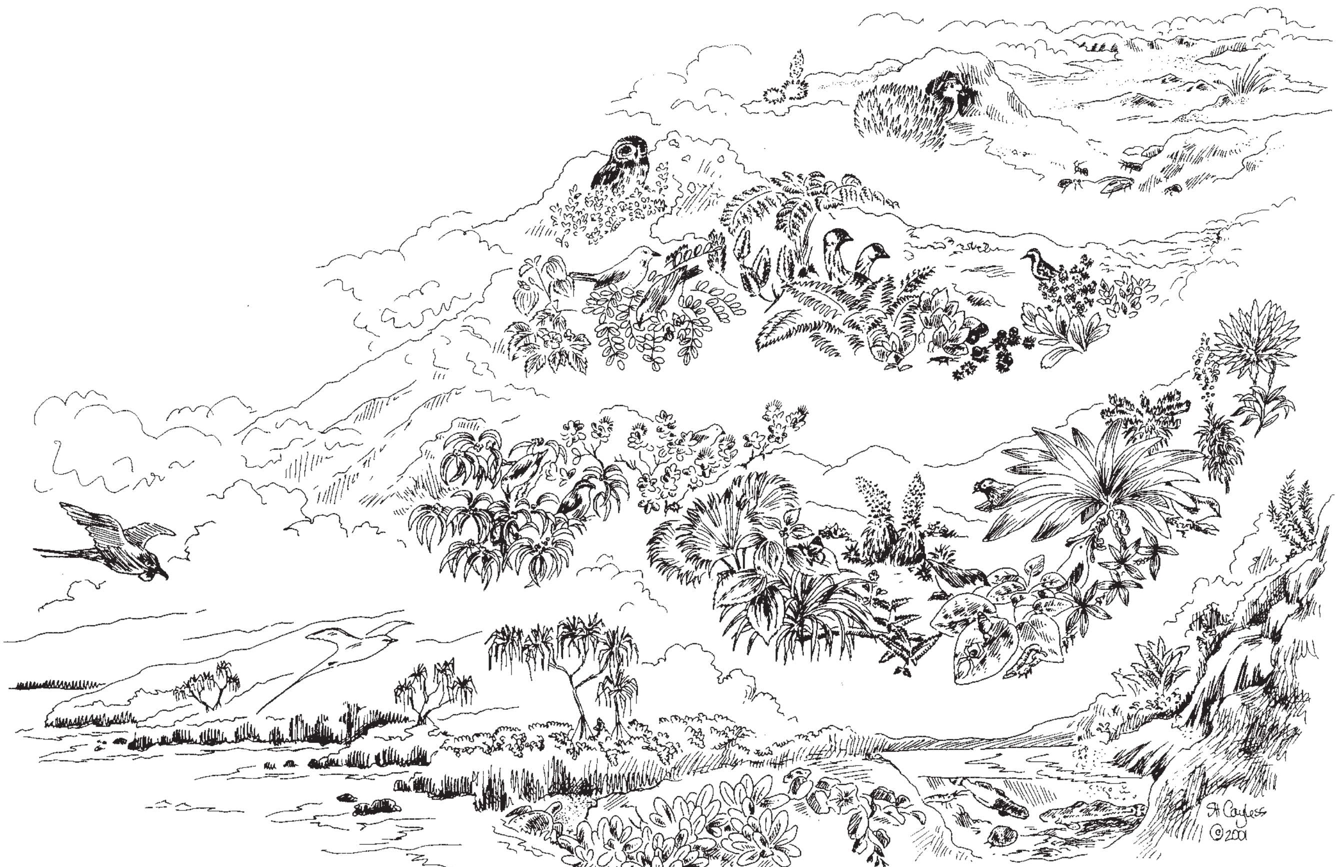
Hōʻike o Haleakalā

Haleakalā revealed: an opening to view our past and embrace our future
Reveal yourself, summit to sea



A Multidisciplinary, Science-Based
Environmental Education Curriculum for High Schools

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Produced by
Hawaiʻi Natural History Association
Nā Kumu o Haleakalā
Haleakalā National Park
The Nature Conservancy

Major funding provided by the Strong Foundation
Additional support provided by the Alexander & Baldwin Foundation,
Atherton Family Foundation, Fred Baldwin Memorial Foundation, and Cooke Foundation, Limited

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Foreword

Nā Kumu o Haleakalā is a partnership on the island of Maui, Hawaiʻi, comprised of teachers from public and private high schools, members of interested community organizations, and staff from the Hawaiʻi Natural History Association, Haleakalā National Park, and The Nature Conservancy. The *Nā Kumu* partnership has worked with a highly qualified curriculum writing and development team to produce the beginnings of a comprehensive environmental education curriculum, *Hōʻike o Haleakalā*, specific to Maui to promote understanding of island ecosystems, a feeling of shared ownership, and a commitment to active stewardship. The target group is primarily high school level, though testing will occur in the local community college and in intermediate schools, as well. The effort was initiated by the National Park Service and local teachers in 1996, and gradually gathered momentum until 1999, by which time sufficient funding had been raised from several private sources to move ahead. The partnership has recently completed ecosystem-based modules for aeolian, rainforest, and the coastal/marine zones of Haleakalā. Future plans call for these to be followed by modules on dryland forest, the subalpine zone, watersheds, and a culminating module on alien species.

Although not entirely conceived as such originally and having much broader educational objectives, *Hōʻike o Haleakalā* can be thought of as an innovative effort at educating local students to understand the overwhelming effects of invasive alien species (IAS) on biodiversity, agriculture, health, economy, and quality-of-life of an oceanic island ecosystem, and to obtain long-term public support of and participation in such efforts. Each ecosystem-based module has one or more units on the effects and/or future threats of alien species. Haleakalā National Park is the most biologically intact summit-to-the-sea reserve in the Hawaiian Islands and among the most important reserve sites in the United States for conservation of biodiversity. However, the park's future depends on resource managers' success in combatting invaders already present and on efforts to prevent additional IAS from establishing on the island of Maui. Since oceanic islands are particularly vulnerable to biological invasions, IAS threats to Hawaiʻi and to Haleakalā National Park on Maui are an order of magnitude greater than threats to most other U.S. national parks. The red imported fire ant and Asian longhorn beetle are not yet established in Hawaiʻi, but both have been recently intercepted in quarantine. Unless major action is taken – a circumstance which will require solid public support — invasions can be expected to erode the biological integrity of oceanic island ecosystems, eventually even the last strongholds of the endemic island biota.

Lloyd Loope
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Introduction

Hōʻike o Haleakalā

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Project Background and Purpose

There are some 6,000 high school students in Maui County. Many of them have never seen a native bird or experienced a native Hawaiian forest. Many of them have no reference point, no experience to know whether the birds they see or the forests they visit are native to the Hawaiian Islands.

This lack of knowledge and experience may not be surprising. Roughly 75 percent of the original Hawaiian forest is gone and the remnants of native forest that remain tend to be difficult to access. Forests, scrublands, and coastal areas dominated by nonnative species are all many Hawaiian residents know. Over 100,000 species of plants alone have been introduced to the Hawaiian Islands since the arrival of the first Polynesians, and many of these now predominate in areas once covered by native vegetation. Furthermore, while the Hawaiian Islands make up well under one percent of the total land mass of the United States, 75 percent of the country's recorded plant and bird extinctions are of Hawaiian species.

Intimately tied to the land, traditional Hawaiian culture, values, and ways of life have declined along with the native plants and animals. Today's residents have little connection to the land—and little connection with the achievements and customs of the ancient Hawaiians. Like many native Hawaiian birds, insects, and plants, Hawaiian cultural values sometimes seemed threatened by extinction—through lack of awareness and understanding.

Hōʻike o Haleakalā aims to help sustain the native Hawaiian landscape and culture by helping students establish and deepen connections to the land and the culture it supports. Project goals are to enable high school students in Maui County—and elsewhere throughout the Hawaiian Islands and beyond—to:

- Gain a greater understanding of island ecosystems;
- Develop an awareness of relationships between people and the environment;
- Build observation, critical-thinking, and decision-making skills;
- Feel a sense of inspiration for and shared ownership of natural areas; and
- Become informed decision-makers active in the stewardship of their island home.

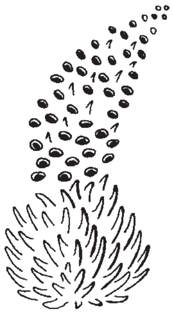
From Vision to Reality

Since 1996, educators from public and private Maui high schools, Haleakalā National Park, Hawaiʻi Natural History Association, The Nature Conservancy, and members of several community groups have been sharing ideas for improving natural history education in Maui County's secondary schools. Out of these discussions came the idea to, in effect, bring the mountain and its fascinating array of natural systems to the classroom.

Hōʻike o Haleakalā is a fulfillment of that vision. This classroom-based curriculum provides educators with background information, resources, teaching suggestions, and activities for teaching science and other academic skills in the context of topics and issues relevant to Haleakalā, Maui, and the other Hawaiian Islands.

Hō‘ike o Haleakalā is a multi-disciplinary, science-based environmental education curriculum that supports State of Hawai‘i high school educational standards, particularly in the science disciplines. Each activity is correlated to state science standards, offering educators a way to fulfill educational requirements using local ecosystems and issues as a context. These materials help you bring science home for your students while fostering a strong science background and critical-thinking skills.

Today's young people have the future of Hawai‘i in their hands. They need to know the value of our natural and cultural environment before they can be active stewards. *Hō‘ike o Haleakalā* is a celebration of this unique heritage, an exploration of the modern landscape, and an invitation to stewardship.

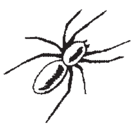


How to Use This Curriculum

Hōʻike o Haleakalā can be used to structure a semester-long (or longer!) course focusing on native ecosystems and natural resource management issues. Alternatively, the modules, units, and activities in this curriculum may be taught separately. Activities may be infused into standard science classes and some are also suited to use in language arts, mathematics, Hawaiian studies, or social studies classes.

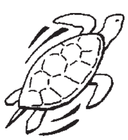
Curriculum Components

The *Hōʻike o Haleakala* curriculum is divided into four modules, each of which covers a discrete ecosystem on Haleakalā. The modules—and the icons used to represent the ecosystems—are:



Alpine/Aeolian
The wolf spider (*Lycosa hawaiiensis)* is an endemic species found only near the summit of Haleakalā.

Rain Forest
The *ʻākohekohe* or crested honeycreeper (*Palmeria dolei*) is an endemic forest bird once found on both Maui and Molokaʻi but now found only on East Maui. It is endangered.



Coastal
The *honu* or green sea turtle (*Chelonia mydas*) is an indigenous reptile that spends much of the year in the coastal waters around the main Hawaiian Islands, migrating up to 800 miles to the Northwestern Hawaiian Islands for summer nesting season. The *honu* is listed as a threatened species.

Marine
The *humuhumunukunukuapuaʻa* or Picasso triggerfish (*Rhinecanthus rectangulus*), a common fish on shallow reef flats, was voted the Hawaiʻi State Fish in 1984. Its Hawaiian name means "nose like a pig."

You'll find the icon for each module in the header of each page of that module.

All of the pages associated with the curriculum as a whole (such as this introduction or the glossary) are indicated by an icon depicting *ʻāhinahina*, the Haleakalā silversword (*Argyroxiphium sandwicense* subsp. *macrocephalum*). The *ʻāhinahina* is a threatened endemic plant found only on the upper slopes of Haleakalā, and associated around the world with this place.

Each module is divided into five units, each comprised of two to four distinct activities. Each unit and many of the activities may be used separately to supplement your existing lesson plans. Or teach one or more units or an entire module in sequence for a more complete learning experience.

Module Format

Each module consists of five units. Together these units comprise a thorough exploration of the ecosystem. Individual units in each module address key aspects of the ecosystem's physical characteristics, plant and animal species and relationships, and related management issues.

Module Introduction

- **Ecosystem Connections—**Two pages that give a visual sense of the ecosystem and, through quotations and Hawaiian chant, illustrate its importance to humans

  Photocopy these pages for students or make acetates of them to introduce the ecosystem before beginning a module or unit.
- **Ecosystem Summary—**An overview of ecosystem characteristics and status
- **Traditional Hawaiian Significance—**A brief account of the Hawaiian cultural significance of the life zone
- **Journal Ideas—**Suggested topics for journal entries or writing assignments to get students thinking about the ecosystem
- **To Get a Feel for . . . —**A brief activity to introduce students to the life zone
- **Units at a Glance—**An overview of the five units that comprise each module, including the topics covered, the importance of the unit, and constituent activities
- **Optional Field Activities—**A description of field trips, service projects, and other field learning opportunities related to the ecosystem

Five Units

Each unit includes:

- **Introductory Information—**Includes a brief unit overview (read aloud to students before beginning a unit or an activity), length of the unit, and unit focus questions.
- **Unit at a Glance—**Activity-by-activity summary including:
  - Description
  - Length
  - Prerequisite Activity (if any)
  - Objectives
  - DOE Science Standards and Benchmarks met by the activity.
- **Enrichment Ideas**

  Use these ideas to build on the activities in each unit. These include suggestions for independent projects, additional research, extending the activities, and putting knowledge into action.
- **Resources for Further Reading and Research**

  These resources may be equally useful to both instructors and students.

- **Activity Instructions and Materials**
  - Materials & Setup—Materials and equipment needed for the activity
  - Instructions—Step-by-step guidance for conducting the activity
  - Journal Ideas—Topics for journal entries or stand-alone writing assignments

    These written assignments are integral parts of each activity, often helping students explore their personal connections with the subject matter and cement key learning objectives. Selecting from among these—or creating your own topics—also help you focus on the standards and objectives that are most important to you. Some of the journal ideas are appropriate for using before and after a unit to give students an opportunity to reflect on what they learned.

    Have students keep a journal if you are teaching the entire curriculum or a substantial piece of it. Collect journals periodically to assess student learning and reflection. If you are teaching a single activity or unit, you may choose to use the journal ideas as writing assignments instead of topics for journal entries.

  - Assessment Tools—Ideas to help you assess student performance
  - Teacher Background—Additional information, intricate activity instructions, and other support
  - Masters for Overhead Acetate Transparencies, Game Cards, and Other Instructional Materials—These masters may be easily identified by looking for the descriptive label in the page header (e.g., "Game Card Master").
  - Masters for Student Pages—These activity, data, or reading sheets to duplicate for student use are easily identified by a shaded bar running the length of the page in the right-hand margin containing the label "Student Page."

Vocabulary Words

Technical terms and those that might be difficult for students to understand are explained or defined in the text of student pages and enclosed in quotation marks the first time they are used. These words are also included in the glossary that accompanies this curriculum at the beginning of each module. This glossary is designed as an easy reference for instructors, but it may be photocopied for student use as well. Most glossary words are followed by a notation indicating the unit(s) in which the terms are used. Those that include no unit number notation are words common to most of the units such as "ecosystem."

Additional Resources

A complement of additional resources such as reports, game boards, reference books, and video tapes accompanies this curriculum. See notations within individual activities that indicate these materials. Where possible, these materials are included in a pocket that accompanies the relevant unit. Resources that are too large to fit in such a pocket are included separately.

Beyond the Classroom & Beyond This Curriculum

With the help of *Hōʻike o Haleakalā,* you can brings Haleakalā into your classroom, helping to make the unique natural history and ecology of the island a part of your students' lives. The activities that are included in *Hōʻike o Haleakalā* are an excellent accompaniment to field trips, service projects, and other activities that take students outside the classroom to experience the unique natural environment they are studying. Each module contains suggestions and contact information for field-based learning.

Whether you select a single activity or teach an entire course using *Hōʻike o Haleakalā*, we thank you for joining us in spreading the word about the unique and imperiled environment of our island home.

Rain Forest Module

● ● ● What Does the Rain Forest Zone Mean to You?

These reflections are offered by individuals involved in studying and protecting the native ecosystems of Haleakalā.

I like listening to the native birds there. The first time I saw an *‘i‘iwi* sipping nectar from a ruby-red *lehua* blossom, I held my breath because I thought that if the *‘i‘iwi* heard me breathing hard with excitement, it would be disturbed by my loud noise and fly away.

