Rain Forest Unit 4

Impact of Invaders: Pigs in Forests and Bogs

Overview

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, support a unique community of native grasses, sedges, and herbs. Dwarfed shrubs and trees such as *ʻōhiʻa (Metrosideros polymorpha)* also occur in bogs.

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 a thorough investigation of the bogs on Haleakakā was not to 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.

Until the1970s, the bogs on Haleakalā were relatively undisturbed. Then researchers began to see and record signs of damage caused by feral pigs rooting in the bogs. Starting in 1979, the National Park Service began fencing some of the bogs to protect them from feral pig impacts.

This unit introduces students to the montane bog environment of Haleakalā and the threats posed by feral pig damage. It also helps them learn basic field observation skills similar to those used by researchers observing the revegetation of Greensword Bog after it was fenced.

Length of Entire Unit

Five class periods

Unit Focus Questions

1) What makes the montane bogs in the Hāna rain forest unique?

2) What threats do feral pigs pose to bogs and other parts of the rain forest?

3) How do researchers study bog vegetation and monitor its regrowth after disturbances by feral pigs?

Unit at a Glance

Activity #1

Small Wonders: Bogs in the Haleakalā Rain Forest Slide Show

Students watch and discuss a slide show to learn about montane bogs and the threats that feral pigs pose to this unique habitat within the Haleakalā rain forest.

Length
One class period

Prerequisite Activity
None

Objectives
- Become aware of and appreciate the montane bog environment on Haleakalā.
- Describe basic features of the montane bog environment.
- Describe the personal significance of the bogs and the impacts of feral pigs.

DOE Grades 9-12 Science Standards and Benchmarks
None

Activity #2

Bogs and Pigs Don't Mix

Students read about Greensword Bog and the damage that feral pigs did to the native plant community there. A reasoning activity helps them identify the main threats that pigs pose to rain forest ecosystems including bogs. Students also read about vegetation monitoring at Greensword Bog and analyze data from that study.

Length
One class period, preceded and followed by homework

Prerequisite Activity
Activity #1 "Small Wonders: Bogs in the Haleakalā Rain Forest Slide Show"

Objectives
- Describe the basic biology of montane bogs.
- Identify major threats that feral pigs pose to rain forest ecosystems including bogs.
- Interpret results of a study of vegetation recovery in a bog area that was damaged by feral pigs then fenced to exclude them.
- Describe factors that could affect reestablishment of the native bog plant community after disturbance.

DOE Grades 9-12 Science Standards and Benchmarks
DOING SCIENTIFIC INQUIRY: Students demonstrate the skills necessary to engage in scientific inquiry.
- Formulate scientific explanations and conclusions and models using logic and evidence.

USING UNIFYING CONCEPTS AND THEMES: Students use concepts and themes such as system, change, scale, and model to help them understand and explain the natural world.
- CHANGE: Explain the effect of large and small disturbances on systems in the natural world.

"MĀLAMA I KA 'ĀINA" SUSTAINABILITY: Students make decisions needed to sustain life on Earth now and for future generations by considering the limited resources and fragile environmental conditions.

- CONSERVATION OF RESOURCES: Analyze, evaluate and propose possible solutions in sustaining life on earth, considering the limited resources and fragile environmental conditions.

Activity #3

School Grounds Vegetation Surveys

Students conduct a survey of vegetation on school grounds, using methods similar to those used by researchers studying the Haleakalā bogs.

Length
Three class periods

Prerequisite Activity
None

Objectives

- Demonstrate basic field study skills including establishing sample plots and observing and recording vegetative cover.
- Analyze data from vegetation surveys using the concepts of frequency and cover.

DOE Grades 9-12 Science Standards and Benchmarks
DOING SCIENTIFIC INQUIRY: Students demonstrate the skills necessary to engage in scientific inquiry.

- Organize, analyze, validate and display data/information in ways appropriate to scientific investigations, using technology and mathematics.

LIVING THE VALUES, ATTITUDES, AND COMMITMENTS OF THE INQUIRING MIND: Students apply the values, attitudes, and commitments characteristic of an inquiring mind.

- HONESTY: Report findings accurately without alterations and draw conclusions from unaltered findings.

Enrichment Ideas

- Extend Activity #2 by researching the impact of feral pigs on Hawaiian rain forests and preparing multimedia presentations, research papers, or oral reports.

- Research the cultural importance of pigs in traditional Hawaiian culture and the importance of pig hunting in today's society.

- Debate maintaining pig populations for hunting versus eliminating pigs to protect forests.

- Characterize environmental conditions in bogs in greater depth than is covered in Activities #1 and #2 and describe plant adaptations that enable them to survive in these conditions.

