater walls and the crater bottom have been modified by observatory construction activity. These results raise the possibility that observatory construction and other human activities have not impacted Wekiu bug or lycosid spider distributions at the summit, outside of the immediate vicinity of the paved and covered areas. It has been hypothesized that Wekiu bugs prefer habitat with loose tephra over ashy substrate (Howarth and Stone 1982). Earth-moving activity may create these conditions in some cases. It should be, understood however, that cause-and-effect inferences cannot be reached in this case because the data are observational. Valid cause-and-effect inferences can only be made with properly designed experiments, in which disturbance levels are assigned at random to experimental units.

The preference of the Wekiu bug for the summit area has important implications for MKSR management. A statistically sound monitoring plan should be designed and implemented. Monitoring, including designed experiments, is required to determine factors influencing Wekiu bug distributions and population changes, and the effectiveness of protection efforts.

VIII. TASK 5. A COMPARISON OF ARTHROPOD DIVERSITY BETWEEN SUMMIT AND BUFFER ZONE HABITATS

Task 5 called for a comparison of arthropod diversity between the summit area and selected sites in the surrounding buffer area within the MKSR. The effort was important, not only to determine where Wekiu bugs and lycosid spiders occurred outside the immediate summit area, but also to ascertain the general distribution of other arthropods in the summit and buffer areas. These other arthropods may be important predators or prey of the Wekiu bug and the lycosid spider.

Questions of Interest:

1. Is there a difference between arthropod diversity in the summit area and surrounding selected "buffer areas" within the MKSR?

2. Is there a sufficient food base for Wekiu bugs and other endemic summit-dwelling arthropods in the buffer zones below the summit area?

Methods:

The arthropods were collected in the same traps used to assess Wekiu bug and lycosid spider activity in Tasks 1, 2, and 4. We identified all specimens to the lowest taxon possible, and compared the species richness in each area. Details of the analysis can be found in the Appendix A. Documentation of Methodology Final Report.

Results:

The results are presented in Table VIII-1. The table is arranged taxonomically by Class, Order, Family, Genus and Species. Information is given about the regional status. Endemic species lives only in Hawaiʻi. Arthropods that were released purposefully for biological control are designated purposeful. Arthropods that arrived in Hawaiʻi by other means are designated adventive. The residence status is also provided. Arthropods that live and reproduce in the MKSR are designated resident. Species transported to the MKSR by winds are designated aeolian. An "X" was placed in the Habitat Occurrence column if that species was collected or observed in that habitat

Table VIII-1. Checklist of Arthropods Species Collected Within The MKSR During 1997-98. Summit Type 2 habitats (scoria habitats) include Pu‘u Wekiu and Pu‘u Hau‘Oki; Summit Type 5 habitats (talus habitats) include the Northslope Plateau. Buffer zone Type 2 habitats include Pu‘u Mahoe and Pu‘u Lilinoe; Buffer zone Type 5 habitats include North Pu‘u Kea Ridge to Pu‘u Mahoe and the base of Pu‘u Lilinoe.

TAXON	**REGIONAL**	**RESIDENCE**	**HABITAT OCCURRENCE**			
FAMILY	**STATUS**	**STATUS**	**TYPE 2**		**TYPE 5**	
SPECIES			**SUMMIT**	**BUFFER**	**SUMMIT**	**BUFFER**
Acari						
Bdellidae						
Undetermined species	unknown	resident	X			
Acaranae						
Clubionidae						
Meriola arcifera	adventive	resident	X	X	X	X
Linyphiidae						
Lepthyphantes tenuis (Blackwall)	adventive	resident	X		X	
More than one undetermined species	unknown	unknown	X	X	X	
Lycosidae						
Lycosa sp.	endemic	resident	X	X	X	X
Salticidae						
One undetermined species	adventive	unknown	X			
Collembola						
Entomobryidae						
More than one undetermined species	endemic?	resident?	X	X	X	X