—*Kalei Tsuha*

Everything covered with ferns, mosses, and plants growing on plants

—*Kim Martz and Forest Starr*

Here are the elements and senses of life, the musty wet vapor in all her states:

Lilinoe—a cool caressing mist, at times opaque and others rainbow-hued.
Hu‘ihu‘i—frosty icicles exuding the spectrum of color from leaves of red and green.
Ka wailele—the trickle and rush of a stream cascading over waterfalls.

—*Eric Andersen*

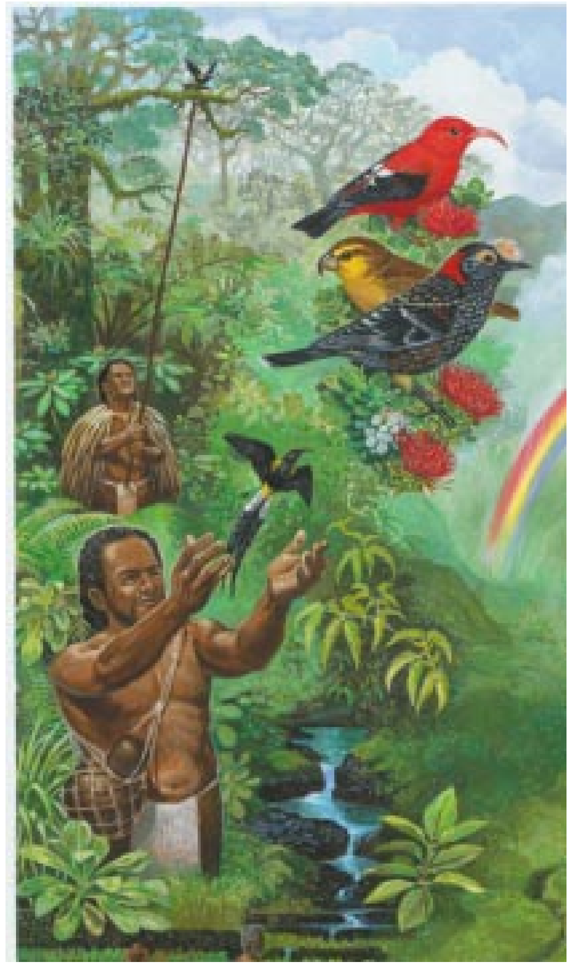


Illustration: John Dawson

Noho Ana Ke Akua

Noho ana ke akua i ka nāhelehele
I ālai ʻia e ke kīʻohuʻohu
E ka ua koko
E nā kino malu i ka lani

Malu e hoe

E hoʻoūlu mai ana ʻo Laka i kona mau kahu
ʻO mākou, ʻo mākou no a

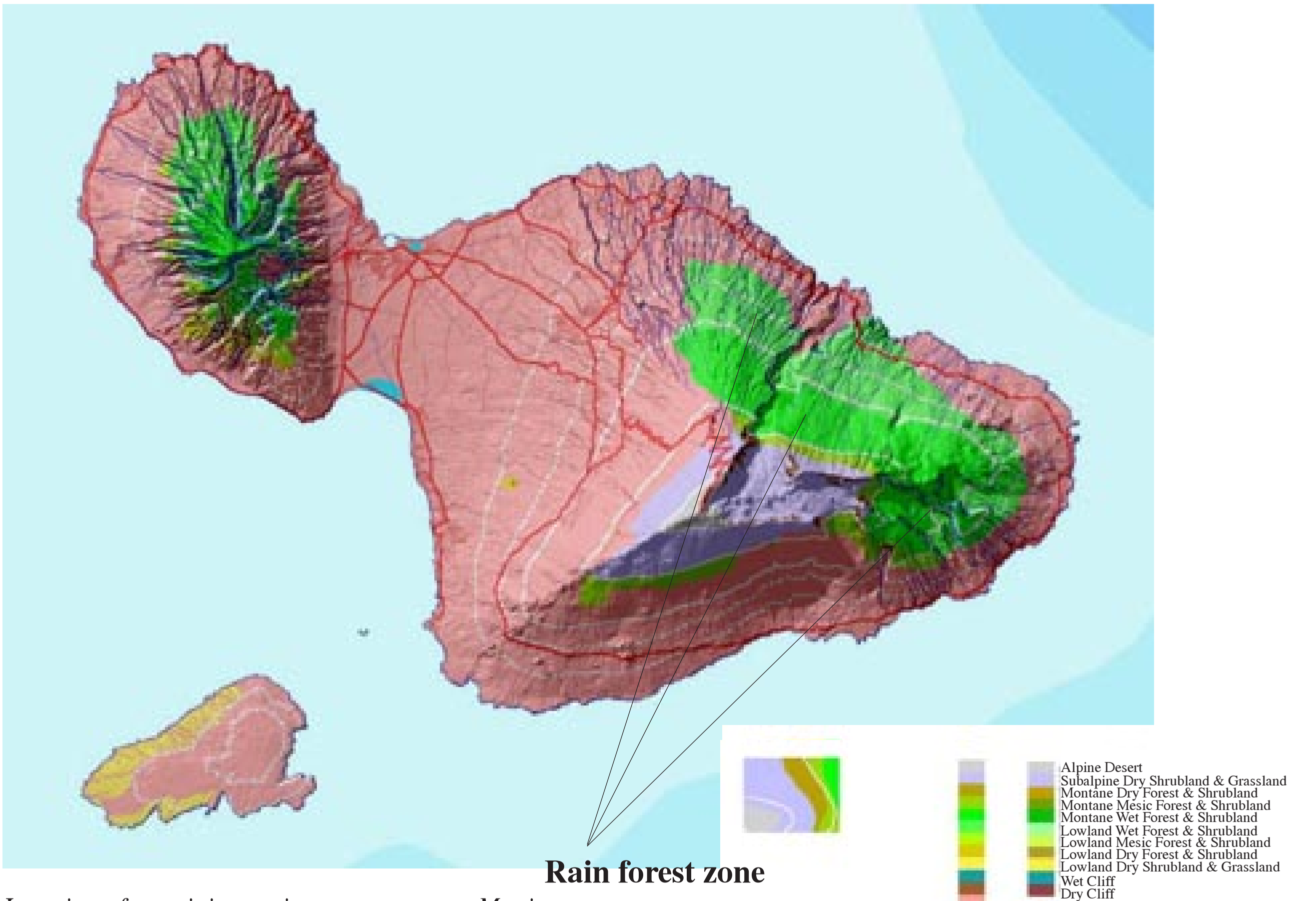
The Gods Dwell

The gods dwell in the forest
Hidden by the mists
By the low lying rainbow
O beings sheltered by the heavens
Clear our paths (of all that may trouble us)
Laka will inspire and enrich her devotees
That's us, us indeed

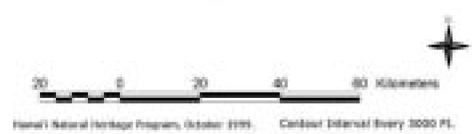
● ● ● Ecosystem Summary

Where on Haleakalā?

Located between 600 meters (1968 feet) and about 1900 meters (6232 feet) elevation on the windward slopes of Haleakalā.



Location of remaining native ecosystems on Maui
(Map: Hawai'i Natural Heritage Program, October 1999)



Basic Characteristics

Rainfall in this zone is over 200 centimeters (80 inches) per year. A continuous canopy layer covers lower subcanopy trees and understory trees and shrubs, and a ground cover layer of herbs and ferns. Epiphytes and climbing vines and shrubs are common.

Unlike other parts of the island, there is not a distinct dry period during the year. Rain normally falls year-round as a result of moisture-laden northeast trade winds that predominate for most of the year.

Did You Know?

In some parts of the Haleakalā rain forest, rainfall can exceed 1000 centimeters (390 inches) per year. The highest rainfall ever recorded in the Haleakalā rain forest was at Kīpahulu Valley in 1994 when a rain gauge measured 14 meters (551 inches) of rain in a single year!

Sixty billion gallons of surface water per year from this part of East Maui already provide much of Upcountry and East Maui drinking water and most of the irrigation water that goes to the Hawaiian Commercial & Sugar Company in Central Maui.

Status and Threats

The native Hawaiian rain forest on Haleakalā once extended from just above the coast up to approximately 2500 m (8200 ft). Much of the lower-elevation rain forest has been extensively altered by cultivation, logging, and introduced plant and animal species. The upper rain forests are a refuge for many species of native birds, insects, and plants. Much of the remaining native rain forest on East Maui is designated as national park, private preserves, and state natural area reserve and forest reserves.

Threats to native rain forest communities include Axis deer, mongooses, black and Polynesian rats, and mice; feral pigs, goats, and cats; nonnative slugs; a number of introduced, invasive plants; and diseases that threaten native birds. These introduced species prey upon and compete with natives, degrade habitat, and restrict the range of many native species to smaller and smaller areas.

● ● ● Traditional Hawaiian Significance

In the traditional system of dividing the Hawaiian Islands into political regions, the *ahupua'a* was the most important land division. *Ahupua'a* usually extended from the mountains to the outer edge of the reef in the ocean, cutting through all of the major environmental zones along the way. Each *ahupua'a* encompassed most of the resources Hawaiians required for survival, from fresh water to wild and cultivated plants, to land and sea creatures. Because of their dependence on the land's resources, the Hawaiians developed a complex system of resource management and conservation that could sustain those resources over time. This system was tied intimately to the religious and cultural beliefs of the Hawaiian people.

In Hawaiian tradition, the upper reaches of the native rain forest were *wao akua*, the realm of Kū, god of war, governance, and upright growth. Humans could only enter this sacred area for specific purposes and with permission from the gods. Below the *wao akua* is the *wao kānaka*, where people lived, worked, and cultivated their crops.

Among those who were allowed to enter the *wao akua* were the skilled *kia manu* (bird catchers). Colorful feathers from native forest birds were fashioned into *lei*, capes, and ceremonial helmets for the *ali'i*. The trained *kia manu* captured birds, plucked the desired feathers, and then released the birds.

Rain forests were also the source of *koa* logs and other wood necessary for making traditional canoes. From the rain forest came plants used for fiber, weaving, *kapa* cloth, and medicines.

In the lower-elevation *wao kanaka* area of the rain forest, *kalo* or taro was grown as a food staple, planted along streams and drainages where it would grow naturally. Today, *kalo* continues to be an important part of the culture of Hawai'i.

The ancient Hawaiians depended upon the rain forests for food, clothing, medicine, transportation, and building materials. They realized that their physical and spiritual well-being depended upon perpetuating these resources and maintaining a respect for the land.

● ● ● Journal Ideas

Use some or all of the following topics for student journal entries:

- Listen to the chant. How would you describe the feeling of the chant? What did it make you think about?
- Listen to the English translation of the chant. Do you have different thoughts and feelings now that you know what this chant means in English?
- Have you ever been to the rain forest? What are your impressions of this area?
- What comes to mind when you think about the rain forest? What are your memories or observations of this ecosystem?

● ● ● To Get a Feel for the Rain Forest Zone

The “Rain Forest Slide Show” (Unit 2, Activity #1 “Rain Forest Slide Show”) helps students visualize the rain forest and learn about basic human connections to and impacts on the Haleakalā rain forest. You may use it as an introduction for any unit or activity if you are not using Unit 2.

● ● ● Rain Forest Units at a Glance

Unit 1
Why is the Rain Forest Wet?

Subjects
Climate of the rain forest
The relationship between rainfall, intact rain forest, and human water supply

Importance
Climate is a key factor in shaping the environmental conditions of the rain forest. Water is one of the defining features of the rain forest, with high levels of rainfall and humidity the norm year-round. And the rain that falls on the rain forest is also an important source of water for human use.

Activities in this unit
- Climate Connections
  Students identify signs of the importance of climate and weather in traditional Hawaiian society and in their lives. They use Hawaiian descriptions to help them describe the climate of a familiar location.

- Why Does It Rain on the Rain Forest?
  Working with maps, students identify and explain weather patterns that influence the location of the rain forest on Haleakalā and the environmental conditions within it.

- Rain Forest on a Budget
  Students create a water budget for the Haleakalā rain forest and hypothesize about how changes in the rain forest structure might affect it. They simulate these changes on a rain forest model to test their hypotheses.

Unit 2
Rain Forest Relationships

Subjects
Native plant and animal species and relationships
Structure of Hawaiian rain forests

Importance
Hawaiian rain forests are among the richest of Hawaiian ecosystems in species diversity, with most of the diversity occurring close to the forest floor. This pattern distinguishes Hawaiian rain forests from continental rain forests, where most of the diversity is concentrated in the canopy layer.

Activities in this unit
- Rain Forest Slide Show
  Students learn about the Haleakalā rain forest by watching a slide show and writing about their feelings about the importance of preserving native rain forests.

- Rain Forest Species Research
  Students research a native rain forest species, finding and presenting information about it in an educational and attractive format.

- Rain Forest Species Presentations
  Students present information about native rain forest species.

- Rain Forest Trivia
  In teams, students demonstrate their knowledge of rain forest species.

Unit 3
Rain Forest Birds: A Study in Adaptation

Subjects

Native birds
Adaptive radiation and evolution

Importance

Surviving native bird species and the growing fossil record present plenty of evidence for the remarkable diversity of bird life that evolved on the Hawaiian islands. But human pressures have altered and continue to alter the natural dynamics of evolution.

Activities in this unit

- Win, Lose, or Adapt Game
  Students play a game to develop a basic understanding of the process of adaptive radiation, the effects of habitat loss and competition for food, and the concepts of feeding "specialists" and "generalists."

- Adaptive Radiation in Hawaiian Rain Forest Birds
  Through a homework reading, questions, and class discussion, students learn about adaptive radiation in Hawaiian honeycreepers.

- Rain Forest Birds Research Projects
  Students select a topic related to native Haleakalā rain forest birds and conduct an independent research project on that topic.

Unit 4
Bogs, Pigs, and Scientists

Subjects

Montane bogs
Feral animal damage, protection, and ecosystem recovery
Field botany skills

Importance

Montane bogs are an important habitat for native rain forest plant species. Beginning in the 1970s, damage caused by feral pigs prompted protective measures for many bogs, and created opportunities to study the recovery of these native plant communities.

Activities in this unit

- 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.

- 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.

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

Unit 5
Weed Warriors

Subjects

Invasive plants and control measures
Values and decision-making

Importance

At least 100 of over 10,000 plant species that have been introduced to the Hawaiian Islands pose a threat to native Hawaiian ecosystems. Resource managers are concerned about these potential invaders, but some people see certain non-native plants in a different light. Differences in values and perspectives sometimes make decisions about invasive plant control difficult.

Activities in this unit

- *Kāhili* Ginger Values and Perspectives
  Students role-play different perspectives about a nonnative plant species and a proposal to ban the propagation and sale of this plant in Hawai'i. They explore different types of values and consider how those values might affect people's decisions and actions.

- What Makes a Plant Invasive?
  Students learn about invasive plant characteristics and how those characteristics influence management decisions by completing homework reading, questions, and a class discussion.

- Managing Invasives on Survivor Island
  Students apply knowledge and information about invasive plants to a management scenario.

● ● ● Optional Field Activities

Getting students out in the field puts them in direct contact with the ecosystem and gives them a context for learning. These are excellent supplements to the classroom-based activities of the rain forest module, giving students the excitement and challenge of hands-on experiences. Here is a listing of resources for field trips and other extensions.

Field Trips

Waikamoi Preserve

Rose Gardner Memorial Boardwalk or Bird Loop Hike

Description
Naturalist-guided hikes

<u>Boardwalk Hike</u>
Students walk through a plantation of introduced pine and eucalyptus species into intact native rain forest with a guide from The Nature Conservancy. Students will see native plants and vegetative layers of intact rain forest and common native forest birds as well as possibly the endangered *'ākohekohe* and Maui parrotbill. The guide will help students compare the native forest with the plantation forest, and teach them about management activities being used to protect the rain forest.

<u>Bird Loop Hike</u>
Students walk through native and introduced forest vegetation looking for common native forest birds. The guide will teach students about management activities being used to protect the rain forest.

You may end either hike by eating lunch at the picnic tables at Hosmer Grove.

Field Trip Time
9 a.m. to 12 or 1 p.m. (not including lunch or travel time)

Cautions
The weather in the rain forest is most often cool and overcast, but it may also be rainy, windy, or even warm and sunny.