- Use field guides to identify the plants they find in their "School Grounds Vegetation Survey" plots (Activity #3). Because most of the plant species are likely to be nonnative, it may not be easy to identify them, even with the aid of a field guide. Here are a few field guides that might be helpful:
  - Haselwood, E. L., and G. G. Motter, *Handbook of Hawaiian Weeds*, University of Hawai'i Press, Honolulu, 1991.
  - Whistler, W. A., *Wayside Plants of the Islands*, Isle Botanica, Honolulu, 1995.
  - Wagner, et al., *Manual of the Flowering Plants of Hawaii*, 1990.

- Set up a monitoring project on school grounds that lasts for a few weeks, a whole semester, or longer. If there is a site that's been disturbed by recent construction, students could monitor the regrowth of vegetation. This kind of monitoring project could help students understand the concept of succession.
  - — To simulate a disturbance, students could sample vegetation in several plots then dig up the ground in some of them to monitor the growth of vegetation on the disturbed ground. The undisturbed sites could provide a base for comparison.
  - — Another way to simulate a disturbance is to cover some plots with a dark-colored tarp for a couple of weeks. When the tarps are removed, have students sample the areas again, listing whether the plants are alive or dead. Sampling the plots periodically after that will enable students to monitor recovery of plant species.

Resources for Further Reading and Research

You may request a copy of the following three reports from the Pacific Cooperative Studies Unit, University of Hawai'i, 3190 Maile Way, St. John 410, Honolulu, HI 96822.

Loope, Lloyd L., Arthur C. Medeiros, and Betsy H. Gagné, "Aspects of the History and Biology of the Montane Bogs, Technical Report 76," in *Studies in Montane Bogs of Haleakala National Park*, Cooperative National Park Resources Studies Unit, University of Hawai'i at Manoa, 1991.

Loope, Lloyd L., Arthur C. Medeiros, and Betsy H. Gagné, "Recovery of Vegetation of a Montane Bog Following Protection from Feral Pig Rooting, Technical Report 77," in *Studies in Montane Bogs of Haleakala National Park*, Cooperative National Park Resources Studies Unit, University of Hawai'i at Manoa, 1991.

Arthur C. Medeiros, Lloyd L. Loope, and Betsy H. Gagné, "Degradation of Vegetation in Two Montane Bogs: 1982-1988, Technical Report 78," in *Studies in Montane Bogs of Haleakala National Park*, Cooperative National Park Resources Studies Unit, University of Hawai'i at Manoa, 1991.

Activity #1

Small Wonders: Bogs in the Haleakalā Rain Forest Slide Show

● ● ● Class Period One *Bogs Slide Show*

Materials & Setup

- "Small Wonders" slide show (included with this curriculum)
- "Small Wonders" slide show script (pp. 6-8)
- Slide projector and screen

Instructions

1) Show and narrate the "Small Wonders" slide show.

2) Use the journal ideas as discussion questions, or have students work on them during the remainder of the class and as homework.

Journal Ideas

- Have you ever overwatered a houseplant or left it without enough sunlight? What happened? (If you've never done this, what do you think would happen?) Why would most types of plants have difficulty living in bog areas with heavy cloud cover, frequent fog, and standing water or soggy soils?
- Besides bogs, what are some other waterlogged habitats? Find pictures on the Internet or in magazines to illustrate some of these environments. How do they seem to compare with the bogs on Haleakalā?
- How would you feel if you were the person who discovered the pig damage in Greensword Bog? What would you want to do about it?
- Do you think it's worth the effort to put up fences to keep pigs out of bogs and other parts of the rain forest and then to continually patrol and repair the fences? Why or why not?

Assessment Tools

- Journal entries
- Participation in class discussion

Slide Show Script

Small Wonders: Bogs in the Haleakalā Rain Forest

Slides #8 and #12: Jeff Bagshaw
All other slides: Betsy Harrison Gagné

Slide 1

High in the rain forest on the northeastern flank of Haleakalā is a scattering of montane bogs. This is Mid Camp Bog, with the East Maui endemic greenswords in bloom. These plants are in the same family as the well-known *ʻāhinahina*.

Slide 2

In general, bogs sit on relatively level sites within an otherwise steeply sloping, deeply eroded rain forest terrain. They are apparently underlain by a compacted, relatively impervious layer that impairs drainage. This is Lake Waiʻānapanapa, a freshwater lake surrounded by bog vegetation.

Slide 3

Why do we call some vegetation "bog vegetation" even though it may grow along the shores of a lake, like Lake Waiʻeleʻele. . .

Slide 4

. . . or the banks of a stream like this one in the rain forest above Hāna?

Slide 5

The type of vegetation that grows in bogs is adapted to a unique set of environmental conditions that are unfriendly to most other plants. These tussocks are dominated by the moss *Racomitrium lanuginosum*. This bog community occurs only on East Maui and only in areas with heavy cloud cover, frequent fog, and a clay substrate that is mostly impervious to water. In other words, only in bogs!