TAXON	**REGIONAL**	**RESIDENCE**	**HABITAT OCCURRENCE**			
FAMILY	**STATUS**	**STATUS**	**TYPE 2**		**TYPE 5**	
SPECIES			**SUMMIT**	**BUFFER**	**SUMMIT**	**BUFFER**
Coleoptera						
Chrysomelidae						
Altica torquata LeConte	adventive	aeolian	X	X	X	
Cleridae						
Necrobia rufipes (DeGeer)	adventive	aeolian	X		X	
Coccinellidae						
Coccinella septempunctata (L.)	purposeful	aeolian	X	X	X	
Iharmonia conformis (Blaisduval)	purposeful	aeolian			X	
Hippodamia convergens Guerin-Meneville	purposeful	aeolian	X	X		X
Curculionidae						
One undetermined species	adventive	aeolian	X			
Hydrophilidae						
One undetermined species	unknown	unknown			X	
Scarabaeidae						
One undetermined species	purposeful	aeolian		X		
Staphylinidae						
More than one undetermined species	unknown	unknown	X	X	X	X
Diptera						
Calliphoridae						
Lucilia cuprina (Wiedermann)	adventive	resident	X	X	X	X
Calliphora vomitoria (L.)	adventive	unknown	X	X	X	X
At least 3 undetermined species	unknown	aeolian	X	X	X	X
Ceratopogonidae						
Forcipomyia sp.	endemic	unknown			X	X

TAXON	**REGIONAL**	**RESIDENCE**	**HABITAT OCCURRENCE**			
FAMILY	**STATUS**	**STATUS**	**TYPE 2**		**TYPE 5**	
SPECIES			**SUMMIT**	**BUFFER**	**SUMMIT**	**BUFFER**
Chironomidae						
One undetermined species	unknown	unknown			X	
Drosophilidae						
Drosophila suzukii complex	adventive	aeolian	X	X	X	X
Drosophila sp.	adventive	aeolian	X		X	
Ephydridae						
Hydrellia tritici Coquillett	adventive	aeolian	X	X	X	X
Hydrelia sp.	endemic	unknown		X	X	
Lonchopteridae						
Lonchoptera furcata (Fallen)	adventive	aeolian	X	X	X	X
Muscidae						
Atherogona orientalis Schiner	adventive	aeolian	X	X	X	X
Haematobia irritans (L.)	adventive	aeolian	X	X	X	
Stomoxys calcitrans L.	adventive	aeolian		X		
Muscoidea						
One undetermined species	unknown	unknown		X	X	
Mycetophilidae						
Leia sp.	adventive	aeolian			X	
Phoridae						
More than one undetermined species	unknown	unknown	X	X	X	X
Psychodidae						
Psychoda sp.	unknown	unknown	X	X	X	
Sarcophagidae						
More than one undetermined species	adventive	aeolian	X	X	X	

TAXON	**REGIONAL**	**RESIDENCE**	**HABITAT OCCURRENCE**			
FAMILY	**STATUS**	**STATUS**	**TYPE 2**		**TYPE 5**	
SPECIES			**SUMMIT**	**BUFFER**	**SUMMIT**	**BUFFER**
Sciaridae						
Bradysia (?) species 1	unknown	aeolian	X	X	X	
Bradysia (?) species 2	unknown	aeolian	X	X		
Sciara sp.	unknown	unknown		X	X	
Sepsidae						
Sepsis thoracica (Robineau-Devoidy)	adventive	aeolian	X	X	X	X
Sepsis species 1	adventive	aeolian	X	X	X	X
Sepsis species 2	adventive	aeolian	X	X	X	X
Sphaeroceridae						
Copromyza equina	adventive	aeolian	X	X	X	X
Leptocera spp.	unknown	aeolian	X	X	X	X
More than one undetermined species			X	X	X	X
Syrphidae						
Allograpta species	purposeful	aeolian	X	X	X	
Tachinidae						
Gonia pallens Stal	adventive	aeolian	X	X	X	X
Phasiormia pallida Townsend	adventive	unknown			X	
Heteroptera						
Anthocoridae						
Lasiochilus sp.	purposeful	aeolian	X			
Lygaeidae						
Geocoris pallens Stal	adventive	resident	X	X		X
Neacoryphus bicrucis Say	adventive	aeolian	X			
Nysius wekiucola Ashlock & Gagne	endemic	resident	X	X	X	
Nysius (more than one undetermined species)	endemic ?	aeolian	X		X	