What to Bring
- Rain gear, including a hood or hat
- Dress in layers to accomodate a range of weather conditions. At an elevation of 7,000 feet, this hike can be chilly even in the summer.
- Shoes with good traction (not slippers) that will have good footing in muddy conditions
- Water and a lunch or snacks
- Optional: Camera, binoculars

Group Size Limits
The usual group size limit is 20 people. Larger groups can be accommodated with special arrangements.

Contact
The Nature Conservancy—Maui Field Office, 572-7849
Make arrangements at least three months in advance. Parents must sign waivers for students under 18 years of age.

Fees
A donation is requested but not required. The park entrance fee is waived for educational groups doing a hike with The Nature Conservancy.

Getting There
These field trips begin at Hosmer Grove in Haleakalā National Park, about an hour and a half drive from Wailuku.

Keʻanae Arboretum

Description
Short, unguided walk

Students walk approximately one mile roundtrip through a lush tropical valley planted with native and nonnative plants. In the nonnative plants section, students will see marked plantings of bamboo, palm trees, heliconia, ginger, and other nonnative species. Students will see many varieties of native and Polynesian-introduced plants, such as hibiscus, *ti*, and breadfruit. There are also plantings of different varieties of dryland and wetland taro.

Field Trip Time
One to one and a half hours (not including lunch or travel time)

What to Bring
• Rain gear, including a hood or hat
• Shoes with good traction (not slippers)
• Water and a lunch or snacks
• Mosquito repellant
• Optional: Camera, binoculars

Group Size Limits
None for noncommercial groups

Contact
Inform the Hawaiʻi Department of Land and Natural Resources, Division of Forestry and Wildlife office of your field trip plans so field staff are aware that you are a school group and not a commercial group. The number is 984-8100.

Fees
No fees

Getting There
Enter the Ke‘anae Arboretum on foot through a marked gate off the Hāna Highway, 35 1/2 miles (about an hour drive) from Wailuku. You may want to stop and use the restrooms at Kaumahina State Wayside, about six miles before the arboretum. Park the bus or your vehicles in one of the wide turnouts on either side of the highway at the arboretum gate.

Connecting Your Field Trip to the Rain Forest Module

Here are some ideas for student assignments that link the field trips (especially those to Waikamoi Preserve) to the classroom activities of the rain forest module:

- Have students take photographs or make sketches that show the five main vegetative layers of the native rain forest (groundcover or forest floor, understory, subcanopy, canopy, and epiphytes and climbing plants). See Rain Forest Unit 2, Activity #3 “Rain Forest Species Presentations” for an explanatory diagram (p. 43).

- Have students bring their plant and bird species cards from Rain Forest Unit 2, Activity #2 “Rain Forest Species Research,” and look for these species in the field.

- Have students make journal entries that reflect what they learned about management activities designed to protect the rain forest, how and why the nonnative species they saw were introduced, or differences they observed between the native rain forest and the introduced vegetation that has replaced it.

Extensions

Take a Hike

Individual students or small groups may join regularly scheduled hikes to Waikamoi Preserve by The Nature Conservancy or Haleakalā National Park. Park hikes are scheduled for Mondays and Thursdays, and The Nature Conservancy hikes take place on the second Saturday of each month. Contact The Nature Conservancy at 572-7849.

Join a Work Trip

The Nature Conservancy has regular work trips scheduled for the third Saturday of each month. Small groups of up to eight students can volunteer to do trail maintenance or invasive species control on one or more of these work days by calling The Nature Conservancy at 572-7849.

To make arrangements for a larger group or specialized service projects, contact The Nature Conservancy at 572-7849. You may be able to arrange a work day or overnight trip including “roughing it” in tents at high elevations. As with the regularly scheduled work trips, students would volunteer to do trail maintenance or invasive species control.

Volunteer to Maintain Trails

The Hawai‘i Department of Land and Natural Resources *Na Ala Hele* Trails and Access Program organizes volunteer trail maintenance opportunities. Individuals or groups of students over age 14 are welcome to volunteer. Trail maintenance takes place in a variety of forested and coastal areas. Call 873-3509 for information about upcoming volunteer opportunities.

Adopt a Fence

Your class or school may volunteer for service projects through the Adopt-a-Trail and Adopt-a-Fence programs at Haleakalā National Park. You will be responsible for maintaining a specific stretch of trail or fence under this program. Find out more about these programs and other volunteer opportunities for individuals and small groups by contacting the park volunteer coordinator at 572-4487 or <HALE_VIP_Coordinator@nps.gov>.

Rain Forest Unit 1

Why is the Rain Forest Wet?

Overview

Water, of course, is one of the defining features of the rain forest environment. Rain forest plants and animals are adapted to living with high levels of rainfall and humidity year-round. And from the rain forest of East Maui comes the water supply for much of Upcountry, Central, and East Maui. In this unit, students examine rainfall patterns and their causes in the rain forest zone of windward Haleakalā and explore the rain forest as a source of water for human use.

Length of Entire Unit

Five class periods

Unit Focus Questions

1) How are climate and weather important in traditional Hawaiian culture?

2) What climatic forces influence the location of the rain forest on Haleakalā?

3) What are the environmental conditions for plants and animals in the rain forest?

4) How does the native Haleakalā rain forest protect the water supply for much of East, Central, and Upcountry Maui?

5) What effects do changes in the structure of the rain forest have on the function of the watershed?

Unit at a Glance

Activity #1

Climate Connections

Students identify signs of the importance of climate and weather in traditional Hawaiian society and in their lives. They use Hawaiian descriptions to help them describe the climate of a familiar location.

Length
One period, preceded and followed by homework

Prerequisite Activity
None

Objectives
- Make connections between water-related or weather-related Hawaiian place names and the weather patterns on the island.
- Describe the weather in a familiar location using Hawaiian rain descriptions.

DOE Grades 9-12 Science Standards and Benchmarks
None

Activity #2

Why Does It Rain on the Rain Forest?

Working with maps, students identify and explain weather patterns that influence the location of the rain forest on Haleakalā and the environmental conditions within it.

Length
Two periods

Prerequisite Activity
None

Objectives
- Explain trade wind patterns, orographic lifting, the lifting-condensation level, and the trade wind inversion.
- Relate these climatic phenomena to the location of the rain forest on Haleakalā and the environmental conditions within it.

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.
- Communicate and defend scientific explanations and conclusions.

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.
- Explain the function of a given system and its relationship to other systems in the natural world.

Activity #3
Rain Forest on a Budget

Students create a water budget for the Haleakalā rain forest and hypothesize about how changes in the rain forest structure might affect it. They simulate these changes on a rain forest model to test their hypotheses.

Length
Two class periods, preceded and followed by a homework assignment

Prerequisite Activity
Activity #2 "Why Does It Rain on the Rain Forest?"

Objectives
- Identify and describe the major components of a water budget.
- Analyze and graph data related to a water budget for East Maui.
- Hypothesize about the impact of altering the rain forest on the water budget.
- Manipulate a rain forest model to test these hypotheses.

DOE Grades 9-12 Science Standards and Benchmarks
DOING SCIENTIFIC INQUIRY: Students demonstrate the skills necessary to engage in scientific inquiry.
- Develop and clarify questions and hypotheses that guide scientific investigations.
- Design and conduct scientific investigations to test hypotheses.
- Organize, analyze, validate and display data/information in ways appropriate to scientific investigations, using technology and mathematics.
- Formulate scientific explanations and conclusions and models using logic and evidence.
- Communicate and defend scientific explanations and conclusions.

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.
- Explain the function of a given system and its relationship to other systems in the natural world.
- Explain the effect of large and small disturbances on systems in the natural world.
- Design or create a model to represent a device, a plan, an equation, or a mental image.

Enrichment Ideas

- Find out where the water students drink at home comes from. How about at school? Research local issues related to water consumption. Look in local newspapers for stories related to water supply or water use.

- Write a paper about how altering the rain forest would likely affect human water supply or the impacts the loss of forests on Maui has already had on rainfall and human water supply.

- Find Hawaiian chants or hula about the Hāna, Kīpahulu, or Koʻolau areas, or about other parts of the rain forest on Haleakalā. Or create original chants and dance based on the information learned in this unit.

- Research the East Maui Watershed (which covers the whole windward side of Haleakalā). It is the single largest source of harvested surface water in the state. East Maui supplies drinking water to Upcountry and East Maui, and irrigation water to the Hawaiian Commercial & Sugar Company in Central Maui.

  One place to start looking for information—and another research topic in itself—is the East Maui Watershed Partnership. The partnership is a collaborative effort among six public and private landowners and Maui County to protect the 100,000-acre rain forest core of this critical watershed. Online information about the partnership can be found at <ice.ucdavis.edu/~robyn/mauimgt.html>. Students may also want to contact the major partners directly: The Nature Conservancy, East Maui Irrigation Company, Hawaiʻi Department of Land and Natural Resources, National Park Service, Haleakalā Ranch, Hāna Ranch, and Maui County.

- Instead of doing the condensation demonstration in Activity #2, have students do it as a lab.

Resources for Further Reading and Research

Giambelluca, Thomas, and Marie Sanderson, "The Water Balance and Climatic Classification," in Marie Sanderson (ed.), *Prevailing Trade Winds: Weather and Climate in Hawaiʻi*, University of Hawaiʻi Press, Honolulu, 1993, pp. 56-72.

Juvik, S. P., and J. O. Juvik, *Atlas of Hawaiʻi,* third edition, University of Hawaiʻi Press, Honolulu, 1998. (Page 59 provides general background about rainfall on the Hawaiian Islands.)

Juvik, J. O., and D. Nullet, "Relationships Between Rainfall, Cloud-Water Interception, and Canopy Throughfall in a Hawaiian Montane Forest," in Hamilton, L. S., J. O. Juvik, and F. N. Scatena (eds.), *Tropical Montane Cloud Forests*, New York, Springer-Verlag, 1995, pp. 165-182.

Kert, Harold Winfield, *Treasury of Hawaiian Words in One Hundred and One Categories,* Masonic Public Library of Hawaiʻi, Honolulu, 1986.

Loope, Lloyd L., and Thomas W. Giambelluca, "Vulnerability of Island Tropical Montane Cloud Forests to Climate Change, with Special Reference to East Maui, Hawaii," *Climatic Change,* Vol. 39, 1998, pp. 503-517. (Although this article focuses on the potential effects of climate change, it provides excellent background on the characteristics of the cloud forest climate on Haleakalā, as well as several points of comparison between the windward and leeward side climate.)

Maui Department of Water Supply at <www.mauiwater.org>.

Pukui, Mary Kawena, Samuel H. Elbert, and Esther T. Mookini, *Place Names of Hawaii*, University of Hawaiʻi Press, Honolulu, 1974.

Shade, P. J., *Water Budget of East Maui, Hawaii*, U.S. Geological Survey, Honolulu, 1999.

Activity #1

Climate Connections

● ● ● In Advance *Student Assignment*

- Assign the Student Page "Climate Connections" (pp. 7-9) as homework.

● ● ● Class Period One *Climate Connections*

Materials & Setup

- *'Auhea wale ana oe - E ka ua 'Ulalena* acetate (master, p. 6)
- Overhead projector and screen
- Map of Maui

For each student

- Student Page "Climate Connections" (pp. 7-9)

Instructions

1) Show the *"'Auhea wale ana oe - E ka ua 'Ulalena"* acetate. Have one or more students read the Hawaiian chant, then read the English translation. Ask the class why they think Hawaiians would be strongly connected to the rains and weather of specific places. Ask if they know anyone who is a keen weather observer.

2) Ask students to share some of their responses to the questions on the "Climate Connections" homework assignment. Begin with the place names and their meanings. Locate each place on the map as you discuss it. Then ask several students to share their rain descriptions, and locate the places they describe on the map as well.

3) Allow students the rest of the class period to write on one or more of the journal topics suggested below.

Journal Ideas

- Why was it important for early Hawaiians to observe, understand, and be able to predict the weather?
- Why is observing and understanding—and even predicting—the weather important to you and the activities you do?
- Do you have friends or family who live in more severe climates than Hawai'i? How is knowing about the weather important to them?
- Have you ever lived in a place where it rained a lot? What was it like to live there?

Assessment Tools

- Student Page "Climate Connections"
- Participation in the class discussion
- Journal entries

Photo: Howard D Terry

ʻAuhea wale ana oe - E ka ua ʻUlalena

Auhea wale ana oe
E ka ua ʻUlalena
Kahiko mai la i uka
I ka nani o Piʻiholo
Ua like me Koʻopua
Noho mai la i ʻAwalau
Au aʻe nei ka manaʻo
E pili me ke aloha
Aloha o Makawao
I ka ua Ūkiukiu
He tiu na ka Nāulu
I ke tula o Kamaʻomaʻo
O ka loa kaʻu i ana
I ka oni o ka lihilihi
Ilihia iho nei loko
I ka ukana o ke aloha
Haina mai ka puana
Makaihiana he inoa.

Oh where are you,
ʻUlalena rain,
Beautiful one of the upland
The beauty of Piʻiholo
Is like the clouds
That nestle over ʻAwalau.
The mind reaches out
To be near the loved ones,
Beloved is Makawao
With its Ūkiukiu rain,
It is a scout for the Nāulu rain
On the plain of Kamaʻomaʻo
I measured its length
With a single glance,
A thrill possesses me
With this thing called love,
This ends my song,
In honor of Makaihiana.
—*Bishop Museum Library*

Climate Connections

Dependent upon their environment, early Hawaiians were great and careful observers of weather and climate. Understanding seasonal patterns of temperature, wind, and rainfall, linked with lunar cycles, helped Hawaiians know when to plant and harvest different crops, when and where to fish, and even where and how to build their homes.

In Hawaiian society, *kilo lani* were the seers who were able to predict the future by looking at the sky. Among their powers was the ability to look at the stars and moon, the atmosphere, the ocean, and what was happening on land and tie it all together.

Kilo lani and their students (*haumana*) were astute observers of the heavens and the weather, and over time built up personal storehouses of knowledge and experience about the connection between the two. They also relied on, and added to, the body of local weather knowledge that was passed on orally from generation to generation. Unlike the modern-day weather forecaster who can consult computers and satellite images, the *kilo lani* drew their knowledge from their surroundings and carried it in their heads.

Many Hawaiians were regional experts in the folklore and weather patterns of their home place. If you know someone who fishes a lot or farms or surfs, you probably know a modern-day regional weather expert. You may even be one yourself! Some people are good at observing weather patterns and knowing what those signs mean for weather conditions in the coming days.

Hawaiians have many names for the wind and rain, depending on characteristics such as temperature, how steady it is, where it comes from, and so forth. From ancient times, Hawaiians have given names to each variety of rain and wind that is particular to each part of the islands. If you live on Ukiu Street in Makawao, for example, you have personal experience with the cold, wet *ukiu* wind that is unique to Makawao.

Weather and water were important elements in the lives of early Hawaiians. This is reflected in the names of many places on the Hawaiian Islands. *Mauna Kea*, for example, means “white mountain.” It is named for the snow that often caps the summit, especially in winter. *Waikamoi*, the name of a stream that flows out of the rain forest on Haleakalā is interpreted by many people to mean, “water of the *moi* taro.”

For fun...

Hawaiian words often have more than one meaning.