Rainfall tops 400 inches per year in many of the montane bogs on Haleakalā. Much of the available moisture is a result of plants intercepting clouds, and the moisture they take directly from the clouds is called "fog drip."

Slide 6

This is Greensword Bog, and here is another bog plant common in bogs on East Maui and other Hawaiian Islands: *Oreobolus furcatus*. This plant is a "sedge," a grass-like plant that grows in wet areas. What is the difference between a sedge and a grass?

(Answer: Sedges have triangular stems and grasses have round stems. Some people like to remember this with the saying "Sedges have edges.")

Slide 7

Bogs provide habitat for the *pinaʻo*, the native Hawaiian dragonfly. This newly emerged dragonfly is perched on *Carex nealae.* What kind of plant is this? (Answer: It's a sedge.)

The *pinaʻo* is the largest native Hawaiian insect and the largest insect found in the United States.

Slide 8

One of the interesting characteristics of bog vegetation is that, unlike the giant *pinaʻo,* vegetation that grows in bogs tends to be dwarfed because of low levels of nutrients and oxygen in the bog's water-logged soil. Occasional winter frost and wind damage, and extended warm, sunny, drying periods are other challenges encountered by plants growing in montane bogs.

What is this tree? (Answer: *ʻŌhiʻa.*) *ʻŌhiʻa* can grow to be quite a large tree in a forest environment.

Slide 9

But in a bog, this is what *ʻōhiʻa* looks like. It's dwarfed!

Slide 10

Here's another tiny plant of the bogs, the Maui violet (*Viola mauiensis).* This plant is endemic to Maui and Molokaʻi, and survives in only the most pristine bog areas.

Slide 11

This is *Lobelia gloria-montis*, a Maui endemic, that grows at the drier edges of bogs, in the rain forest, and on ridge lines. Unlike its tinier bog companions, this species forms flowering spikes that can tower over ten feet tall. Like the Maui violet, it's a plant that's extremely vulnerable to disturbance.

Slide 12

But what could be disturbing the bogs on East Maui and the unique plants, like this *Geranium hanaense* that is found only in East Maui bogs?

Slide 13

Pigs. Feral pigs are currently the primary force damaging the remaining Hawaiian rain forest, including the bogs.

Slide 14

Although pigs were brought to the Hawaiian Islands by Polynesians as early as the fourth century A.D., the current severe environmental damage inflicted by pigs apparently began much more recently and seems to have resulted from the release of domesticated pigs originally from European stock.

This is Greensword Bog, and we saw a slide of this bog earlier when we were talking about sedges. The earlier slide was taken in 1974, when the bog was in nearly pristine condition. By 1981, here's what large parts of Greensword Bog looked like. This

damage was caused by feral pigs grazing on and uprooting the vegetation in search of grubs and introduced earthworms.

Slide 15

In order to protect bogs from pig damage—and to allow damaged bogs to recover—volunteers, National Park Service employees, and others have helped to fence many East Maui bogs. Here, Art Medeiros and Terry Lind help to fence a bog above Greensword Bog.

Once fences were erected around the bogs, the pigs had to be removed from inside the fences. And it's an ongoing job to patrol the fence lines, fix areas of broken fence, and make sure no pigs have slipped through the gaps.

Slide 16

After the pigs were fenced out, researchers began monitoring how the bogs recovered. This meant making extensive and regular observations of the plant life in the bogs.

Slide 17

Researchers are monitoring the regrowth of bog species such as this greensword (*Argyroxiphium grayanum*), the plant after which Greensword Bog was named. . .

Slide 18

. . . *Phyllostegia ambigua*, a fragrant mint found only in the wettest areas of Maui and Mauna Loa on the island of Hawai'i. . .

Slide 19

. . . and *Clermontia grandiflora*, one of 22 species in the Hawaiian endemic genus. It occurs only in the rain forest and margins of bogs on Maui, Moloka'i, and Lāna'i.

Slide 20

Keeping pigs out of pristine rain forest areas, as well as out of special areas such as the bogs, is one way that people are protecting Maui's unique plant and animal life for future generations. Fenced areas such as Greensword Bog provide an excellent opportunity to learn about how plant communities recover after disturbances, knowledge that may be applicable to the restoration of other natural areas in the future.

Activity #2

Bogs and Pigs Don't Mix

● ● ● In Advance *Student Reading*

- As homework reading, assign the Student Page "Bogs and Pigs Don't Mix" (pp. 19-21).

