Bogs and Pigs Don't Mix

Bogs punctuate the rain forest throughout East Maui. High in the Hāna section of the rain forest on the northeastern flank of Haleakalā is a scattering of "montane bogs." These openings of low vegetation, surrounded by rain forest, are permanently saturated—or nearly so. These montane (or mountain) bogs sit on relatively level sites within an otherwise steeply sloping, deeply eroded rain forest terrain high on the slopes of Haleakalā. Under the bogs, usually within two meters (6.5 feet) of the soil surface, is a layer that water cannot easily filter through. Because of this layer, the bogs act as a catchment for the rainwater that falls at a rate exceeding ten meters (400 inches or around 33 feet!) per year.

These montane bogs support a unique community of native grasses, sedges, and herbs. Dwarfed shrubs and trees such as *ʻōhiʻa (Metrosideros polymorpha)* also occur in bogs. Within the bog, shrubs such as *ʻōhelo* (*Vaccinium reticulatum)* grow smaller and closer to the ground than they do outside the waterlogged bog environment.

Montane bogs are found in rain forests on the islands of Kauaʻi, Oʻahu, Molokaʻi, Hawaiʻi and Maui. By the early part of the 20th century, naturalists had described most of the major bogs on the Hawaiian Islands—even those on Puʻu Kukui (West Maui). But getting to the bogs on Haleakalā is not an easy job. One naturalist who explored Hawaiian bogs in the early 1900s wrote of the terrain around the bogs:

> The entire windward slope of the Hale-a-ka-la calderon is characterized by torrential precipitation. A large part of the upper jungle is inaccessible unless the party is equipped with machetes and axes. The complete exploration of this deeply eroded and densely vegetated area lies in the future.
>
> —*V. MacCaughey*

Despite visits by an occasional, adventurous naturalist, a thorough investigation of the bogs on Haleakakā did not begin until the 1970s. Since then, several field biologists have made plant surveys and other observations, studied plant succession in and around the bogs, and monitored plant growth in the bogs. And now, getting there

Hāna High Elevation Montane Bogs: Facts and Figures

- Rainfall tops 1000 centimeters (400 inches) per year in many of the montane bogs on Haleakalā.
- The bogs within the Hāna rain forest are located high up in the rain forest at elevations from 1450 to 2270 meters (4756 to 7446 feet). Montane bogs are also found scattered throughout the East Maui rain forest.
- There are seven major bogs in the Hāna rain forest on East Maui. Five are located within Haleakalā National Park. The other two, along with several smaller bogs, are located on state-owned conservation land.
- Bogs cover hundreds of acres of the rain forest on East Maui.
- Fifteen endemic plant species are largely confined to these bogs. Some bog species used to be found elsewhere in the rain forest, but grazing goats and cattle, along with rooting feral pigs, have all but eliminated their habitat outside the bogs.

is at least a little bit easier—*if* you have access to a helicopter and permission to fly into this remote and off-limits area of the Park!

It's a Bog's Life

Bog plants are adapted to a unique set of environmental conditions. The montane bogs in the Hāna rain forest are located in an extremely wet area. Clouds cover the bogs almost continually, precipitation is high, and drainage is poor. Here are some other features of the bog environment:

An Oreobolus *bog in its natural state (Photo: Courtesy of Betsy Gagné)*

- High water tables and low temperatures slow decomposition. Buildups of waterlogged and underdecomposed organic material (such as dead roots and leaves) mean low pH and low levels of available oxygen. In part because of these characteristics, bogs are typically deficient in nutrients for plant growth.

- Water tends to be relatively stagnant in bogs. During and after heavy rains in the East Maui bogs, water travels laterally toward sinkholes, moving nutrients around in the bog, removing toxins, and providing aeration for plant roots.

- Extended periods of high solar radiation dry out the normally wet bogs. Bogs on East Maui can be subjected to extended warm, sunny, and dry periods. During these periods, which can last up to several months in rare instances, plants may wilt, die, or lose foliage or growing tips. Some plants are more susceptible to this kind of exposure than others.

- Occasional winter frost and wind damage may help to keep most forest species from becoming established in the bogs. In the bogs, tree cover offers no shelter from frost and wind. The exposed plants can be damaged or killed by frost and the high winds that sometimes follow cold snaps. Researchers have observed that woody plants and ferns are more vulnerable to damage than some of the main bog species such as native sedges, grasses, geranium, and *ʻōhelo*.