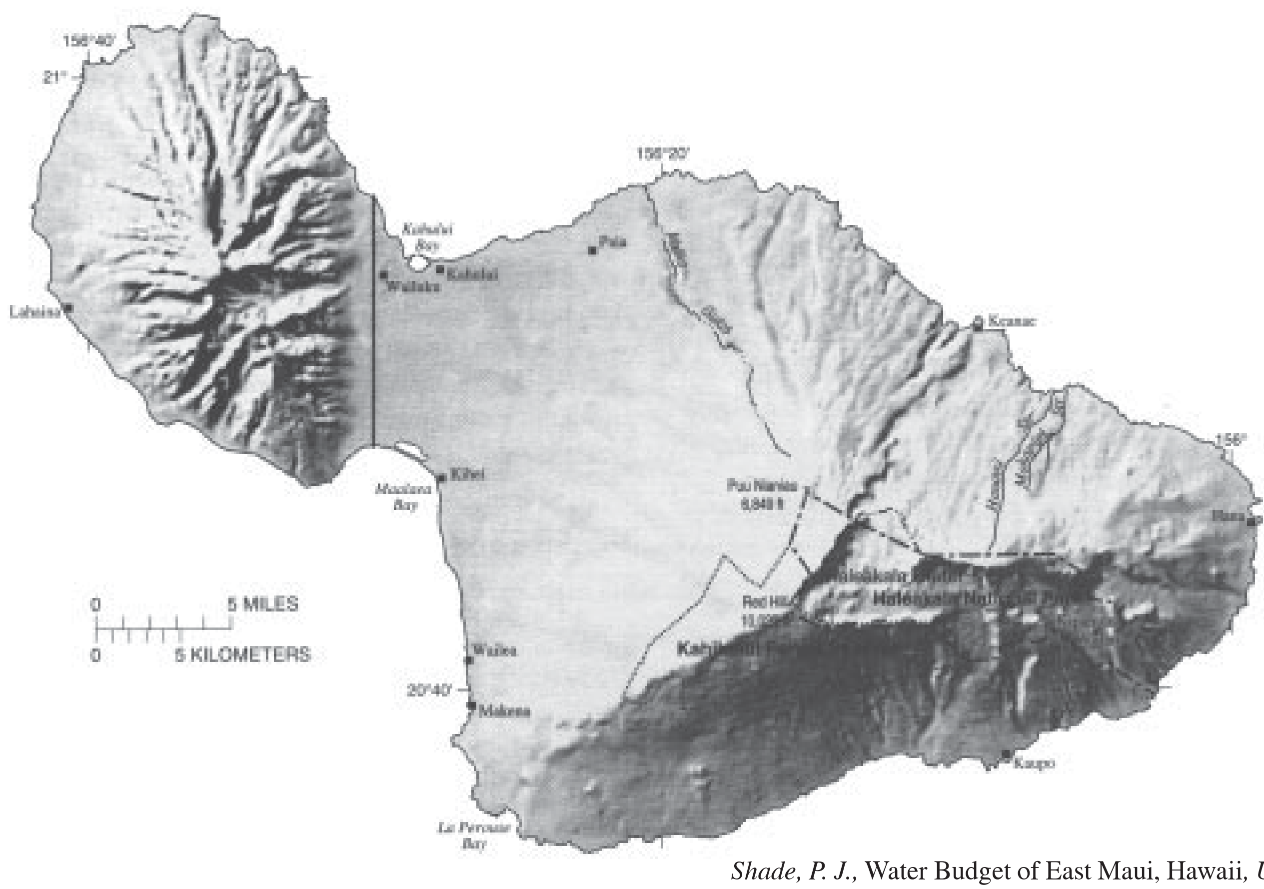
- Look up *kilo lani* in the Hawaiian dictionary, as well as *kilo* and *lani* separately. What different possible meanings of *kilo lani* can you come up with using the definitions offered in the dictionary?
- Talk to your parents, grandparents, aunts, or uncles to find out how they define *kilo lani*.
- What words have similar meanings in the English language?

In order to answer some of the questions below, you will need a map of Maui or Haleakalā National Park and a Hawaiian dictionary.

1) Using a map of Maui or Haleakalā National Park, find at least one place that is named for water or something associated with weather such as wind or clouds. You can use the Hawaiian dictionary to help you. Your school library may have helpful books such as:
   - Mary Kawena Pukui, Samuel H. Elbert, and Esther T. Mookini, *Place Names of Hawaii*, University of Hawaii Press, Honolulu, 1974, and
   - Kert, Harold Winfield, *Treasury of Hawaiian Words in One Hundred and One Categories,* Honolulu, Masonic Public Library of Hawai‘i, 1986.

   What is the name of the place? What does it mean?

2) On this map of Maui, place a dot where this place is located. Does the name of the place seem to tell you anything about that part of Maui? If so, what?



Shade, P. J., Water Budget of East Maui, Hawaii, *U.S. Geological Survey, Honolulu, 1999.*

3) Think of a place that you are familiar with or that is near where you live. Write a paragraph, poem, or chant describing the rain that typically falls there. Include how hard the rain is, what direction it usually comes from, the time of day it generally falls, its temperature, or other characteristics that help to identify it. In your writing, incorporate at least one rain name in Hawaiian from the glossary below or another source.

Hawaiian Rain Names

ʻawa — Fine rain or mist
ʻawaʻawa — Fine, misty rain that frequently can be cold
hau — Snow, ice, frost
he ua lanipali — Shower reaching to heaven, i.e., a very heavy shower
hoʻokili — Fine, gentle rain, a form much beloved
ililani — Unexpected rain; rain from a seemingly clear sky
kahakikī — To pour down violently with a roar, as rain or rushing water
kēhau — Mist; cold, fine rain floating in the air, usually in the mountains
kēwai — Mist merging with rain some distance off
kili — Fine, light rain; peal of thunder; raindrops
kili hau — To fall gently, as a cold, soft shower; to stop falling and fade away, as rain at the end of a shower
kiʻo wao — Cool, mountain rain accompanied by wind and fog
koʻiawe — Light moving shower
koko — Falling rain with light looking reddish as it shines through
līhau — Gentle, cool rain believed to bring luck to fishermen
maʻau — Rain in the upland forest; rain forest
nākikikiʻi — Slanting rain
nāulu — Sudden shower of fine rain without seeming benefit of cloud or clouds
noe — Mist or fine rain, spray or fog; to sprinkle a little, as fine rain; to be damp, as fog; to rain, yet be scarcely discernible
pakakū — Rain falling in large drops
pakapaka — Heavy shower of large rain drops; spattering noise that such drops make on a hollow or dry substance, as on dry leaves
pākiʻo — Showery rain
pākiʻokiʻo — Showery rain; to rain in short showers and often
pīpinoke — To rain continuously
pulepe, pulu pē — To rain heavily; to be drenched
ua ʻawa — Chilly rain, cold and bitter
ua hānai — Rain that nurtures the earth
ua hōʻokina — Continuous rainfall
ua lanipili — Several-days downpour; heavy rain, cloudburst
ua poko — Short rain
ua poʻo nui — Light, steady rain (literally, big-head rain)

— *Kert, Harold Winfield,* Treasury of Hawaiian Words in One Hundred and One Categories*, Honolulu, Masonic Public Library of Hawaiʻi, 1986, pp. 380-382.*

Activity #2

Why Does It Rain on the Rain Forest?

• • • Class Period One *Rain Forest Location and Characteristics*

Materials & Setup

- "Maui Map Pack" acetates (masters, pp. 21-26)
- Overhead projector and screen

For each group of 3 or 4 students

- Student Page "Maui Map Pack" (pp. 28-30)

For each student

- Student Page "Why Does It Rain on the Rain Forest?" (pp. 31-34)

Instructions

1) Draw a simple diagram on the board or overhead showing the ocean and Haleakalā. Ask students to predict what the average annual rainfall is over the open ocean. Then ask them to predict the highest annual rainfall ever measured at 1650 meters (5412 feet) in the Haleakalā rain forest. After gathering student ideas, share the actual data. Over the open ocean near Maui, an average of 56 to 71 centimeters (22-28 inches) of rain falls each year. In 1994, a rain gauge placed at 1650 meters in the Haleakalā rain forest measured more than 14 meters (46 feet or 551 inches) of rainfall in one year.

2) Ask students to hypothesize why there is such a huge difference in rainfall between the open ocean and the rain forest. Each student should write down a hypothesis. This activity will help students determine whether their hypotheses are correct.

3) Divide students into groups of three or four. Give each group a copy of the Student Page "Maui Map Pack." Have them look at these maps and answer the questions on the student page.

4) Bring the class back together and discuss the questions on the student page. Use the acetates as visual aids, and work from the teacher's notes to guide the discussion. (These are the same maps students received, along with a map of the location and extent of rain forests on Maui.)

5) Assign the Student Page "Why Does It Rain on the Rain Forest?" as homework.

● ● ● Class Period Two *Condensation Demonstration and Discussion*

Materials & Setup

- Three shiny metal cans
- Room temperature water to fill each can half full
- A tray of ice cubes
- Two thermometers (Celsius)
- A stirring tool
- "Condensation Demonstration Data Table" posted on the board or overhead (master, p. 27)
- "Condensation Demonstration Relative Humidity Table" posted on board or overhead, or handed out (master, p. 27)

Instructions

1) Ask students to discuss the factors that affect the rainfall pattern on the windward slopes of Haleakalā, where the East Maui rain forest is. (The factors include the interplay among topography, the prevailing wind patterns, and how water behaves at different temperatures.)

2) Ask students to discuss how condensation plays into the cycle of rainfall on the Haleakalā rain forest. (They should be able to link condensation to the formation of clouds and discuss the lifting condensation level.)

3) With the class, brainstorm a list of examples of condensation from daily life.

4) So that students may see the condensation of water in action, do the "Condensation Demonstration" following the instructions (pp. 16-17).

5) After the demonstration, go through the discussion questions in the teacher background (p. 18) with the class.

6) Discuss student responses to the questions in the Student Page "Why Does It Rain on the Rain Forest?" If you need more information to help students understand the atmospheric forces that form the trade winds and trade wind inversion see Marie Sanderson (ed.), *Prevailing Trade Winds,* University of Hawaiʻi Press, Honolulu, 1993, or Alpine/Aeolian Unit 2 of this curriculum.

Journal Ideas

- What did you learn during this activity that confirms or refutes your original hypothesis about what explains the difference in rainfall between the open ocean and the Haleakalā rain forest?
- Have you ever been in the clouds or fog? What does it feel like compared to being in the rain?

Assessment Tools

- Participation in class discussion
- Student Page "Maui Map Pack" (teacher version, pp. 13-15)
- Student Page "Why Does It Rain on the Rain Forest?" (teacher version, pp. 19-20)
- Journal entries

Teacher Version

Maui Map Pack

Use the maps provided in this activity sheet to answer the following questions:

1) Where does most of the rainfall occur on Maui? on Haleakalā? What might explain that pattern?

   Most rainfall on Maui and Haleakalā occurs on the windward slopes of the mountains. (On the maps, the highest rainfall looks to be about 1/3-1/2 way up the mountain.) On Haleakalā, the heavy rainfall occurs in a band that runs across the northeast flank of the mountain and wraps around a bit toward the south.

   Students do not have a lot of information to work from yet to attempt to explain the pattern of rainfall. They might speculate that the winds pick up moisture from the ocean and dump it when they reach land.

2) Rain forests generally occur where annual rainfall is greater than 203 centimeters (80 inches) per year. According to the rainfall map, what parts of Maui get enough rain to support a rain forest? (Draw an outline on the rainfall map of where you would expect to find rain forests.)

   Note that this anticipated rain forest area goes all the way to the ocean for the majority of the northeast coast of East Maui.

3) Other than rainfall, what other characteristics do you expect to find in the area where you think the rain forests would be? (Use all of the maps provided for information.)

   From the wind map, students might speculate that a lot of the rain forest area would have light winds most of the time and that winds would tend to be blowing across the face of the mountain there.

   From the solar radiation map, they might speculate that the rain forest is cloudy.

Map Notes

(To accompany the map acetates, pp. 21-27)

Average Annual Rainfall on Maui (inches)

1) Notice that rainfall will support a rain forest all the way to the coastline on much of the northeast coast of East Maui. Driving the Hāna Highway will confirm that you are going through wet forest terrain. On maps of present day ecosystems, though, the native rain forest meets the coastline in very few areas. This is due to human disturbance in the lower reaches of the rain forest from Polynesian settlement onward.

2) Recent data suggest that average rainfall estimates for the rain forest on windward Haleakalā are low. Hawai‘i has many precipitation gages, but the rainfall of its more inaccessible reaches (e.g., much of the East Maui rain forest) is largely conjectural. Beginning in 1992, researchers began collecting climate information in this rain forest area, providing a new base of information.

New Estimates of Rainfall

Students do not have this information in their Maui Map Packs. Use it to show them the evolution of knowledge about the rain forest, comparing it to the rainfall map that is included in the student page.

In 1992, researchers established HaleNet II, a network of four microclimate sensing stations on windward Haleakalā. This network is currently providing data in an area where very little climatic data have been available. These measurements provide the first solid evidence to date of the extremely high rate of rainfall (Lloyd L. Loope and Thomas W. Giambelluca, “Vulnerability of Island Tropical Montane Cloud Forests to Climate Change, with Special Reference to East Maui, Hawaii,” *Climatic Change,* Vol. 39, 1998, pp. 503-517). In addition, the data collected are providing evidence of extreme spatial gradients for other climate variables such as humidity and solar radiation.

Based on these new data, as well as older and ongoing research and calculations, rainfall maps for East Maui are sure to change. The data from HaleNet II suggest that past maps probably underestimate the amount of precipitation within the wettest part of the Haleakalā rain forest.

Prevailing Wind Patterns on Maui

This map shows how Haleakalā diverts most air flow around its slopes. The prevailing trade winds from the east-northeast split and most of the airflow goes around the mountain rather than over the top of it.

In *Prevailing Trade Winds* (Marie Sanderson, (ed.), University of Hawai‘i Press, Honolulu, 1993), Thomas Schroeder explains that this effect has to do, in part, with the trade wind inversion:

> In Hawai‘i the combination of mountainous islands and persistent trade winds creates mesoscale systems that dominate local climate.
>
> If the mountains are below the inversion, a substantial amount of trade wind air will pass over the barrier. This is the case for O‘ahu, where the maximum elevation in the windward Ko‘olau Range is 960 m (3150 ft). On the island of Hawai‘i, Mauna Loa and Mauna Kea are more formidable barriers. Most trade winds are diverted around these mountains except for a small amount that penetrates the high, 2 km (6600 ft) saddle between them (p. 22).

See the teacher version of the Student Page “Why Does It Rain on the Rain Forest?” (pp. 19-20) and Alpine/Aeolian Unit 2 for more information about the trade wind inversion and its effect on the climate of Haleakalā.

Average Annual Solar Radiation Intensity (Watts/Meter^2)

Average annual solar radiation received on Maui differs from place to place. The highest levels occur along leeward coastal areas and at the tops of mountains.

Many factors can affect the amount of solar radiation that is absorbed and reflected before it can reach the ground. These include air pollutants, "vog" (smog-like air pollution caused by volcanic gases and particulates), particles of salt suspended in the air, and water vapor in the atmosphere.

Higher areas tend to receive more solar radiation because radiation traverses shorter distances through the atmosphere to reach them**.**

Clouds are the most important cause of variation in solar radiation intensity (based on *Atlas of Hawai'i,* 3rd ed., p. 50).

Limits of Native Ecosystems Before and After Human Settlement

Students do not have this information in their Maui Map Packs. Use it to show them the current location of the native rain forest on Haleakalā, as well as its past extent.

As background, you may want to look on pages 122-123 of *Atlas of Hawai'i*, 3rd ed., for generalized maps of the extent of native ecosystems before human settlement and today. These maps help to show patterns in where rain forests are located on all of the islands (i.e., windward mountain slopes) and that rain forests once extended to the ocean on Maui. (Sonia P. Juvik and James O. Juvik, editors, University of Hawai'i Press, Honolulu, 1998.)

Human disturbance of the lower reaches of the rain forest, from the time of Polynesian settlement onward, has converted most of the low-elevation native rain forest into a rain forest dominated by nonnative species. This effect is clear on the acetate maps "Native Ecosystems on Maui Before Human Habitation" and "Limits of Native Ecosystems on Maui Today." Native rain forests still exist over much of their historic extent, where climate conditions are conducive, but the lower elevations are now dominated by nonnative species.

Teacher Background

Condensation Demonstration

This demonstration is designed to help students visualize the behavior of water vapor in the trade winds that are pushed upslope on the windward side of Haleakalā. You may also use it to demonstrate the concept of a microclimate created when moist air is trapped in a steep valley such as Kīpahulu. As this air is pushed upward through the valley, it reaches the "lifting-condensation level" the altitude at which water vapor condenses out of rising air, forming clouds and/or rain), and the water vapor condenses, forming clouds and rain.

In this demonstration, you will determine the dew point of the air in your classroom and calculate the relative humidity. "Dew point" is the temperature at which water vapor in the air begins to condense. "Relative humidity" is the ratio between the amount of water vapor in the air and the highest amount of water vapor possible in the current air temperature.

Materials

Listed in the activity instructions

Instructions

1) Measure the air temperature in the classroom.

2) Fill one can half full of room temperature water.

3) Slowly stir the water with a stirring rod, adding small amounts of ice. Ask the class to help you watch for condensation to appear on the outside of the can. Record the water temperature when that happens, being careful not to let the thermometer touch any ice. This is the dew point.