● ● ● Class Period One *Impact of Pigs in the Rain Forest*

Materials & Setup

For each group of three to four students

- One set of "Pig Impact Clue Cards" (master, pp. 16-18)

For each student

- Student Page "Bogs and Pigs Don't Mix" (pp. 19-21)
- Student Page "Monitoring Revegetation in Greensword Bog" (pp. 22-24)
- Student Page "Analyzing the Data" (pp. 25-28)

Instructions

1) Begin the class by asking students for their ideas about the main problems linked with feral pigs feeding in rain forests and bogs. Make a list on the board or overhead.

2) Divide students into groups of three to four and hand out one set of "Pig Impact Clue Cards" to each group. Tell students that scientists and resource managers have identified five main problems linked with feral pigs feeding in the rain forest. Their task is to use the clue cards to identify those five problems. (If students need help figuring out how to use the cards, suggest that they read each card first and then try to group together cards that relate to each other. There are between two and five clue cards that describe each of the five problems.)

3) Groups should write a description of each of the five problems and the clue cards they used to arrive at each.

4) Once groups have completed their work, have groups report their results by having each group describe one problem and the clue cards they used to arrive at it. Continue until all the problems have been reported. There may be more than five, depending upon how groups interpreted the clues. Use the teacher background "Five Problems With Pigs" (pp. 11-12) as a guide, but also be prepared to accept other well-reasoned conclusions.

5) Open a class discussion about the impact of pigs in the rain forest.

6) Assign the Student Pages "Monitoring Revegetation in Greensword Bog" and "Analyzing the Data" as homework.

Journal Ideas

- Do you think that pigs should be fenced out of intact rain forest on Haleakalā and special areas such as bogs? Why or why not?
- How are pigs important in traditional Hawaiian culture? Do they have the same significance today?
- Researchers monitoring the regrowth of vegetation in Greensword Bog saw only eight nonnative plant seedlings in the plots during the course of their study. Researchers recorded these plants and then pulled them out. How might that approach have influenced the regrowth of vegetation in the bog? Do you think this approach is acceptable for scientific researchers in this situation? Why or why not?

Assessment Tools

- Group descriptions of problems associated with feral pigs in the rain forest
- Participation in group work and class discussion
- Student Page “Analyzing the Data” (teacher version, pp. 13-15)

Teacher Background

Five Problems with Pigs

Problem #1: Pigs spread nonnative plants and create conditions conducive to their growth in the rain forest.

- The fruit of strawberry guava, a nonnative plant that has become established across thousands of acres of rain forest on Haleakalā, are a preferred food source of pigs.
- Strawberry guava seeds pass through pigs' digestive tracts and are still able to germinate when excreted. Other plants, such as clidemia, produce seeds that stick to pigs' coats.
- Strawberry guava and many other nonnative plants thrive in areas where the native plant cover has been disturbed and the soil exposed. They germinate, grow, and reproduce rapidly.

Problem #2: Pigs feed on native plants, reducing their populations and sending ripple effects through the natural systems that depend on them.

- Pigs selectively seek out certain native plant species for food. Plants with particularly fragile stems and leaves, such as many of the lobeliad species, have drastically declined because of predation by pigs.
- Of all the layers of rain forest vegetation, the ground layer of mosses and small ferns has probably been altered most by pigs, but they have not been totally eliminated because they survive as epiphytes, using other plants for support, especially the trunks of native tree ferns.
- Starch from native tree fern trunks (such as the *hāpu'u*) is a favored food source of pigs. Pigs knock over mature tree ferns and eat them.
- In bogs, pigs eat the central growth stem of the rosette-shaped *Plantago pachyphylla* as well as other native plants, such as those in the lobeliad group.
- Some native bird species have specialized beaks for extracting nectar from lobeliad flowers, their preferred source of food.

Problem #3: Pig wallows become breeding grounds for the mosquitoes that carry avian malaria, which threatens native rain forest birds and reduces their potential range.

- Pigs create wallows in the rain forest, which form pools of standing water.
- Mosquitos breed in open water.
- Nonnative mosquitos transmit avian malaria, a disease introduced in the early 1900s along with nonnative birds.
- Many Hawaiian honeycreepers, including the rare *'ākohekohe*, are highly susceptible to avian malaria.
- Mosquitos rarely occur above 1200 meters (3936 feet) in elevation.

Problem #4: Pigs rooting and wallowing expose soils to compaction and erosion, lessening the ability of these areas to support vegetation.

- Pigs can uproot entire areas of vegetation in bogs and other parts of the rain forest. The exposed areas they leave range from a square meter to several hundred square meters.
- Pigs rooting and wallowing clear the forest floor of leaf litter and mix up the fertile, organic humus with the lower layers. The soil in these areas often becomes compacted and difficult for plants to grow on or susceptible to erosion without the protection of plant cover.