TAXON	**REGIONAL**	**RESIDENCE**	**HABITAT OCCURRENCE**			
FAMILY	**STATUS**	**STATUS**	**TYPE 2**		**TYPE 5**	
SPECIES			**SUMMIT**	**BUFFER**	**SUMMIT**	**BUFFER**
Nabidae						
Nabis capsiformis Gemar	adventive	aeolian	X			
Homoptera						
Aphidae						
Aphis sp.	adventive	aeolian				
Delphacidae						
One undetermined species	adventive	aeolian	X			
Psyllidae						
One undetermined species	unknown	aeolian	X	X	X	X
Hymenoptera						
Braconidae						
Apanteles sp	adventive	aeolian	X	X	X	X
Chalcidoidea						
One undetermined species	purposeful	aeolian	X			
Ichneumonidae						
Diadegma blackburni (Cresson)	adventive	aeolian	X			
Ichneumon cupitus Cresson	adventive	aeolian	X	X	X	
Trathala flavoorbitalis (Cameron)	adventive	aeolian	X			
More than one undetermined species	unknown	aeolian	X			
Undetermined micro-Hymenoptera	unknown	unknown	X	X	X	
Vespidae						
Vespula pensylvanica Saissure	adventive	aeolian	X			

TAXON	**REGIONAL**	**RESIDENCE**	**HABITAT OCCURRENCE**			
FAMILY	**STATUS**	**STATUS**	**TYPE 2**		**TYPE 5**	
SPECIES			**SUMMIT**	**BUFFER**	**SUMMIT**	**BUFFER**
Lepidoptera						
Noctuidae						
Agrotis undetermined species	endemic	resident	X			
Oechophoridae						
Agonopterix ulicetella	purposeful	aeolian	X	X	X	X
Psocoptera						
Ectopsocidae						
Ectopsocus sp.	endemic	aeolian	X			
Elipsocidae						
Palistreptus inconstans (Perkins)	endemic	unknown		X		
Lisposcelidae						
Liposcelis divinatorius (Mulleer)	adventive	unknown			X	
Thysanoptera						
Thripidae						
Thrips sp.	endemic	aeolian			X	

Discussion:

We found the species richness in the buffer zone areas to be similar to that found in the summit area. A few species were exclusively found in one or the other of the two areas, however, these species were not abundant. The uneven pattern of their distribution may be an artifact of the sampling methodology, or, because these species are aeolian waifs, their uneven distribution within the MKSR may have been influenced by prevailing winds and wind patterns caused by observatory structures, pu‘us, lava ridges, and the general geomorphology of the physical environment. The species richness of the summit area did not appear to be diminished by the presence of observatory structures. Hau‘Oki crater, surrounded by large observatories, contained most of the species collected in Wekiu crater, where no observatories exist, and potential prey species for both the Wekiu bug and lycosid spiders were abundant in both craters.

We observed that wind-dispersed arthropods were more abundant at the top of Pu‘u Lilinoe than at the base. Wind swirling around the summit of this cone could be expected to drop passively carried arthropods near the summit. There are three physical reasons to support this conjecture: (1) winds from different directions converge at summits, and most fallout occurs at convergence zones; (2) removed from their energy source, upwardly moving currents caused by the warming ground surface are slowed above summits; and (3) surface irregularities such as ridges and summits cause eddy currents that may increase localized fallout.

Two new, presumably resident spider species were collected in the current study, and both appear to be recently introduced alien species. The first, and most common, is an alien linyphiid sheet-web spider, *Lepthyphantes tenuis* (Blackwall), native to Europe. Three presumably native linyphiid spiders, *Erigone* spp., were collected in 1982, but were not found in 1997-98 study. Not all the recently collected arthropods have as yet been identified to species, so some native linyphiid spiders may have been found in the new study. For reasons noted in earlier chapters, not finding native sheet-web spiders in 1997-1998 may be related to the limitations of pitfall trapping, rather than absence from the MKSR.

The other alien spider species found may have more impact on Wekiu bugs. It is *Meriola arcifera* (Simon), a ground hunting spider (family Clubionidae), native to Chile, Bolivia, and Argentina. Like the lycosid spiders, it does not build a web, but actively hunts on the ground surface. *Meriola arcifera* was first collected in Hawai‘i in 1995. It has been found only from upper elevations on the Saddle Road to the summit of Mauna Kea. Within the MKSR, it may be common enough to be preying upon and reducing populations of the smaller native arthropod species, including the Wekiu bug.