4) Subtract the dew point temperature from the air temperature. Use the relative-humidity table to determine the relative humidity in the air around the beaker. (For a more accurate calculation, use the equations that follow at the end of the questions for discussion.)

	A = Outside air temperature (°C)	B = Water temperature when condensation forms on the outside of the can (°C)	Difference between readings (A-B)	Relative humidity (percent)
Trial 1				
Trial 2				
Trial 3				

Data Table
Relative-Humidity Table

Air Temp. (°C)	Temperature Difference (°C) 1	2	3	4	5	6	7	8	9	10	12	14
10	88	76	65	54	44	33	23	14	4			
12	89	78	67	57	47	39	29	20	11	3		
14	89	79	69	60	51	42	33	25	17	9		
15	90	80	71	62	54	45	37	29	22	14		
18	91	81	73	64	56	48	41	33	26	19	6	
20	91	82	74	66	58	51	44	37	30	24	11	
22	91	83	75	68	60	53	46	40	34	27	16	5
24	92	84	76	69	62	55	49	43	37	31	20	9
26	92	85	77	70	64	57	51	45	39	34	23	14
28	92	85	78	72	65	59	53	47	42	37	26	17
30	93	86	79	73	67	61	55	49	44	39	29	20
32	93	86	80	74	68	62	56	51	46	41	32	23

———Relative Humidity Around Beaker———

Questions for Discussion

1) Why did we have to wait for condensation to form?

The water temperature (and therefore the temperature of the outside surface of the can) had to drop to the dew point.

2) When condensation formed, was the air right around the can saturated?

Yes. Relative humidity is the ratio of the actual amount of moisture in the atmosphere to the amount of moisture the atmosphere can hold. At the dew point, condensation begins to form because the air can hold no more moisture.

3) Why would there be a relationship between relative humidity and the dew point temperature?

At lower temperatures, the atmosphere can hold less moisture (under constant pressure conditions).

4) As the moist trade winds are pushed up along the windward slopes of Haleakalā, what is happening to their temperature? At some point, would you expect the air temperature to reach its condensation point? What factors could influence the elevation at which that happens?

• As air rises, temperature drops.

• Yes, depending upon the moisture level in the air

• Air pressure, moisture level in the winds

5) The level at which water vapor in a rising air mass begins to condense is called its "lifting-condensation level." How does the lifting-condensation level relate to cloud formation?

The lifting-condensation level is the altitude at which clouds begin to form.

Teacher Version

Why Does It Rain on the Rain Forest?

Use the information and graphics provided in this article along with what you learned in class to answer the following questions:

1) On Figure 1:
   a) Indicate the approximate altitude of the inversion layer.
   b) Draw a line indicating the approximate lower limits of the rain forest.

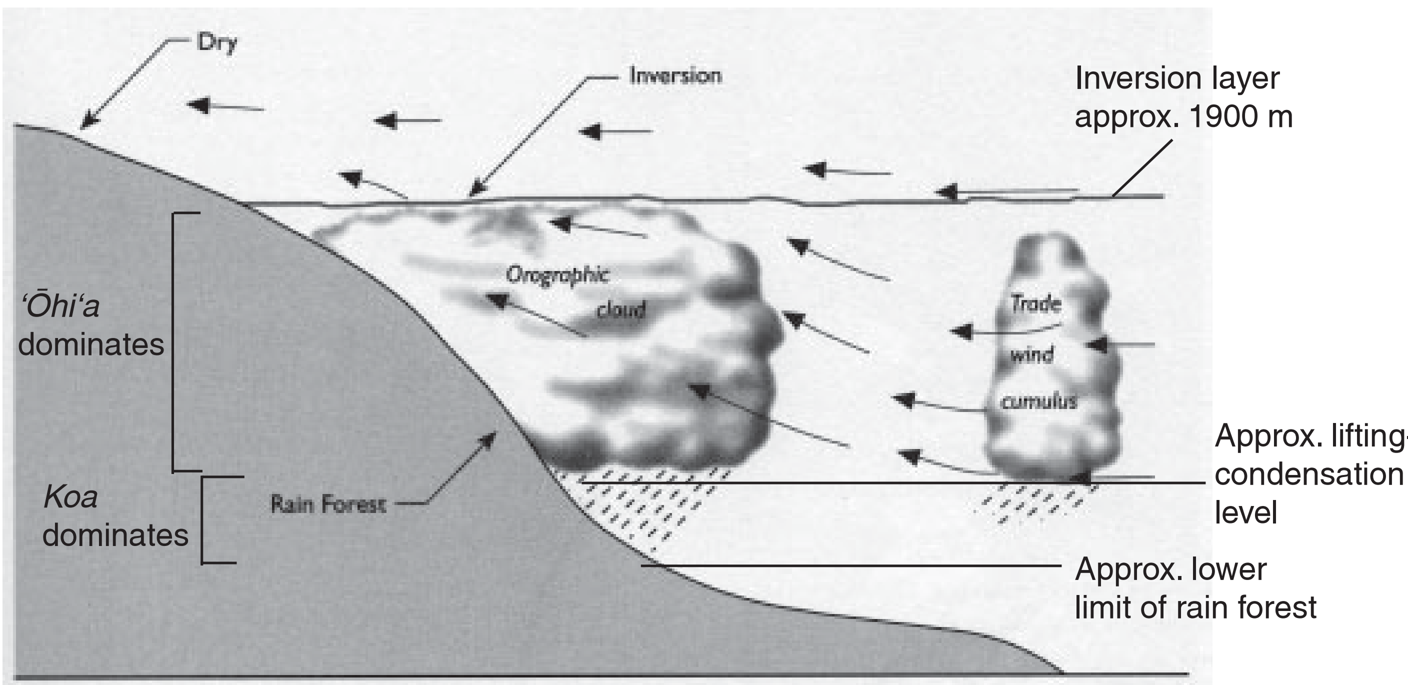


Figure 1: General weather patterns on windward Haleakalā *From Marie Sanderson (ed.),* Prevailing Trade Winds, *University of Hawai'i Press, Honolulu, 1993.*

2) Would the native rain forest extend all the way to sea level in this image? Why or why not?

   Look for well-reasoned responses. In this image, the rain forest would probably not extend all the way to the coast. The rain falling from the orographic cloud stops well short of the coastline, leaving a broad coastal bench without orographically generated rainfall. However, if the orographic cloud regularly gets bunched up and extends further over the coastal bench, then there could be enough rain to support a rain forest to the coastline.

3) Part of the rain forest on Haleakalā is a zone called the "cloud forest." The cloud forest zone is almost always enshrouded in clouds that hug the side of the mountain. It gets moisture from the clouds as well as rainfall. On Haleakalā, the cloud forest zone is between about 1000 meters (3280 feet) and 1900 meters (6232 feet).

How do you think the lower limit of the cloud forest relates to the lifting-condensation level? Explain your reasoning.

The lower limit of the cloud forest is approximately the same as the usual lifting-condensation level. The lower limit of the cloud forest would not be below the lifting-condensation level because there are not clouds below that level. At and above the lifting-condensation level, clouds are continually generated in the rising and cooling air being pushed by the prevailing trade winds.

4) On Figure 1, draw a line that indicates the approximate lifting-condensation level. If you are able to estimate the elevation of that level, do so on Figure 1 and explain your reasoning below. If you are not able to estimate its elevation, what additional information do you need?

The lifting-condensation level should correspond with the bottom of the cloud layer because that is where condensation/cloud formation begins. The lifting-condensation level should roughly correspond with the lower limit of the cloud forest, or approximately 1000 meters (3280 feet).

5) Would the lifting-condensation level always be at exactly the same elevation? Explain your reasoning.

No. As we learned in the dew point demonstration, air pressure and atmospheric moisture content can affect the dew point (lifting condensation level).

While the lifting-condensation level would not always be exactly the same, it should be relatively constant, reflecting the usual range of atmospheric conditions.

6) *ʻŌhiʻa* (*Metrosideros polymorpha*) and *koa* (*Acacia koa*) are the two main tree species in the rain forest canopy on Haleakalā. *ʻŌhiʻa* tends to dominate in the wettest part of the rain forest. *Koa* tends to dominate where it is drier, sometimes in a mixed-species canopy along with *ʻōhiʻa*. More commonly, the koa will grow taller than the *ʻōhiʻa*, sometimes forming a distinct upper canopy layer above the *ʻōhiʻa*.

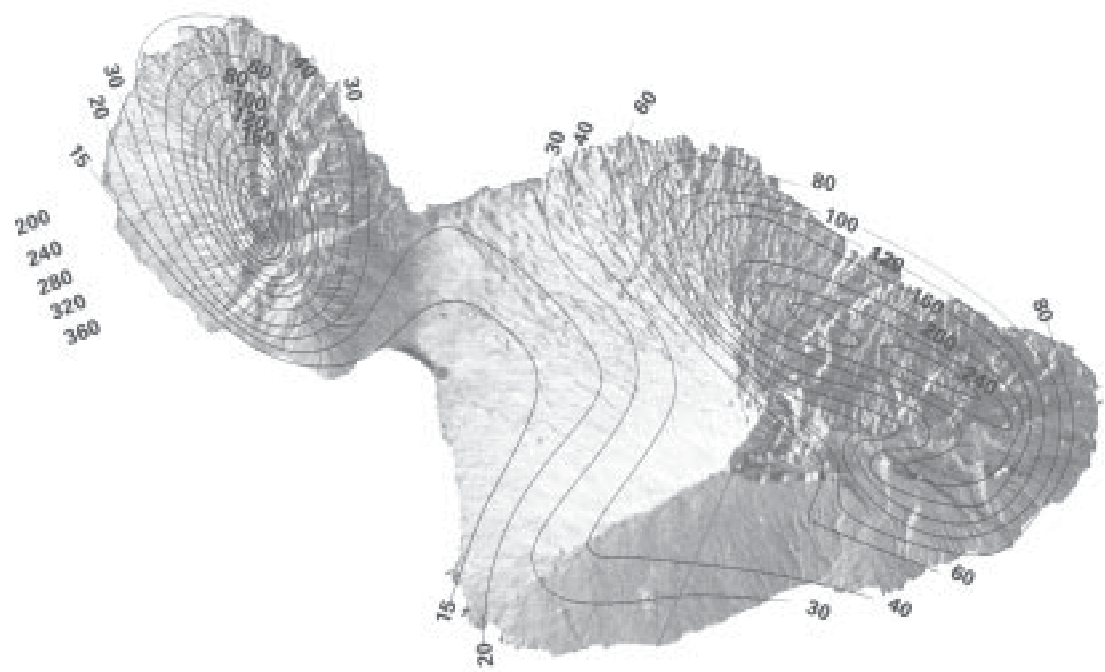
On Figure 1, indicate where you expect *ʻōhiʻa* to be the dominant tree in the rain forest and where you would expect *koa* to dominate. Is there any place where the two species might co-dominate? Explain your reasoning below.

See the graphic (p. 19) for the expected range of *ʻōhiʻa* and *koa*.

One might expect *koa* and *ʻōhiʻa* to codominate at the lower limit of the cloud forest, where rainfall is still relatively high but lessening with loss of elevation.

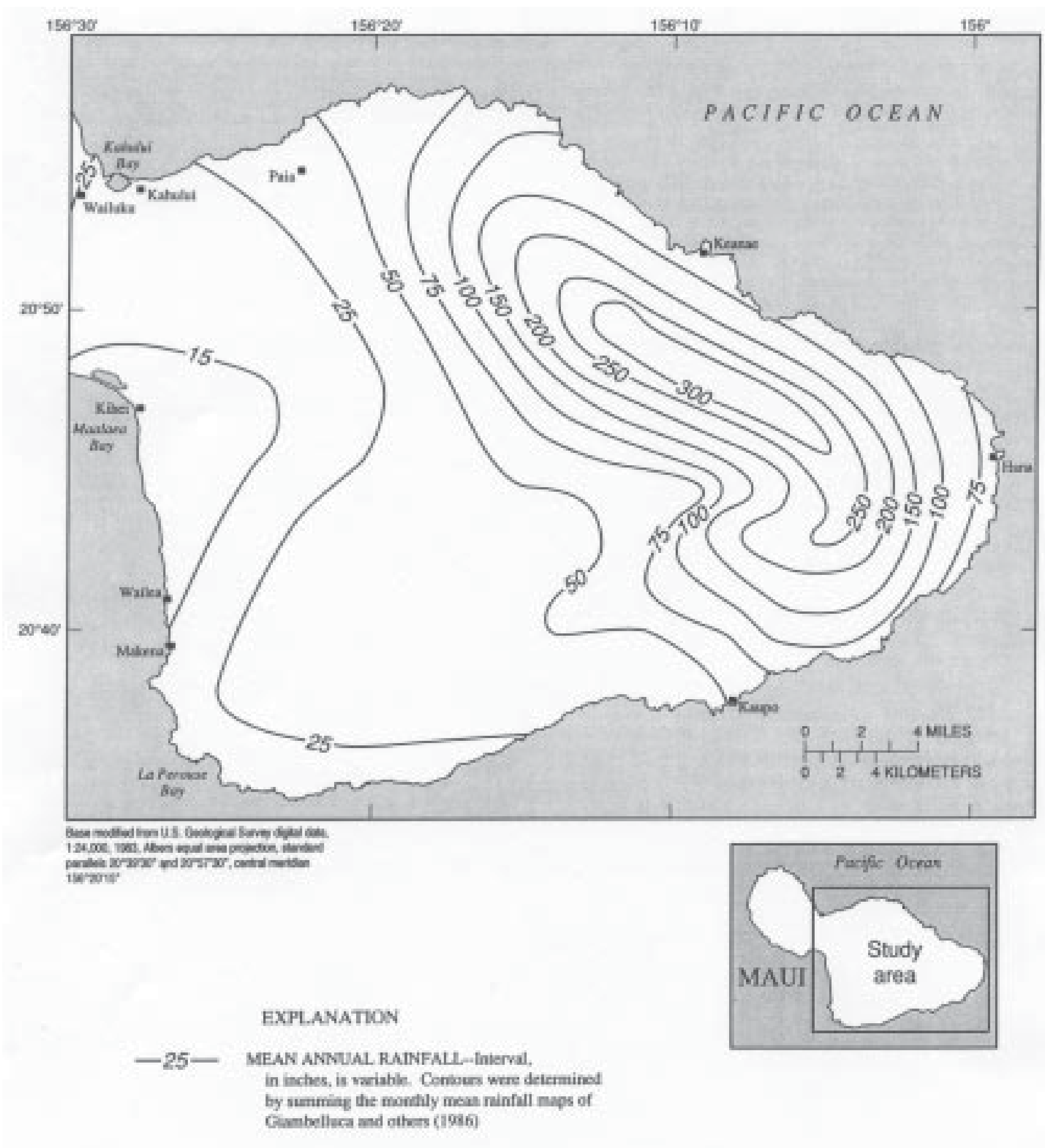
Maui Map Pack Acetate Masters

Average Annual Rainfall on Maui (inches)



Sonia P. Juvik and James O. Juvik (eds.), Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