Problem #5: Over time, repeated pig disturbances disrupt the cycles and fertility of the native forest, down to the fundamental level of decomposition and soil formation.

- Pigs often revisit the same areas time after time.
- Soil-dwelling larvae and earthworms are a preferred food source of pigs, which they find by rooting in the soil.
- The fertility of rain forest soils depends upon a cycle of decomposition and soil formation in which leaf litter and other organic matter is recycled from the forest into the soil by microorganisms.

Teacher Version

Analyzing the Data

At the end of these questions, there is a table that summarizes data collected by researchers studying Greensword Bog. [Data table included in student version only.] Use this table to answer the following questions.

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

   Carex echinata and *Oreobolus furcatus* are the dominant plant species. Each has 100 percent frequency and coverage of over 33 percent. The other plant species do not have nearly as high frequency and coverage.

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

   These species could include:
   - *Dichanthelium cynodon*
   - *Vaccinium reticulatum*
   - *Plantago pachyphylla*
   - *Argyroxiphium grayanum*
   - *Viola maviensis*
   - *Sadleria pallida*

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

   These species could include:
   - *Carex echinata*
   - *Deschampsia nubigena*
   - *Metrosideros polymorpha*

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.

The most likely explanation is that the plants of these species are smaller and probably younger plants than had occurred in 1973. Seedlings may have established themselves in more plots but together would not cover as much ground as fewer, more developed individuals.

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.

These species could include:

- *Oreobolus furcatus* (53 percent coverage in 1986 dropped to 34 percent in 1987)
- *Dichanthelium cynodon* (84 percent frequency in 1986 dropped to 79 percent in 1987)
- *Vaccinium reticulatum* (46 percent frequency in 1986 dropped to 42 percent in 1987)
- *Plantago pachyphylla* (eight percent frequency in 1986 dropped to six percent in 1987)
- *Argyroxiphium grayanum* (19 percent frequency and 1.6 percent coverage in 1986 dropped to 18 percent and negligible in 1987)
- *Metrosideros polymorpha* (32 percent frequency in 1986 dropped to 15 percent in 1987)
- *Sadleria pallida* (12 percent frequency in 1986 dropped to one percent in 1987 — again, an example of a decline that began earlier than 1987)

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.

Look for clear reasoning and plausibility. Possible answers include:

- The number of surviving plants to produce seed, send out vegetative sprouts, or expand (in the case of species that grow in clumps such as *Carex echinata* and *Oreobolus furcatus*)—More survivors should have a positive effect on reestablishment

- Distribution of surviving plants—If surviving plants are distributed throughout the bog, rather than in just one place, reestablishment should be enhanced.

  *TEACHING EXAMPLE: In Greensword Bog, pig damage had eliminated greenswords (*Argyroxiphium grayanum*) from the central bog. Greenswords survived only at the bog margins. Reestablishment of greensword frequency and cover in the central bog has been slow.*

- Whether the species is well-adapted to disturbed areas—Species that are better adapted to disturbed areas should have an advantage.

  TEACHING EXAMPLE: In Greensword Bog, the native grass Deschampsia nubigena *continually increased, surpassing its 1973 occurrence.* Deschampsia *occurs in nearby bogs under a regime of chronic pig disturbance as well as in the natural disturbance of windward stream sources.*

- Competition from other species—A slow-growing species might have difficulty re-establishing itself in the face of competition from other, faster-growing species. Or a species could reestablish quickly but then decline due to competition from other species.

  *TEACHING EXAMPLE: In Greensword Bog,*Oreobolus furcatus *expanded quickly. In the sixth year, it declined sharply (from 53 percent cover to 34 percent) with* Carex echinata *and* Deschampsia nubigena *overtopping it and reducing the amount of sunlight available to it.*

- Other sources of seedling mortality such as excessive sunlight or unusually dry conditions—These would have a negative effect on reestablishment.

- Alteration or compaction of the soil—These would probably have a negative effect on reestablishment.

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?

The basic answer is that larger vegetation generally requires larger plots and smaller vegetation requires smaller plots.

Pig Impact Clue Cards

Cut on dashed lines

The fruit of strawberry guava, a nonnative plant that has become established across thousands of acres of rain forest on Haleakalā, are a preferred food source of pigs.	Strawberry guava seeds pass through pigs' digestive tracts and are still able to germinate when excreted. Other plants, such as clidemia, produce seeds that stick to pigs' coats.
Strawberry guava and many other nonnative plants thrive in areas where the native plant cover has been disturbed and the soil exposed. They germinate, grow, and reproduce rapidly.	Pigs selectively seek out certain native plant species for food. Plants with particularly fragile stems and leaves, such as many of the lobeliad species, have drastically declined because of predation by pigs.
In bogs, pigs eat the central growth stem of the rosette-shaped *Plantago pachyphylla* as well as other native plants, such as those in the lobeliad group.	Pigs can uproot entire areas of vegetation in bogs and other parts of the rain forest. The exposed areas they leave range from a square meter to several hundred square meters.