IX. NEW QUESTIONS OF INTEREST

New questions of interest have been developed during the course of this study. As data were analyzed, and old hypotheses tested, new hypotheses were generated to explain the distribution and abundance of resident arthropod populations. These new questions of interest may point the way for future work.

We compared the current captured rates of Wekiu bugs to those measured during the 1982 study, and found that Wekiu bug populations have dramatically dropped over the last 17 years. Our study was the first attempt since 1982, to investigate population changes of those arthropods. More frequent and sustained monitoring is necessary to fully document the long-term population fluctuations. Long-term monitoring may also reveal weather, habitat, and ecological changes associated with Wekiu bug population decline and/or increase.

In this study, we tested the hypothesis that Wekiu bug activity has seasonal fluctuations. Although we found no significant seasonal differences, our sample size was small. Our study covered only one and one-half years. With more information collected through long-term monitoring, we may discover significant seasonal patterns.

We surveyed the buffer zone and found habitats similar to those at the summit where the Wekiu bug occurs. Potential habitats were wide-spread throughout the buffer zone. We compared Wekiu bug activity in the summit area to activity in surrounding buffer areas, and discovered significantly more Wekiu bugs at the summit. This finding leads to questions about the conditions that limit the Wekiu bug to the summit. We hypothesized that food resources and predator populations may be different between the two areas. Arthropod collections in the two areas showed that prey diversity was not different. Our trapping methods were specifically designed for Wekiu bugs. These methods may not be as effective at capturing endemic and alien Wekiu bug predators, like lycosid and clubionid spiders. Future studies could be designed to characterize the spatial distributions of potential predators, and compare these to Wekiu bug distributions.

More detailed analysis of microhabitats may also reveal factors influencing Wekiu bug distributions. The Wekiu bug is extremely sensitive to heat. Sub-surface temperature fluctuations thus may be associated with preferred habitat. Wekiu bugs may require loose tephra or similar deposits for refuge, but may actively forage in neighboring habitats. The significantly different capture rates between disturbed and undisturbed habitats may have resulted from the greater efficiency of traps set in ash compared to those set in blocky tephra. Low levels of snow occurring during our study may also be associated with spatial distribution, and apparent population decline. Long-term studies could be useful in characterizing the optimal temperature and moisture regimes, as well as habitat-trap efficiency.

Alien species have been hypothesized to have significant impacts on Wekiu bug populations. Several parasitoid species have been released for biological control of pests in lowland areas, and some of these species were common in our trap collections. We found in our diversity studies that alien species occur in both the summit and buffer areas. New traps, specifically designed to capture alien arthropods, should be developed, and studies implemented to answer questions about alien and predator populations.

A species closely related to the Wekiu bug lives near the summit of Mauna Loa. A reconnaissance of the northern slopes of Mauna Loa during 1998 found the Mauna Loa bug, *Nysius aa* Polhemus (1998), to be apparently much more abundant than its relative on Mauna Kea. The factors causing the decline of the Wekiu bug population on Mauna Kea may not have occurred on Mauna Loa. There is a need to concurrently study Mauna Loa arthropods to determine population changes of the Mauna Loa bug, and differences between Mauna Loa and Mauna Kea habitats. The invasive alien predator *Meriola arcifera* (family Clubionidae), first collected on Mauna Kea in 1995 (Beatty et al. in press), is now abundant within the MKSR and may be impacting native species populations. If these spiders have been not yet invaded Mauna Loa, this may be evidence that alien predator species are associated with Wekiu bug decline. This type of information could be gathered with a properly designed and implemented long-term environmental monitoring program.

X. MANAGEMENT RECOMMENDATIONS

Task 6 required the development of management recommendations for the MKSR to preserve and protect the resident arthropod populations. We offer the following recommendations for consideration.