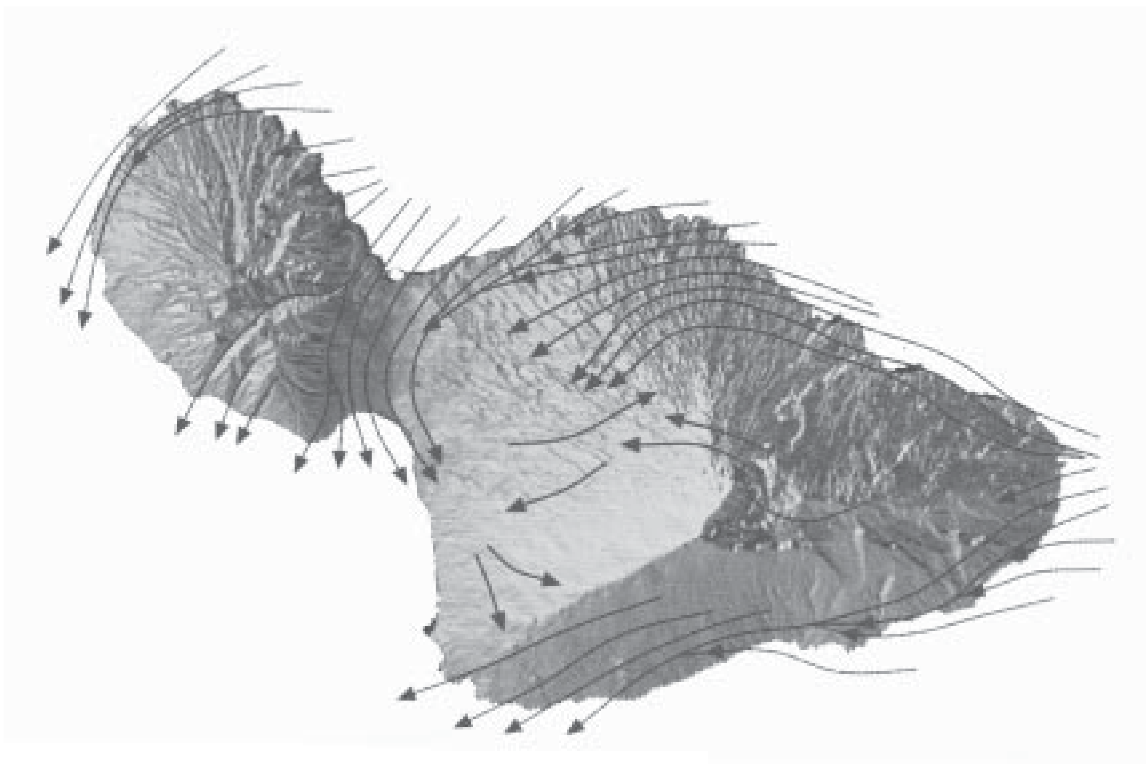
New Estimates of Rainfall



P. J. Shade, Water Budget of East Maui, Hawaii,
U.S. Geological Survey, Honolulu, 1999.

Prevailing Wind Patterns on Maui

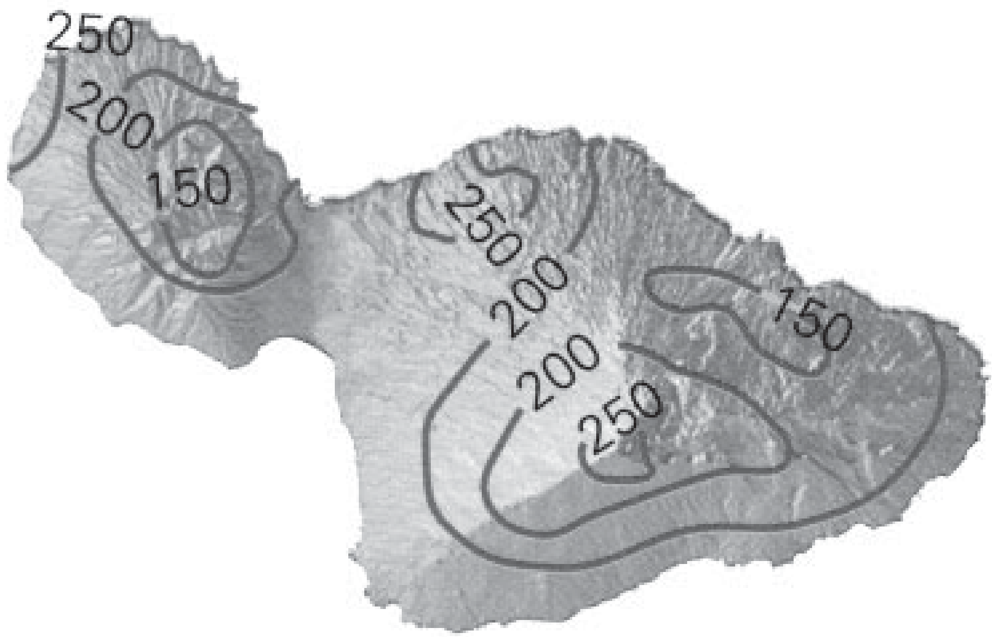
Lines and arrows represent flow lines of the prevailing winds.



Sonia P. Juvik and James O. Juvik (eds.), Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

Average Annual Solar Radiation Intensity (Watts/Meter^2)

Solar radiation is the amount of energy from the sun
that reaches the surface of the earth.



Sonia P. Juvik and James O. Juvik (eds.),
Atlas of Hawai'i, *3rd ed., University of*
Hawai'i Press, Honolulu, 1998.

Native Ecosystems on Maui Before Human Habitation

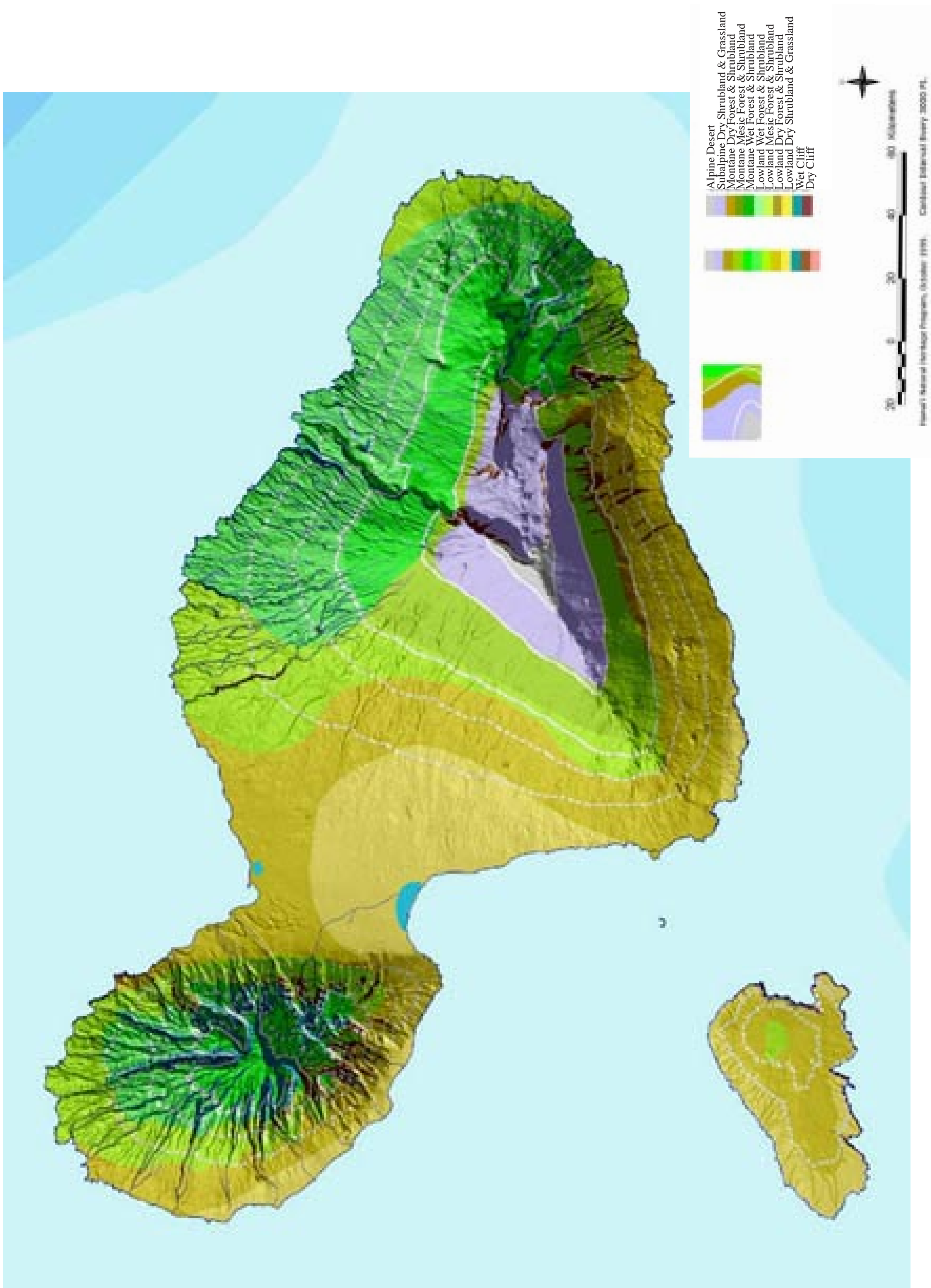


Image: Hawai'i Natural Heritage Program

Limits of Native Ecosystems Today

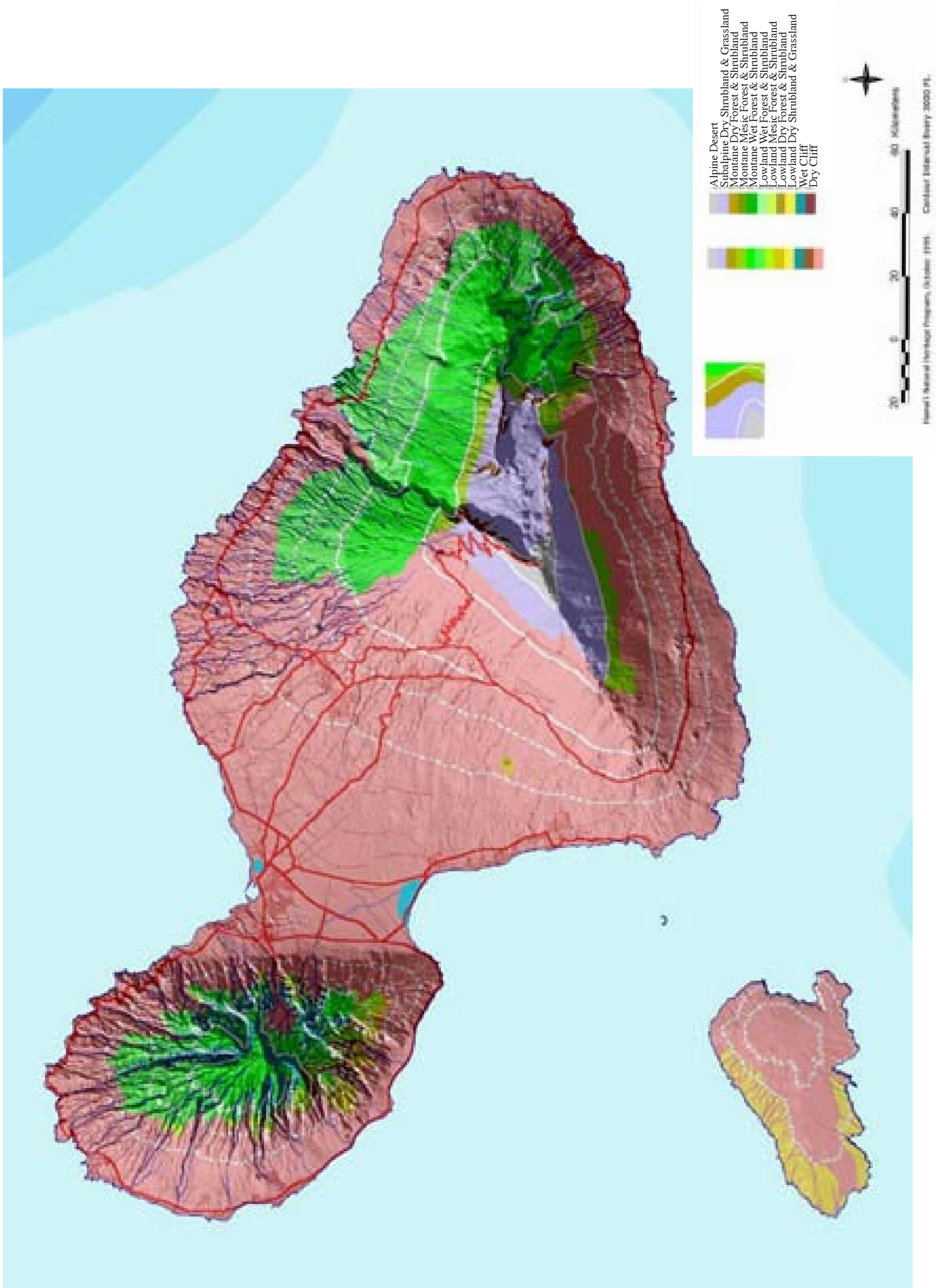


Image: Hawai'i Natural Heritage Program

Data Table

	A = Outside air temperature (°C)	B = Water temperature when condensation forms on the outside of the can (°C)	Difference between readings (A-B)	Relative humidity (percent)
Trial 1				
Trial 2				
Trial 3				

Relative-Humidity Table

Air Temp. (°C)	**Temperature Difference (°C)**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**14**
10	88	76	65	54	44	33	23	14	4			
12	89	78	67	57	47	39	29	20	11	3		
14	89	79	69	60	51	42	33	25	17	9		
15	90	80	71	62	54	45	37	29	22	14		
18	91	81	73	64	56	48	41	33	26	19	6	
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22	91	83	75	68	60	53	46	40	34	27	16	5
24	92	84	76	69	62	55	49	43	37	31	20	9
26	92	85	77	70	64	57	51	45	39	34	23	14
28	92	85	78	72	65	59	53	47	42	37	26	17
30	93	86	79	73	67	61	55	49	44	39	29	20
32	93	86	80	74	68	62	56	51	46	41	32	23

———Relative Humidity Around Beaker———

Maui Map Pack

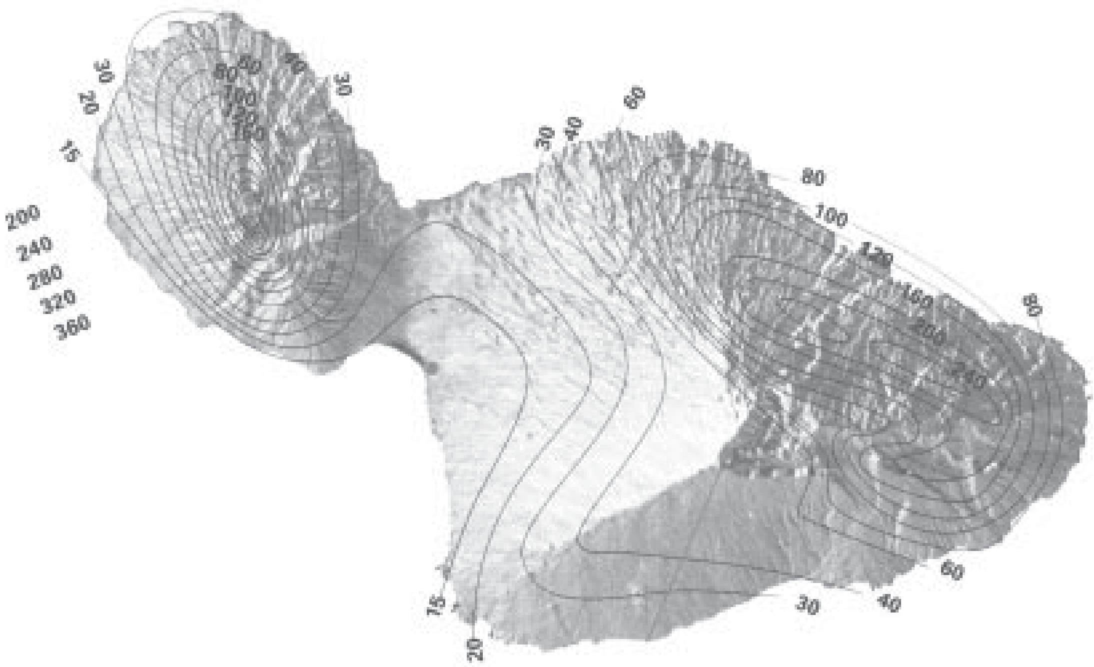
Use the maps provided in this activity sheet to answer the following questions:

1) Where does most of the rainfall occur on Maui? on Haleakalā? What might explain that pattern?

2) Rain forests generally occur where annual rainfall is greater than 203 centimeters (80 inches) per year. According to the rainfall map, what parts of Maui get enough rain to support a rain forest? (Draw an outline on the rainfall map of where you would expect to find rain forests.)

3) Other than rainfall, what other characteristics do you expect to find in the area where you think the rain forests would be? (Use all the maps provided for information.)