Cut on dashed lines

Of all the layers of rain forest vegetation, the ground layer of mosses and small ferns has probably been altered most by pigs, but they have not been totally eliminated because they survive as epiphytes, using other plants for support, especially the trunks of native tree ferns.	Starch from native tree fern trunks (such as the *hāpu'u*) is a favored food source of pigs. Pigs knock over mature tree ferns and eat them.
Some native bird species have specialized beaks for extracting nectar from lobeliad flowers, their preferred source of food.	Pigs create wallows in the rain forest, which form pools of standing water.
Mosquitos breed in open water.	Nonnative mosquitos transmit avian malaria, a disease introduced in the early 1900s along with nonnative birds.

Cut on dashed lines

Many Hawaiian honeycreepers, including the rare *ʻākohekohe*, are highly susceptible to avian malaria.	Mosquitos rarely occur above 1200 meters (3936 feet) in elevation.
Pigs often revisit the same areas time after time.	Pigs rooting and wallowing clear the forest floor of leaf litter and mix up the fertile, organic humus with the lower layers. The soil in these areas often becomes compacted and difficult for plants to grow on or susceptible to erosion without the protection of plant cover.
Soil-dwelling larvae and earthworms are a preferred food source of pigs, which they find by rooting in the soil.	The fertility of rain forest soils depends upon a cycle of decomposition and soil formation in which leaf litter and other organic matter is recycled from the forest into the soil by microorganisms.

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 re-cover.

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.

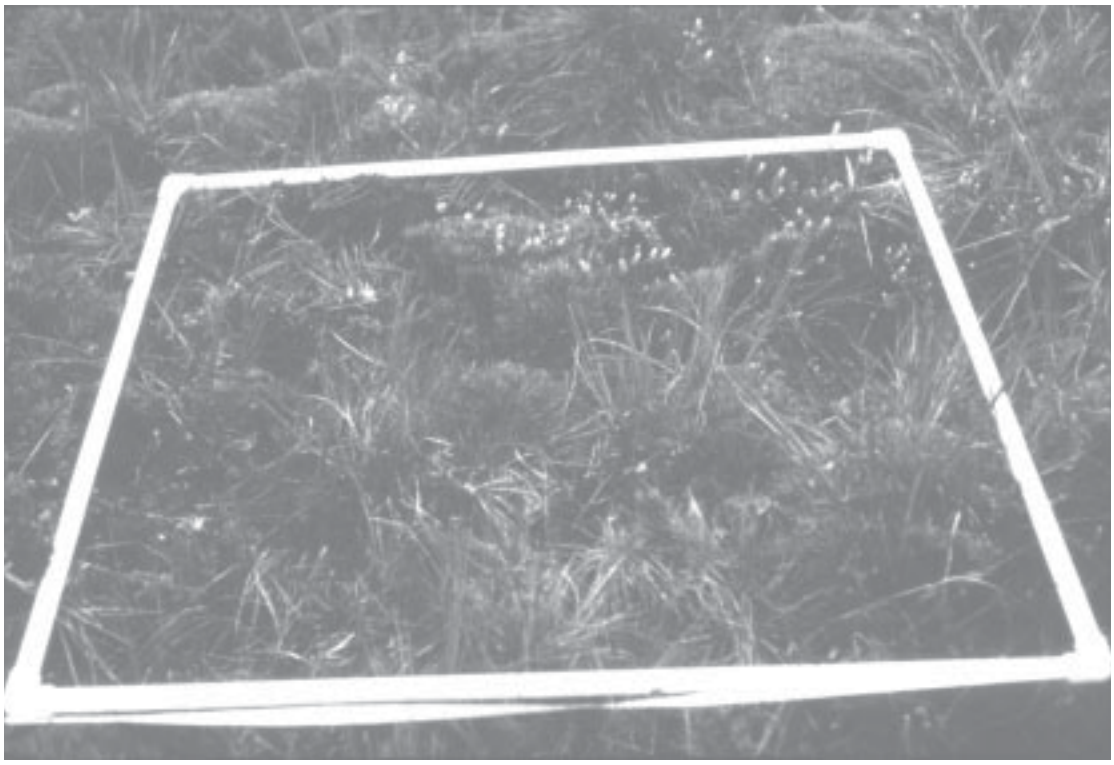
3) Analyzing data

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.

•

•

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

•

•

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

•

•

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.

•

•

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.