Hogs in the Bogs

In the 1970s, around the same time as biologists started paying more attention to the bogs, another visitor started coming around: the feral pig (*Sus scrofa*). Feral pigs are descendants of European hogs brought here by Cook and other Europeans who followed him, beginning in 1778. These hogs, whether escaped from captivity or intentionally released, reverted to a wild (feral) state. They may have interbred with the pigs already on the Hawaiian Islands, introduced by ancient Polynesians. The smaller Polynesian pigs were more likely to stay around homes and villages; because of their size and

Pig damage in a bog—the foreground is relatively undamaged while the area where the researcher is walking has been uprooted. (Photo: Courtesy of Betsy Gagné)

domestication, they were not a large threat to native plants and animals. Today's feral pigs are a different story.

Hawaiian ecosystems evolved without large land mammals such as pigs. The plants have no defenses such as thorns or poisons to protect themselves from grazing or browsing animals. From the pig's perspective, the rain forests and grasslands of Maui and other Hawaiian Islands provide plenty of food and only one predator—humans.

When pigs feed in the rain forest, there is no mistaking that they have been there. Large areas may look like a rototiller has gone through, churning up the soil and uprooting plants. Pigs root in the soil for earthworms and larvae. They also feed directly on plants, exhibiting a strong preference for *hāpu'u* (Hawaiian tree-fern, *Cibotium glaucum*) and other native ferns and native lobeliads. In the bogs, pigs eat the central growth stem of the rosette-shaped *Plantago pachyphylla* as well as other plants, and uproot entire areas of vegetation. Pigs can return to bogs and other areas of the rain forest time and time again, allowing plants little opportunity to recover.

Pigs are one of the reasons why researchers started focusing more attention on bogs. Between 1979 and 1988, the National Park Service (with help from volunteer groups such as the Sierra Club) fenced all of the major bogs in Haleakalā National Park. While the fencing project was going on, researchers studied the ongoing effects of pig rooting in unfenced bog areas as well as the recovery of native plant communities in one of the fenced bogs.

Researchers say that the bogs of Haleakalā are rich with opportunities for studying how species adapt to extreme environments. Looking for insights into evolutionary processes, researchers will continue to study these bogs.

Lobelia gloria-montis *grows at the drier margins of bogs, in the rain forest, and on ridge lines. It forms flowering spikes as tall as 4 meters (13 feet).*
(Photo: Arthur C. Medeiros)

'Apapane
This native bird commonly ventures into the bogs from the surrounding rain forest habitat.
(Photo: Eric Nishibayashi)

Monitoring Revegetation in Greensword Bog

In the late 1970s, researchers working in the Hāna rain forest started noticing signs of pigs rooting in Greensword Bog, but it was not until May 1981 that the pigs came to the bog in full force. In the summer of 1981, a group of Haleakalā National Park staff and volunteers put a hog-wire fence around the perimeter of Greensword Bog.

Greensword Bog was named for the Maui greensword—a relative of the *ʻāhinahina* (Haleakalā silversword)—that grew in and around the bog. But in June 1981, there were no greenswords to be seen in the bog. In fact, there was very little vegetation of any sort left in the central part of the bog.

Pig damage in a bog
(Photo: Betsy Gagné)

Once the pigs were fenced out, researchers set up a monitoring study aimed at documenting the natural revegetation of the area. They were curious about how well the native vegetation would reestablish itself and whether nonnative plant species would become established in the bog. They were also interested in studying the "succession" of plants—which plants would take off quickly in the disturbed environment, which would grow more slowly, and how the balance between species would change over time as the plant community reestablished itself.

Once a year for seven years, researchers visited the bog to survey the vegetation in the area. Here is how the study worked:

1) Establishing study plots.

Researchers set up five 10-meter transects (lines) in the most disturbed part of Greensword Bog. The end points of each transect were marked with a 5/8" PVC (poly-vinyl chloride) pipe stuck in the ground. Each time the researchers came to sample the plants, they stretched a metric tape between the ends of each transect. They constructed a one-meter square frame from PVC pipe and used it to define one-meter plots along both sides of the transect. They simply moved the plot frame one meter at a time, using the markings on the metric tape as a guide.

Because the researchers left the PVC pipes marking the transect ends in the ground, they were able to sample virtually identical one-meter square plots each year. With ten plots on each side of the five transects, researchers sampled 100 plots altogether, representing the worst-disturbed areas of the 2 1/2-acre bog.

2) Making observations

Each year when they came to study the bog vegetation, researchers set up the plots and began sampling them. A researcher would identify all of the different plant species present in a plot and visually estimate the percentage of the ground area within the plot covered by each species. Estimates were rounded to the nearest five percent. If researchers estimated the cover area at less than 2.5 percent, it was recorded as one percent.