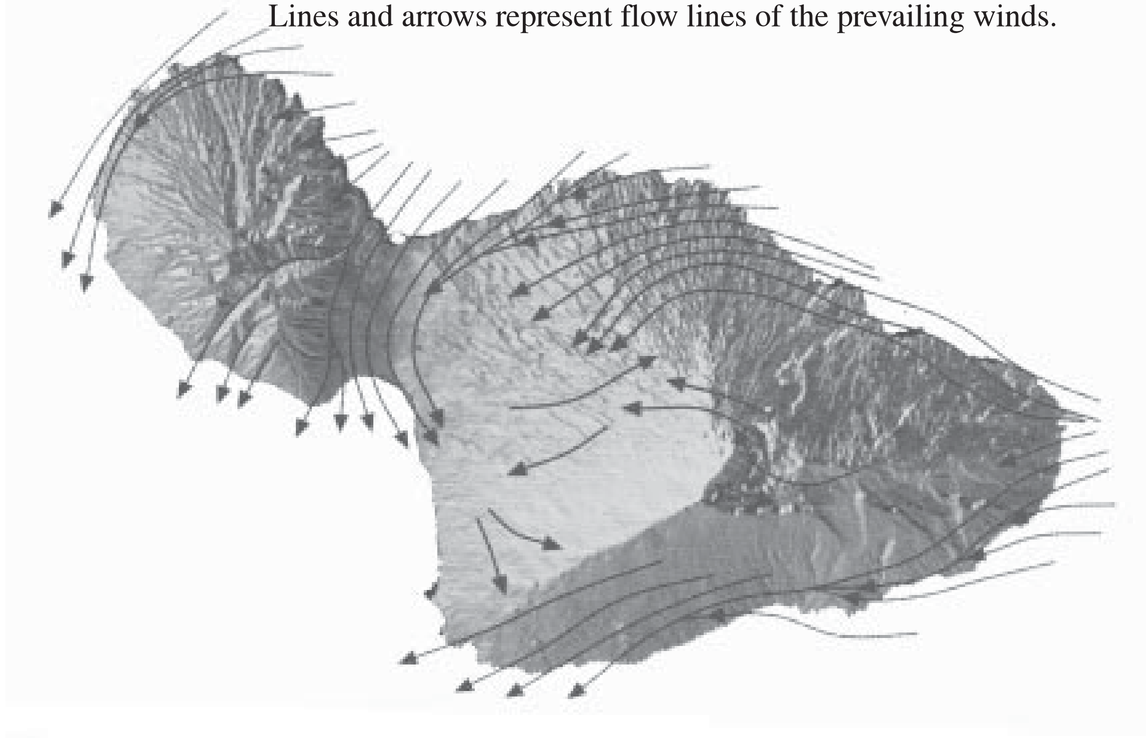
Average Annual Rainfall on Maui (inches)



Sonia P. Juvik and James O. Juvik (eds.),
Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

Prevailing Wind Patterns on Maui

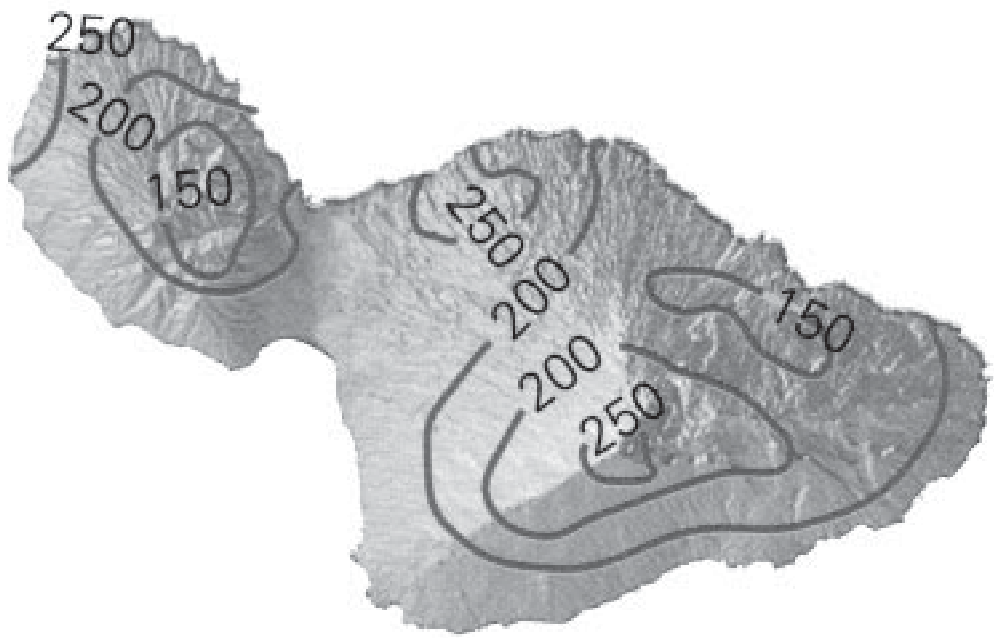
Lines and arrows represent flow lines of the prevailing winds.



Sonia P. Juvik and James O. Juvik (eds.),
Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

Average Annual Solar Radiation Intensity (Watts/Meter²)

Solar radiation is the amount of energy from the sun
that reaches the surface of the earth.



Sonia P. Juvik and James O. Juvik (eds.),
Atlas of Hawai'i, *3rd ed., University of*
Hawai'i Press, Honolulu, 1998.

Why Does It Rain on the Rain Forest?

Over the open ocean near Maui, between 56 and 71 centimeters (22-28 inches) of rain falls in an average year. In 1994, a rain gauge placed at 1650 meters (5412 feet) in the rain forest on the windward flank of Haleakalā measured more than 14 meters (45.92 feet or 551 inches) of rainfall *in one year*! What accounts for this difference?

One factor that accounts for this difference is Haleakalā itself. Trade winds blowing across the ocean from the northeast hit the mountain broadside and are forced upward. Some of the wind is deflected to the sides, flowing around the mountain. But much of the moist air is forced up the mountain's steep slopes in a phenomenon known as "orographic lifting." As the air travels upward it cools. As it reaches the "dew point," or condensation point, clouds form along the mountain slope. The moisture from these clouds and the "orographic rain" that falls from them is what accounts for the rain forest climates on windward Haleakalā.

The elevation at which clouds begin to form is called the "lifting-condensation level." In other words, this is the level at which air that is orographically lifted reaches its condensation point.

So now you know how the clouds are formed that make the rain that enables the rain forest to thrive. There is more to the picture, though, if you want to understand why the rain forest occurs in a belt along the northeastern flank of Haleakalā. Why isn't there rain forest all the way to the summit?

The answer to that question has to do with the trade wind "inversion layer." When the rising and cooling clouds meet the warm descending air in the Hadley Cell (see Figure 2, p. 31), the inversion layer is formed. The warm air overlying the

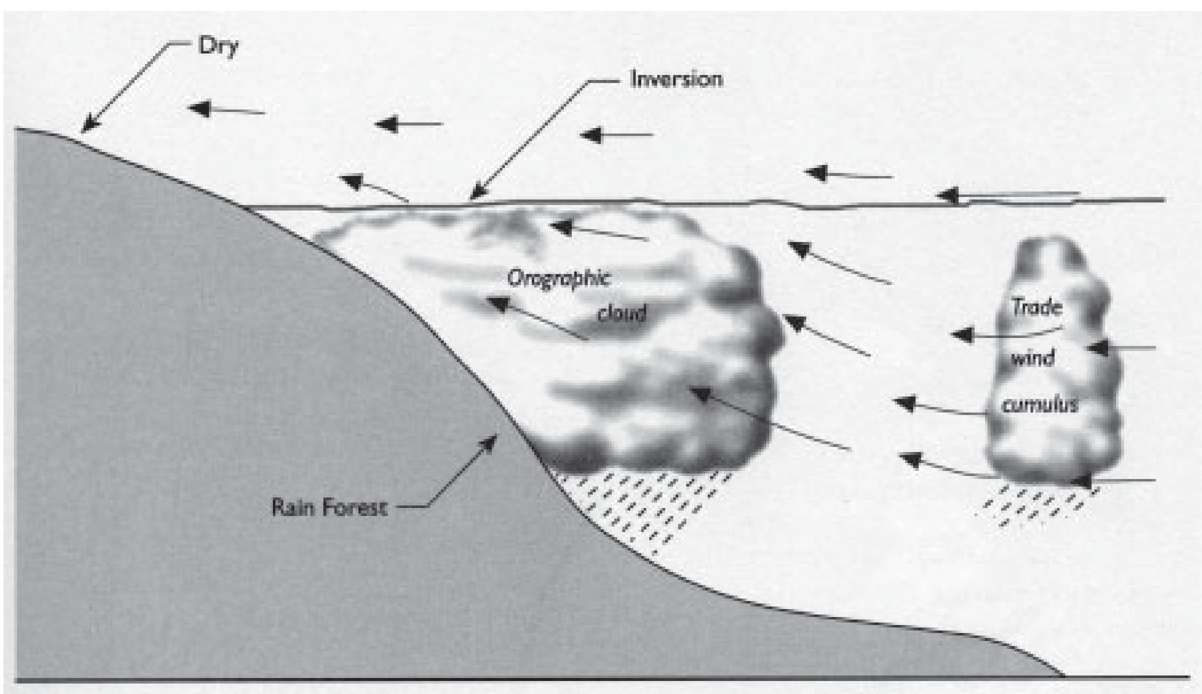


Figure 1: General weather patterns on windward Haleakalā (Marie Sanderson (ed.), Prevailing Trade Winds, *University of Hawai'i Press, Honolulu, 1993.)*

cooler air forms a barrier to clouds—any cloud that is forced through the inversion layer rapidly evaporates in the dry air above it.

Figure 1 (p. 30) illustrates the general pattern of trade wind weather on windward Haleakalā.

The clouds and rainfall are restricted to elevations below the level of the inversion layer. On windward Haleakalā, a good way to estimate the typical elevation of the inversion layer is to look at the upper limits of the rain forest, which are at about 1900 meters (6232 feet).

Before humans settled on Maui, the native rain forest extended all the way to the coastline along much of the northeast coast of Haleakalā. This entire area receives more than enough rain to support a rain forest. Now, however, in most of the lower elevation areas, there are only scattered remnants of native rain forest. It is still wet and lush, as a drive along the Hāna Highway will prove. But ever since the time of Polynesians, these lower reaches of the rain forest have been favored for human settlement, farming, and other activities. This activity has dramatically changed the ecosystem from one dominated by native rain forest species to one dominated by nonnative rain forest species. In some areas, such as around Hāna, the native rain forest did not extend all the way to the coast, even before human settlement. Looking at the rainfall map will show you one reason why this is the case.

Use the information and graphics provided in this article along with what you already know to answer the following questions about how the interaction of climate and topography forms the limits to the rain forest on Haleakalā.

The Hadley Cell

The Hadley Cell is a part of the large-scale circulation of the earth's atmosphere. Warm air rises near the equator and moves toward the north pole at high altitudes. As it reaches 30° N latitude, the air sinks and circulates back toward the equator completing the Hadley Cell.

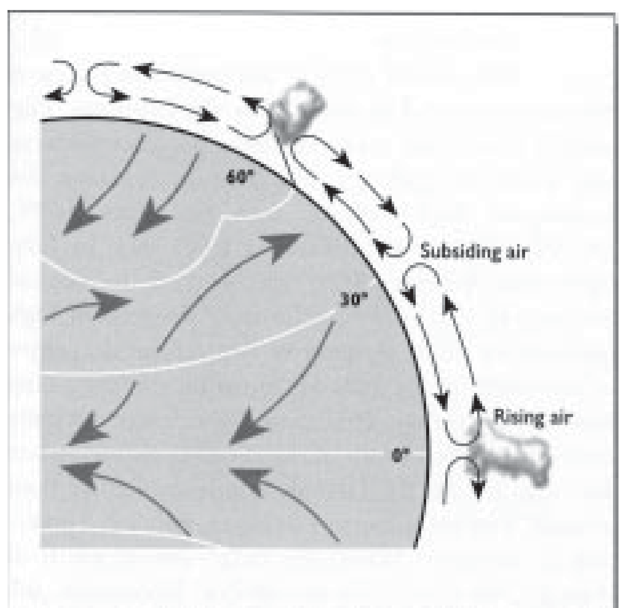


Figure 2: Idealized Hadley Cell, showing vertical and horizontal wind patterns (Marie Sanderson (ed.), Prevailing Trade Winds, *University of Hawai'i Press, Honolulu, 1993.)*

Questions

1) On Figure 1of the reading (p. 30):
   a) Indicate the approximate altitude of the inversion layer.
   b) Draw a line indicating the approximate lower limits of the rain forest.

2) Would the native rain forest extend all the way to sea level in this image? Why or why not?

3) Part of the rain forest on Haleakalā is a zone called the “cloud forest.” The cloud forest zone is almost always enshrouded in clouds that hug the side of the mountain. It gets moisture directly from the clouds as well as from rainfall. On Haleakalā, the cloud forest zone is between about 1000 meters (3280 feet) and 1900 meters (6232 feet).
   How do you think the lower limit of the cloud forest zone relates to the lifting-condensation level?

4) On Figure 1 of the reading (p. 30), draw a line that indicates the approximate lifting condensation level. If you are able to estimate the elevation of that level, do so on Figure 1 and explain your reasoning below. If you are not able to estimate its elevation, what additional information do you need?

5) Would the lifting-condensation level always be at exactly the same elevation? Explain your reasoning.

6) *‘Ōhi‘a* (*Metrosideros polymorpha*) and *koa* (*Acacia koa*) are the two main tree species in the rain forest canopy on Haleakalā. *‘Ōhi‘a* tends to dominate in the wettest part of the rain forest. *Koa* tends to dominate where it is drier, sometimes in a mixed-species canopy along with *‘ōhi‘a*. More commonly, the *koa* will grow taller than the *‘ōhi‘a*, sometimes forming a distinct upper canopy layer above the *‘ōhi‘a*.

   On Figure 1 of the reading (p. 30), indicate where you expect *‘ōhi‘a* to be the dominant tree in the rain forest and where you would expect *koa* to dominate. Is there any place where the two species might co-dominate? Explain your reasoning below.

Activity #3

Rain Forest on a Budget

● ● ● In Advance *Student Assignment*

- Assign the Student Page "Water in the Rain Forest—What Goes In and What Comes Out" (pp. 45-53) as homework.

● ● ● Class Period One *Rain Forest Water Budget & Demonstration*

Materials & Setup

- "Water Budget for Windward Haleakalā" acetate (master, p. 44)
- Overhead projector and screen

For each student

- Student Page "Water in the Rain Forest—What Goes In and What Comes Out" (pp. 45-53)

Four sets of the following materials for the demonstration

- Cardboard box, 17 inches long x 12.5 inches wide x 12.5 inches high (or similar)
- 33-gallon garbage bag
- Scissors
- Household sponges—enough to cover the bottom of the box
- Stapler
- Soil
- Board or dish drainer to put under box
- Leafy branches (leaves one to two inches long)
- Plastic 1/2-gallon jug with small holes drilled into the side (not the bottom, because you have to put water in it without letting it run out) or a garden watering can
- Timer
- Catchment container at open end of box
- Four measuring beakers of the same size

Instructions

1) Discuss student responses to the Student Page "Water in the Rain Forest—What Goes In and What Comes Out." Use the "Water Budget for Windward Haleakalā" acetate as you are discussing question #3.

2) After the discussion, show the water budget acetate again, and ask students what they think would happen to each of the water budget elements if the understory and forest floor vegetation and/or canopy layers were disturbed or removed from the rain forest.

3) Do the "Rain Forest in a Box" demonstration following instructions in the teacher background (pp. 40-42). This demonstration helps students visualize what happens to the forest soil layer as rain falls in an intact rain forest, as well as one in which the understory and forest floor vegetation and/or the canopy layers have been removed.

4) After the demonstration, divide the class into four groups. Each group should select one water budget element and design an experiment to test their hypothesis about the effects of clearing the rain forest on that element. They will be conducting these experiments during the next class period. Encourage students to use the same materials as you used for the demonstration. If a group needs additional materials, students should bring them to the next class.

● ● ● Class Period Two *Testing the Effects of Rain Forest Clearing*

Materials & Setup

For each student

- Student Page "The Waters of Kāne" (pp. 54-55)

For the demonstration

- Same four sets of materials from Class Period One

Instructions

1) Provide each group with one set of "Rain Forest in a Box" materials. Have them conduct their experiments by:
   a) Writing the question they are trying to answer, as well as their hypothesis;
   b) Writing a description of the methods they will use to test their hypothesis;
   c) Setting up and conducting the experiment;
   d) Recording results; and
   e) Writing their conclusions.

2) Have groups share their methods and results with the rest of the class.