•

•

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

Species		1981	1982	1983	1984	1985	1986	1987	1973
Carex echinata	%C	4	13	29	37	39	29	38	26
	%F	100	100	100	100	100	100	100	98
Oreobolus furcatus	%C	1	3	11	43	44	53	34	43
	%F	100	100	100	100	100	100	100	100
Deschampsia nubigena	%C	X	1	1	4	6	12	18	0
	%F	17	20	27	52	64	74	80	14
Dichanthelium cynodon	%C	1	2	2	4	1	1	1	4
	%F	91	82	85	85	88	84	79	14
Vaccinium reticulatum	%C	X	X	X	X	X	0.6	0.7	2
	%F	38	30	25	31	34	46	42	96
Plantago pachyphylla	%C	X	X	X	X	X	X	X	4
	%F	5	3	3	3	5	8	6	60
Argyroxiphium grayanum	%C	-	-	X	X	X	1.6	X	8
	%F	-	-	5	5	6	19	18	76
Metrosideros polymorpha	%C	-	-	-	X	X	X	X	0
	%F	-	-	-	13	8	32	15	6
Viola maviensis	%C	-	-	-	-	-	-	-	0
	%F	-	-	-	-	-	-	-	2
Sadleria pallida	%C	-	-	-	X	X	X	X	0
	%F	-	-	-	1	17	12	1	4
Drypoteris hawaiiensis	%C	X	X	X	X	X	1	2	2
	%F	22	25	23	29	44	60	61	58
Bare ground/dead vegetation	%C	94	81	57	12	11	4	5	15

Activity #3

School Grounds Vegetation Survey

● ● ● In Advance *Selecting a Survey Site*

- Look around the grounds for a site where students will be able to establish several one-meter-square plots with a range of plant species and cover density to survey (e.g., probably not on the lawn!). Look for an area that has vegetation that is mostly low-lying.

● ● ● Class Period One *Vegetation Survey*

Materials & Setup

Per group of three to four students

- Four large, four- to six-inch nails or tent stakes, with their tops painted orange
- Five meters of string
- One-meter measuring stick
- Student Page "Conducting Your Vegetation Survey" (pp. 32-36).
- Ten copies of "Vegetation Survey Data Sheet" #1 and #2 from the student page (pp. 35-36)

Instructions

1) Begin the vegetation survey activity, following the instructions given on the Student Page "Conducting Your Vegetation Survey." Here are the basics:
   - Each student team establishes a one-meter-square plot.
   - Each team draws a map of the survey site that includes all of the plots. As a class, they agree on (or you impose) a numbering system so that each plot has an identifying number.
   - Each team surveys the vegetation in its plot and records its observations on "Vegetation Data Sheet #1."

2) Leave at least the corner stakes of each plot in the ground overnight. You may leave the string that marks the plot boundaries, as well, if the study site is out of the way.

● ● ● Class Period Two *Vegetation Survey, Continued*

Instructions

1) Continue the vegetation survey activity, following the instructions given on the Student Page "Conducting Your Vegetation Survey." Here are the basics:
   - Teams "swap" plots with another team, surveying the vegetation in the other team's plot and recording their observations.
   - The pairs of teams that swapped plots compare each team's recorded observations of the two plots with the partner team's observations. Since each of these two teams has surveyed the same plots, they can look for differences in their observations, figure out why these differences

exist, and go back and look at the plots again to try to reach an agreement. Student teams should note the differences on the student page as well of whether/how they resolved this difference. (Comparing notes and working out disagreements like this is similar to the process that researchers in Haleakalā used when they monitored revegetation in Greensword Bog.)

● ● ● Class Period Three

Materials & Setup

- "Cover and Frequency Chart" (master, p. 31)
- Overhead projector and screen

Instructions

1) Put the blank "Cover and Frequency Chart" on the board or overhead.

2) Record data for all of the plots on this chart. Ask each team to contribute its findings. Because students did not identify the species growing in their plots but rather made sketches, completing the chart for the whole class may be a bit of a challenge. Do the best you can, asking student teams to compare sketches when they need to decide whether they have identified the same species or type of plant as another team.

3) Using this class chart, illustrate the difference between the concepts of "frequency" and "cover."
   - "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. (Frequency is a meaningful calculation only if one is observing more than one plot; otherwise, the frequency can only be zero or 100 percent.) 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 cover value from all of the plots.

4) With the whole class, discuss the findings of their vegetation surveys and what they learned from doing the surveys.

Journal Ideas

- How do you think vegetation surveys could be used as a conservation tool in rain forests, bogs, and other ecosystems on Haleakalā?
- When scientists design vegetation studies, they need to decide plot size and how many plots to use. What do you think scientists need to consider when making those decisions?
- Find photographs of different kinds of vegetation from the Internet or magazines. What size plot would you use to survey each different kind? Why?