Two researchers sampled each plot independently, making their own cover estimates for each plant species. Workers then compared estimates, agreeing on the values to be recorded in the data file. To supplement this information, researchers took photos of each transect and of plot #5 of each transect.

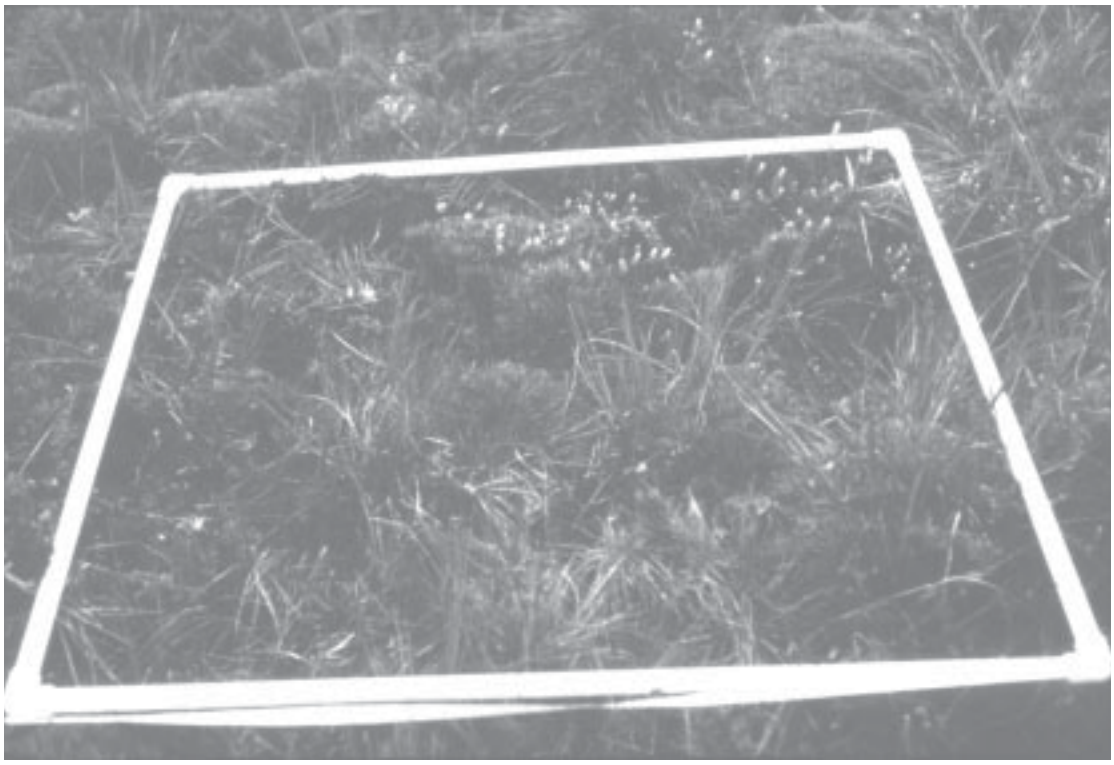
3) Analyzing data

In order to analyze the data they collected over the seven years of the study, researchers used two basic concepts: cover and frequency.

"Frequency" refers to how many plots a particular plant species or type appears in. Frequency is expressed as a percentage of the total number of plots. When researchers are studying a large area with many plots, calculating frequency helps them understand how widely distributed throughout the whole site the species is.

"Cover" refers to the area of ground covered by the plant species or type. It is expressed as a percentage of the total ground area within a plot. When studying a large area with many plots, researchers calculate the total cover of each species by finding the mean of the cover value from all of the plots.

In order to interpret the results of a monitoring study, researchers need a point of comparison, or "baseline data." In their study of Greensword Bog, researchers used two different data sets for comparison. One baseline was the initial survey of the study plots, which was conducted six weeks after the fence was constructed. This data allowed researchers to quantify the condition in which



PVC plot frame used in Greensword bog study
(Photo: Arthur Medeiros and Besty Gagné)

the pigs had left the bog's vegetation. Every year after that, the data gathered could be compared to this baseline to gauge the changes.

The other point of comparison in this study was a survey of Greensword Bog vegetation completed by Alvin Y. Yoshinaga in 1973. Although there may have been some pig damage to the bog prior to Yoshinaga's study, it was minimal. The data he gathered provide a useful approximation of the pristine condition of the bog.

The researchers learned that the dominant bog species (*Carax echinata* and *Oreobolus furcatus*) recovered quickly once they were protected from pig digging. Another species, *Deschampsia nubigena (*a native grass that is common in higher-elevation grasslands and seems to do well in other pig-disturbed areas), increased steadily, surpassing its 1973 abundance in both frequency and cover.