1. Mitigation of Construction Activity:

a. Minimize introductions of alien species:

Boxes, crates, vehicles, and other containers should be inspected before entry into the summit area. Many alien species are introduced to Hawaiʻi every year. The growing number of non-indigenous species impacts native arthropod populations. The introduction of the wrong alien arthropod may decimate the populations of one or more of the sensitive, endemic, summit-dwelling species. Standard inspection techniques exist and can be put in place in staging areas, before shipping up the mountain. Efforts to eliminate pests can also be made at the port of origin. These techniques should be researched, and a plan for the control of non-indigenous species introductions be developed.

b. Minimize disturbance to habitat:

Construction and construction-related activities should be restricted to approved sites. Areas identified as Wekiu bug habitat should be avoided whenever possible.

c. Garbage collection and containment:

Garbage containers should be covered, and remain covered, while they are within the summit area. We observed open refuse containers during the course of this study. Debris from these containers can easily escape during periods of high wind, which occur almost daily. Collection of escaped debris is of great concern. Habitats are easily disturbed and debris removal may actually do more harm than the actual debris. Techniques for appropriate garbage control and removal should be planned and applied.

d. Dust control:

Strict dust control measures should be initiated and enforced. Ash and other dust are easily moved and distributed by wind. These substances are most likely to be deposited in the same protected pockets in which most of the aeolian food resources for resident arthropod species are found. Excessive dust may reduce the structure and porosity of the scoria habitat used by arthropods

2. Mitigation of Visitor activity:

a. Restricted access:

Areas where Wekiu bug populations are the highest, or where they occur during periods of extremely low population levels, should be placed off-limits to visitors to the MKSR. These areas should be clearly marked and delineated. These areas should include; the summit area, portions of the outer scoria slopes of Pu`u Hauoki and Pu`u Wekiu and, in the buffer area, Pu‘u Mahoe and Pu`u Makanaka.

b. Limit Skiing activity on Mauna Kea:

Skiing and snow play on Mauna Kea should be discouraged and/or restricted to specific sites and times when the snow is deep and impacts would be minimal. Wekiu bug activity is hypothesized to be linked to availability of snow patches. Disturbance of snow-patch habitats during periods of high activity, including mating and foraging may be detrimental to the survival of the Wekiu bug.

c. Public outreach:

Efforts should be made to educate the public about the sensitivity of these unique species to disturbance and how the public can contribute to their protection. IFA representatives should participate in more public outreach and education about their efforts to manage the natural resources of the MKSR. News releases of the findings of this and other studies can be helpful in building an image of cooperation and caring for the IFA. Outreach may also include news releases about efforts to protect the summit flora and fauna.

d. Educational signs:

More signs should be placed in sensitive areas to educate visitors about the impact they may be having on sensitive summit-dwelling species. Information about the fauna and flora of the summit and buffer areas should be thoroughly displayed at the Visitors Center.

3. Habitat restoration:

a. Testing of new habitat restoration methodology:

Studies should be conducted to establish methods for habitat restoration. This may include techniques for constructing islands of Wekiu bug habitat with rubble screened to remove dust.

b. Methods should be investigated for captive rearing and release of Wekiu bugs to enhance populations.

c. All habitat restoration efforts should be planned and implemented as designed experiments. Only designed experiments, with randomization, replication, treatment controls, and control of confounding factors, can yield new knowledge about the direct causes of population increase or decline.

4. A comprehensive monitoring program:

Environmental monitoring is the investigation of the changes in environmental functions, attributes, and characteristics that happen over time. Monitoring provides the information necessary for adaptive management of natural systems, biogeographical areas, and their biotic components. The knowledge gained through a properly designed monitoring program will provide the IFA with inferences about ecological changes and the impacts of its management strategies on MKSR natural resources. The ultimate goal of monitoring is to aid in good stewardship and conservation of the natural world. A Long Term Environmental Monitoring Program (LTEMP) should be designed to collect the best scientific information available, and will ensure the IFA's compliance with all applicable laws and directives.

Clarity of purpose is important in planning a monitoring program. While the most general purposes of monitoring are to learn about environmental changes and to increase understanding of the impacts of management activities on native systems, the IFA may have one or more of the following specific purposes for monitoring natural resources within the MKSR:

- To provide historical records of environmental phenomena, attributes, and characteristics.
- To detect threshold events, or critical levels of environmental phenomena, attributes, and characteristics.
- To detect hazards and risks to valued ecosystem attributes and functions.
- To detect specific changes in the environment.
- To detect trends and/or patterns in those changes.
- To correlate auxiliary attributes and characteristics with trends and patterns of change.
- To predict future changes in environmental functions, attributes, and characteristics.
- To evaluate management activities and provide information useful in modifying management actions.