Assessment Tools

- Student Page "Conducting Your Vegetation Survey"
- Participation in group work and class discussion
- Journal entries

Cover and Frequency Chart

Plant Type	Percent Cover Plot #1	Percent Cover Plot #2	Percent Cover Plot #3	Percent Cover Plot #4	Percent Cover Plot #5	Mean Cover Percent	Frequency

Conducting Your Vegetation Survey

You and your team will be conducting a vegetation survey similar to the surveys used by researchers to study changes in bog vegetation over time. A vegetation survey is an inventory of plants. When repeated surveys are done in the same sites over time, that is called "monitoring." Researchers monitor areas if they want to know about a process such as regrowth of vegetation or "succession" (how the composition of plant species at a site changes over time).

It would be very difficult and time-consuming to look at all of the vegetation in a large area such as one of the Hāna rain forest bogs, which can cover several acres. So researchers set up smaller areas called "plots" to study in depth. You will use plots to conduct your own vegetation survey on the school grounds.

Step One: Set Up Your Plots

1) Choose a spot for your plot. Your teacher will show you the general area in which each team will set up its separate plot.

2) Use wooden or metal stakes to mark the corners of a one-meter square area. Measure carefully one meter between the stakes, and make sure your plot is square.

3) Tie one end of a string to one of the stakes. Run the string around the outside of the corner stakes, looping it around each stake to hold it in place. When you get back to the stake you began with, tie the other end of the string to that stake, too. Now you have created a string square that measures one meter on each side. Inside the square is your plot.

Step Two: Make a Map of the Whole Site

1) All of the plots together make up the research site. With your team members, make a map of this site on the "Map of the Study Site" sheet.

2) Now work with the whole class to give each plot a number so the data from all of the plots can be analyzed together later. Note these plot numbers on your map.

Step Three: Survey Your Plot!

1) Look at the plants that are growing in your plot. Make a record of these plants, using the "Vegetation Survey Data Sheet #1."

   For now, **fill out the first four columns of this form**. You will make notes about what kinds of plants you see in your plot and how much of the ground they cover. Sketches of the plants will help you avoid duplication and compare notes later with teams surveying other plots. You will also make an estimate of how much bare ground there is in your plot.

   Since you are not identifying each of these plants by species for this activity, you will need to give each plant type you find and record a descriptive name. Your naming scheme could be something like "Grass #1," "Grass #2," "Flowering Plant #1," and so forth. Or you could use more descriptive labels, such as "Broad-Leaved Grass," "Long-Stemmed Grass," "Plant With Small White Flowers," and so on.

Step Four: Survey Another Team's Plot

1) "Swap" plots with another team. That team will survey the vegetation in your plot, and your team will survey the vegetation in theirs.

2) Do the vegetation survey on the other team's plot, filling in "Vegetation Survey Data Form #2" with your results.

3) Now compare results with the other team. Working with one plot at a time, compare your data forms. Look for differences in your observations such as these:
   - Did one team see a type of plant that the other did not observe?
   - Did one team make a distinction between similar-looking plants that the other team treated together as one plant type? For example, many grasses look similar but may have subtle differences in coloration, leaf shape, or seed heads. One group may have lumped all these grasses together, while the other group split them into separate types.
   - Are your estimates of ground cover percentages for each type of plant different?

   Go back to the plot to work out your differences and come up with results that both teams agree with. Record these adjustments on your data forms.

   One difference that you are likely to find is that the two teams gave the plants different descriptive names. Between the two teams, you will need to agree on one descriptive name for each plant type, so you will be able to compare data and results.

   Move to the second plot when you are finished comparing and adjusting results for the first plot.

Step Five: Compile Your Class Findings

In class, your teacher will help you create a table that summarizes the findings of all of the research teams and do some basic analysis of your data.

Map of the Study Site

In the space below, draw a map that includes all of the plots created by your class. Include any landmarks or notes about direction (north, east, etc.) that will help you orient the map later and locate the plots.

With the whole class, agree on a number to identify each one of the plots. For example, you may decide to number the plots in order from east to west, or if the plots are in a rough circle, you could number the plots in sequence around the circle. It does not matter what kind of numbering scheme you come up with, as long as everyone in the class uses the same one.

Vegetation Survey Data Sheet #1

Plot #:

Names of team members:

Descriptive name for plant			
Plant description			
Sketch of the plant			
Estimate percentage of plot covered by this plant (round to nearest five percent)			
Notes on • differences between teams surveying this plot • resulting data sheet changes			

Vegetation Survey Data Sheet #2

Plot #:

Names of team members:

Descriptive name for plant	Plant description	Sketch of the plant	Estimate percentage of plot covered by this plant (round to nearest five percent)	Notes on • differences between teams surveying this plot • resulting data sheet changes