Other plants that were less common to begin with had not fully recovered by the end of the study period. For example, the Maui greensword (*Argyroxiphium grayanum*), which pigs had eliminated from the central part of the bog, only very slowly reestablished seedlings in the central bog. In 1973, the greensword had eight-percent cover and 76-percent frequency. By 1987, it covered only one percent of the study area with an 18-percent frequency.

In the first three years, the percentage of bare ground within the study site decreased dramatically from 94 percent in 1981 to only 12 percent in 1984. By the end of the study, only five percent of the ground was bare. Introduced species did not become established within the disturbed area. In fact only eight nonnative plant seedlings were seen in the plots during the course of the study. Researchers recorded all of them and then pulled them out.

Overall, researchers concluded that feral pig damage in certain bogs on Haleakalā may be at least partly reversible. Bogs such as Greensword Bog that are dominated by *Oreobolus* seem to be resistant to invasion by nonnative species. This may be due in part to the fact that *Oreobolus* forms dense mats of foliage and may literally crowd out nonnative plants. Studies in the bogs dominated by *Carex echinata* have shown that these bogs are more susceptible to invasion by nonnative plant species once they have been disturbed.

If protected from repeated pig disturbance, *Oreobolus* is able to recover by reseeding itself. This happened in Greensword Bog in about three years. Less common plants recover much more slowly, and researchers speculate that some rare species may not recover at all. Over time and with continued protection from pigs, researchers are hopeful that Greensword Bog will one day look much as it did in 1973.

Greenswords growing in a montane bog
(Photo: Betsy Gagné)

Analyzing the Data

At the end of these questions (p. 28), there is a table that summarizes some of the data collected by researchers studying Greensword Bog. Use this table to answer the following questions.

1) What are the two dominant plant species in Greensword Bog? Explain your reasoning.

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2) Identify two species that by 1987 *had not* regained their 1973 cover *and* frequency levels.

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3) Identify two species that by 1987 *had* regained or surpassed their 1973 cover *and* frequency levels.

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4) There are two native species (*Dichanthelium cynodon* and *Metrosideros polymorpha*) that by 1987 had *surpassed* their 1973 frequency levels but had only *matched or not regained* their 1973 cover levels. Offer an explanation for this phenomenon.

5) In February 1987, cold weather came to Greensword Bog. As happens occasionally, frost covered the ground and the plants. Researchers suspect that the frost caused a setback in the recovery of some plant species in Greensword Bog. When researchers sampled the site in the summer of 1987, they found that certain species seemed to have suffered seedling mortality during that frost. Using the table of results, identify two species for which this *might* be true. Explain your reasoning.

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Use your brains (not the data table) to answer the following questions:

6) Name and explain two variables (besides frost) that could affect the reproduction, growth and re-establishment of native plants in Greensword Bog. Tell whether you think each factor would have a positive or negative effect and explain why.

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7) If you were designing a vegetation study, how might the kind of vegetation you are going to look at affect the size of your plots?

Greensword Bog Vegetation Monitoring Data

wpecies		T98T	T98U	T983	T984	T985	T986	T987	T973
Carex echinata	%g	4	13	29	37	39	29	38	26
	%j	1SS	1SS	1SS	1SS	1SS	1SS	1SS	98
Oreobolus furcatus	%g	1	3	11	43	44	53	34	43
	%j	1SS	1SS	1SS	1SS	1SS	1SS	1SS	1SS
Deschampsia nubigena	%g	X	1	1	4	6	12	18	S
	%j	17	2S	27	52	64	74	8S	14
Dichanthelium cynodon	%g	1	2	2	4	1	1	1	4
	%j	91	82	85	85	88	84	79	14
Vaccinium reticulatum	%g	X	X	X	X	X	S.6	S.7	2
	%j	38	3S	25	31	34	46	42	96
Plantago pachyphylla	%g	X	X	X	X	X	X	X	4
	%j	5	3	3	3	5	8	6	6S
Argyroxiphium grayanum	%g	-	-	X	X	X	1.6	X	8
	%j	-	-	5	5	6	19	18	76
Metrosideros polymorpha	%g	-	-	-	X	X	X	X	S
	%j	-	-	-	13	8	32	15	6
Viola maviensis	%g	-	-	-	-	-	-	-	S
	%j	-	-	-	-	-	-	-	2
Sadleria pallida	%g	-	-	-	X	X	X	X	S
	%j	-	-	-	1	17	12	1	4
Drypoteris hawaiiensis	%g	X	X	X	X	X	1	2	2
	%j	22	25	23	29	44	6S	61	58
f areGroundRdeadGvegetation	%g	94	81	57	12	11	4	5	15