All these monitoring purposes apply to management and conservation of the natural resources within the MKSR. The MKSR has a unique environment with rare endemic plants and animals. Like most Pacific islands, Hawaiian ecosystems have sustained significant impact from human beings over the last few centuries. These impacts have resulted in alterations, extinctions, and introductions of populations of plants and animals. Detection, prediction, and modification of these environmental changes is vitally important to long-term management of Hawaiian natural resources.

The IFA's management of natural resources needs to be an iterative process of monitoring and management actions on a continuous basis. Observational monitoring, and monitoring of experimental treatments, will increase understanding of ecosystem dynamics and the effects of management actions. Monitoring will serve as a feedback mechanism to promote better integration of conservation efforts. As knowledge accumulates, management strategies will be adjusted, and management will become more effective at achieving their goals. Because of this adaptive benefit, monitoring of long-term ecosystem changes has been recommended as an integral component of conservation-oriented management on most state and federally controlled resource land.

Monitoring change within the MKSR natural areas is complicated by habitat fragmentation, invasion of alien species, development near area boundaries, commercial and recreational use, and natural disturbances. The IFA needs scientifically detailed and reliable information about species within its management jurisdiction, about the impacts of management decisions to those species, and about changes in populations of those species over time.

The difficulties in planning for complex, multi-resource monitoring are mitigated by employing a systematic planning process. The following is a seven-step process for planning of long-term monitoring:

1. Prepare clear statements of the questions of interest.
2. Design the sampling systems
3. Develop sampling protocols for data collection
4. Prepare the data management systems
5. Plan the analysis and interpretation systems
6. Develop a reporting system
7. Develop a monitoring sustainability plan

Each of these seven steps must be undertaken and completed to develop a successful monitoring plan. Furthermore, the steps must be undertaken in a comprehensive manner. Planning decisions made in any one stage affect decisions at all the other stages.

1. Prepare clear statements of the questions of interest.

The first step in developing a monitoring plan requires clearly defining the questions of interest. Key questions are those with answers that can be efficiently estimated, and that yield the information necessary for management decision-making. The monitoring program depends upon identifying the important issues and concerns, and reducing general problems to questions of specific, measurable attributes. Identifying issues of concern will require interviews with IFA personnel, Hawaiian biologists, the University of Hawai‘i, concerned environmental groups, and local citizens. Much effort will be spent investigating the key monitoring questions. Therefore, they must be well-considered and carefully elucidated.

2. Design the sampling systems

The second step in monitoring planning is designing the sampling systems. It is expected that several quantifiable questions of interest will be elucidated in the first stage. Each key question must then be evaluated for utility and efficiency. Proposed questions of interest must be prioritized, based on the projected costs to collect the data and the projected value of the knowledge to be gained. The effort expended to answer each question must lead to useful gains in knowledge and remain within budgetary and logistical constraints. Some questions are simply too expensive to answer efficiently. Some questions cannot be answered without controlled experimentation. Designed experiments, based on expected operational activities, should be incorporated into the sampling system.

Expertise in statistics, biometrics, and cost/benefit analysis are required for sampling system design. Some of the design techniques which should be applied are power analysis, cost allocation analysis, sampling structure determinations, sample size determinations, scale evaluations, randomization, replication, blocking, and covariate determinations. Schedules of sampling efforts must also be developed. Monitoring is the investigation of change over time, so timing and frequency of sampling are essential elements in sampling system design.

3. Develop sampling protocols for data collection

The third step in monitoring planning is to develop the data collection system(s). Sampling protocols are necessary to standardize data collection. Data gathered in the future must be comparable to data gathered today in order to statistically detect significant environmental changes. Protocols should include specific methods to be used for every habitat and each animal or plant type, descriptions of the tools necessary for data collection, and randomization schemes for determining trap placement, quadrat size, or measurement device location. Protocols should be field-tested to assure feasibility and efficiency. Field data collection crews should then be trained and tested in the use of the sampling protocols.

4. Prepare the data management systems

The fourth step in monitoring planning is the preparation of a data management plan. The data collected in each sampling exercise must be checked for errors and corrected. Data sets must be entered into a database for easy access and retrieval. The database must be properly archived to be useful many years in the future. Monitoring requires comparisons of attributes over sometimes lengthy periods of time. It is important to recognize that data sets are expensive to obtain, and hence have significant monetary value. Not only will the archived data contribute information for future management decisions on Mauna Kea, they will also provide information potentially useful for management elsewhere in Hawaiʻi and the Pacific. Locational data should be incorporated into the existing IFA GIS.

5. Plan the analysis and interpretation systems

The fifth step in monitoring planning is the development of an analysis and interpretation plan. Statistical analysis and scientific interpretation are necessary to produce logical inferences and new knowledge from monitoring data. The sampling design and the statistical structure of the data must be accounted for in the analysis plan. Techniques of Exploratory Data Analysis (EDA), graphics, statistical distribution tests, data transformations, and modeling should be developed in the plan. Much of the inference gained through monitoring will be evaluated by means of mathematical models. Such models include time trend analysis, survival analysis, growth and mortality models, and population change models. The appropriate model forms should be specified in the planning process. Failure to specify analytical forms could cause gaps and inefficiencies in sampling design and data collection. Prior planning for analysis will help ensure completeness and timeliness of the sampling and prevent wasteful effort.

6. Develop of a reporting system

The sixth step in monitoring planning is the development of a plan for the reporting the results. The new knowledge acquired through monitoring should be communicated to responsible IFA personnel and interested agencies for use in determining management decisions. Charts, tables, and maps may be the immediate products of analysis but do not stand alone. Reports should be carefully planned and clearly written with consideration of the intended audience and the appropriate application of the findings. The reports should clearly explain the results of data analysis and the implications to natural resource management. Monitoring reports need to be produced on time and updated on a regular schedule.

7. Develop a monitoring sustainability plan

The seventh step in monitoring planning is development of a monitoring sustainability plan. Institutional commitment must be developed to secure annual budgetary planning for future monitoring efforts. Monitoring happens in the context of time. Environmental changes, and trends in those changes, are often detected only after several years of data collection. The IFA must consider the LTEMP to be a permanent part of it management strategy. Involving other stakeholders will help to build community commitment to the LTEMP. Planning for sustainability and commitment is a necessary element in long-term environmental monitoring.

In summary, monitoring of ecosystems and natural resources within the MKSR should be comprehensive, cost-effective, statistically designed, executed with analytical integrity, presented to decision makers by way of meaningful reports, charts, and maps, and updated regularly over many decades. Consideration and application of the seven steps will improve efficiency and effectiveness of knowledge acquisition and guarantee managers, regulators, scientists, and citizens useful information on which rational management decisions may be based. Conscientious planning and implementation of a properly designed monitoring plan will provide the IFA the necessary prerequisites for continued good stewardship of its properties.

XI. ACKNOWLEDGEMENTS

We thank Dan Polhemus and Ron Englund, B. P. Bishop Museum, Honolulu; Pete Oboyski, USGS/BRD, Volcano; Fred Stone, Hawai‘i Community College, Hilo; and Steve Montgomery, Waipahu, for their assistance in the field, project design, and interpretation of the results, Matt Kweskin, USGS/BRD, Volcano, and Mike Richardson, USFWS, Honolulu, also assisted in the field work. We thank Mike Dubrasich, of Pacific Analytics, for his biometrical assistance and editorial comments. We further thank Teresa Leon, UH, Manoa, and Joe Beatty, Southern Illinois University, Carbondale, for assistance in identifying the spiders, and Sabina Swift, Gordon Nishida, and Keith Arakaki of Bishop Museum for assistance with curation of the specimens. This study was made possible through a contract with the Institute for Astronomy, to whom we offer our sincere appreciation for their contributions to the study of the resident arthropod community within the Mauna Kea Science Reserve. The cover illustration of *Nysius wekiuicola* was drawn by Mr. C. Sanchez, University of the Philippines, and is from Ashlock and Gagné (1983).

Contribution No. 1999-006 to the Hawai‘i Biological Survey.

XII. LITERATURE CITED

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XIII. MAPS