3) As homework, assign the Student Page "The Waters of Kāne" and/or one or more of the journal writing topics.

Journal Ideas

- What is the likely effect of rain forest degradation on human water supply from the Haleakalā rain forest?
- What do you think would happen to the rain forest if people started pumping large volumes of ground water from the East Maui Watershed? How could you test this hypothesis?
- What are some ways to reduce the growing demand for water from the Haleakalā rain forest? What can you do personally to contribute?
- Do you think surface water should be diverted from East Maui streams for agricultural and household use in Central, Upcountry, and East Maui? West and South Maui? Why or why not?

Assessment Tools

- Student Page "Water in the Rain Forest—What Goes In and What Comes Out" (teacher version, pp. 37-39)
- Participation in class discussion and demonstration
- Design, conduct, record-keeping, and reporting of experiment
- Student Page "The Waters of Kāne" (teacher version, p. 43)
- Journal entries

Teacher Version

Water in the Rain Forest—What Goes In and What Comes Out

1) Using the data in Table 1: Mean Monthly Water Budget for Windward Haleakalā for your calculations, identify the three months in which the ratio of fog drip to rainfall is the highest. Below, list these three months and the contribution of fog drip to the water budget as a percentage of total moisture input (fog drip + rainfall). Express percentages using two decimal places.

    Top three months for fog-drip contribution — Percent of total moisture input

    ___________July__________________ _____26.05%_______

    __________August_________________ _____25.99%_______

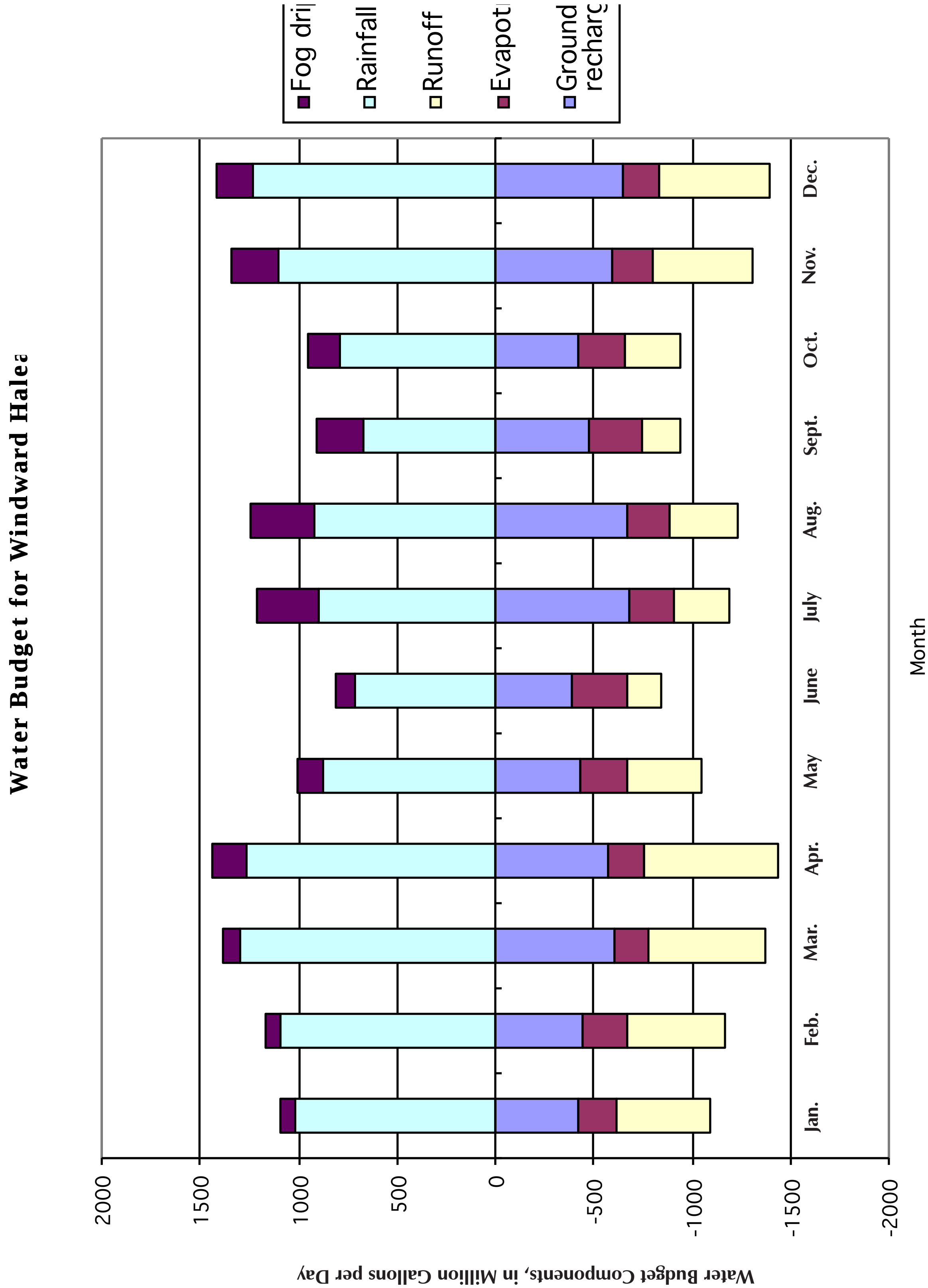
    _________September_______________ _____26.43%_______

2) In the summer months, trade winds tend to be stronger and more reliable than at other times of the year. This pattern produces a well-developed trade wind inversion. How would this seasonally stronger atmospheric inversion help to explain the patterns in high fog-drip contribution you identified in question #1? Explain your reasoning.

    The fog zone on the windward (north) side of Haleakalā volcano extends from the mean cloud base level, at about 600 meters (1970 feet), to the lower limit of the most frequent temperature inversion base height at about 2000 meters (6560 feet). The high July to September ratio of fog drip to rainfall is the result of a well-developed atmospheric temperature inversion and strong trade winds. As the moist air is forced upslope, cloud height is restricted by the inversion, thus favoring fog rather than raindrop formation.

3) Using the data in Table 1: Mean Monthly Water Budget for Windward Haleakalā and the blank chart on the following page, create a stacked-column chart representing the relative proportion of water-budget components for windward Haleakalā. A sample stacked-column chart is shown below.
    Give this chart a title, labels for each axis, and a legend.

    See the completed chart on p. 38.


Water Budget for Windward Halea
Fog dri
Rainfall
Runoff
Evapot
Ground recharg
2000
1500
1000
500
0
-500
-1000
-1500
-2000
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Month
Water Budget Components, in Million Gallons per Day

4) Using the following data, calculate the mean monthly contribution of rainfall and fog drip (in millions of gallons per day) to the water budgets of leeward Haleakalā (zone C on the map) and windward Haleakalā (zone F on the map--see student version for map).

Water budget component	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Windward Haleakalā												
Rainfall	1018	1090	1300	1261	881	713	897	917	671	792	1104	1228
Fog drip	70	77	89	174	129	103	316	322	241	161	237	183
Leeward Haleakalā												
Rainfall	336	268	247	205	107	49	49	82	80	146	192	282
Fog drip	8	7	7	12	6	3	7	12	11	12	16	15

Data in Million Gallons per Day

Answers:

Windward rainfall	989
Windward fog drip	176
Leeward rainfall	170
Leeward fog drip	10

5) Explain the difference in relative contribution of fog drip to total moisture input between the leeward and windward zones using the information on the map and what you know about the climate of windward and leeward Haleakalā.

The basic answer is that there is, proportionately, a much smaller fog zone on leeward Haleakalā than there is on the windward side. The windward side is subject to the prevailing trade winds, which bring moisture-laden air from across the ocean. Haleakalā forces these winds upward (the orographic effect), forming clouds that hug the mountainside, capped by a temperature inversion layer.

The same temperature inversion layer caps the cloud/fog layer on leeward Haleakalā. But the winds coming around the mountain and onshore from the south tend not to be as strong, constant, or moist as the trade winds.

6) A water budget is a model based on past averages. Some people believe that a series of extremely dry years in the late 1990s may be a sign that East Maui is entering into a prolonged period of reduced average rainfall. If East Maui is indeed beginning a long drought, do you think this estimated water budget should be used as a tool for determining how much surface or ground water can be safely withdrawn from the watershed? Explain your response.

Well-reasoned responses are acceptable.

Teacher Background

Rain Forest in a Box

Overview

This demonstration illustrates the importance of the layer of mosses and other vegetation that covers the ground (and many trees) in the rain forest. This thick layer acts as a sponge in the capture and slow release of water in the rain forest. It also illustrates how trees and vegetation slow the speed of water onto the ground.

Materials

- Cardboard box, 17 inches long x 12.5 inches wide x 12.5 inches high (or similar)
- 33-gallon garbage bag
- Scissors
- Household sponges—enough to cover the bottom of the box
- Stapler
- Soil
- Board or dish drainer to put under box
- Leafy branches (leaves one to two inches long)
- Plastic 1/2-gallon jug with small holes drilled into the side (not the bottom, because you have to put water in it without letting it run out) or a garden watering can
- Timer
- Catchment container at open end of box
- Four measuring beakers of the same size

Preparation

In advance of the class period, assemble the four sets of materials in the following manner:

1) Cut away the narrow (12.5 inches) end of the box.

2) Cut open the plastic garbage bag, and line the inside of the box with it. Staple the edges to the box.

3) Support the underside of the box with a board or dish drainer.

4) Put soil into the box to a depth of approx. 1 1/2 inches; pack it down.

5) Completely cover the soil with sponges.

6) Prop the back of the box up two inches, so it is on a slight slope.

7) Place leafy branches in the box so that it looks like a forest inside.

8) Place one quart of water into the 1/2-gallon jug.

Procedure

Experiment 1 - How much water drains out with the forest vegetation intact?

1) Explain to students what you are about to do, and have them write down hypotheses about what will happen.
2) On one “rain forest in a box,” slowly sprinkle the quart of water onto the leafy branches. Note the length of time this takes.
3) Let the box drain into the catchment container for one minute.
4) Pour the water and any soil into a measuring beaker or cup. If there is soil in it, let it stand awhile so the soil can settle out. Then measure the volume of soil and water, and record the results.
5) Squeeze out the sponges and measure the water they hold. Record the results.
6) Have students compare the results to their hypotheses.

Experiment 2 — Simulating understory destruction

Using a different “rain forest in a box,” do exactly the same as above, but without the sponges.

Experiment 3 — Simulating canopy opening

Using a new “rain forest in a box,” repeat the procedure, but without the leafy vegetation.

Experiment 4 — Simulating canopy opening and understory destruction

Carry this investigation one step further by taking both the leafy branches and the sponges out and sprinkling the water on the bare soil.

Interpretation

1) Measure the height of the soil layer in all beakers.
2) Measure the height of the water layer in all beakers.
3) Measure the height of the water taken from the sponges.
4) Make a bar graph for comparison.

Discussion

1) Did the sponge layer do anything to retard the flow of water and soil as runoff?

2) How does the sponge layer appear to be valuable in the forest?

   It slows the water getting to the ground, so the soil isn't washed away and releases the moisture slowly into the ground to recharge the aquifers.

3) What acts like a sponge in the rain forest?

   The forest floor is covered with a mat of mosses, lichens, and low-growing plants, along with a layer of soil and decaying plant matter that act as a sponge.

4) In nature, where does the runoff go?

   Into streams and then to the ocean

5) What destroys the sponge layer in the forest?

   Pigs root in the forest floor for fern roots and earthworms; the hooves of wild cattle break up the sponge; people walking over the same area break down the sponge.

6) Discuss the role that vegetation plays in slowing down the flow of water onto the ground.

   Leaves and branches provide surface area, which forces the rain water to slow as it falls.

7) Why is it important that the rain falls slowly onto the ground?

   Soil isn't washed away.

8) Why is the topsoil valuable?

   Most of the decomposition in the forest happens in the top soil layer, so all the nutrients are here.

Teacher Version

The Waters of Kāne

On the following page is a translation of a *mele* from Kaua‘i that describes elements of the hydrologic cycle. It is entitled "*Ka Wai a Kāne,*" or "The Waters of Kāne." (Kāne is one of the four great Hawaiian gods.)

Read "*Ka Wai a Kāne.*" Then, on this page or a separate piece of paper, write your own *mele* that reflects the hydrologic cycle on windward Haleakalā. Be sure to include the water budget components you worked with in this unit.

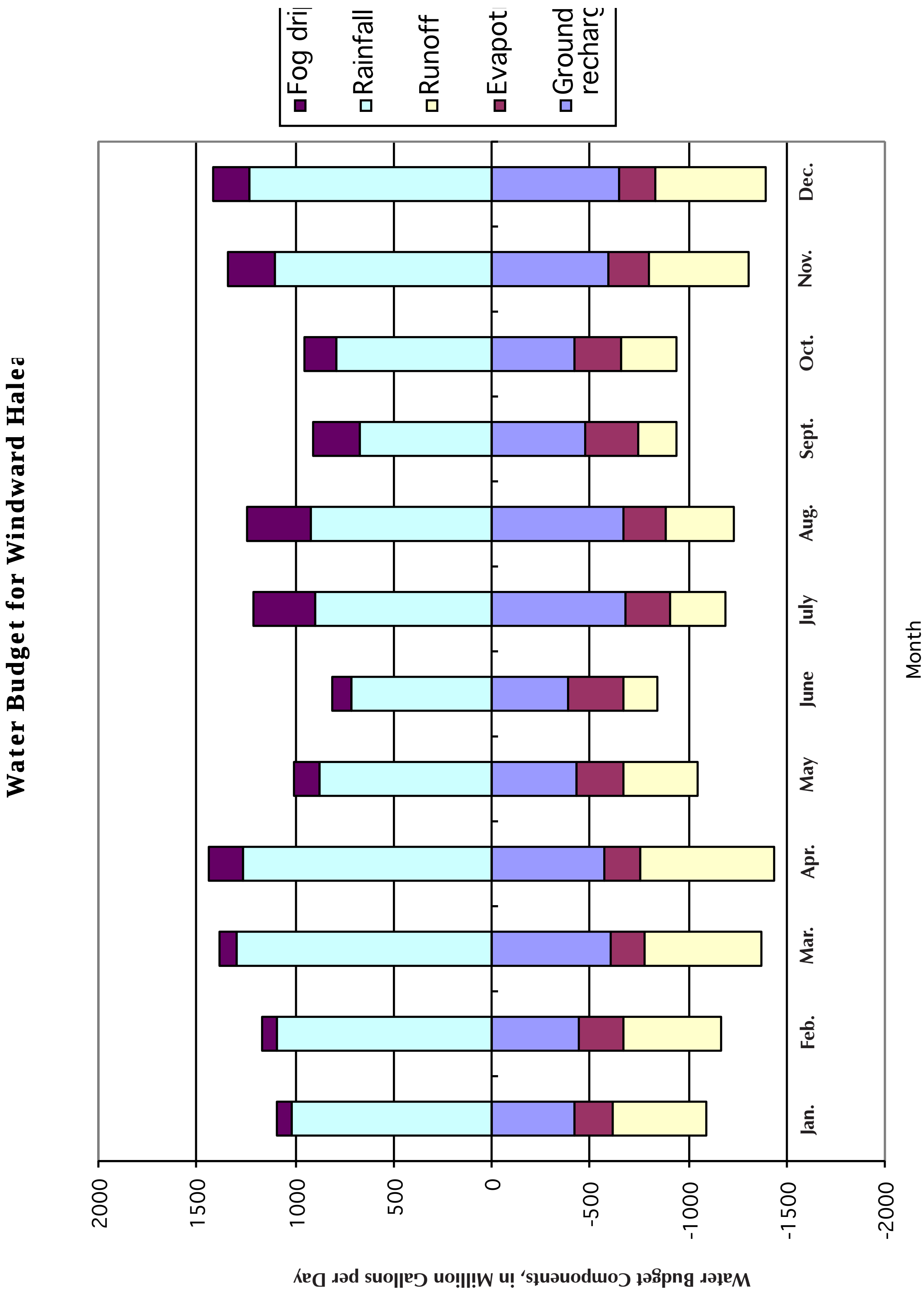
Other ideas for your *mele* include:

- Rain forest alterations that can or have changed the water budget,
- Specific places on East Maui,
- Inversion layer and lifting-condensation levels,
- Seasonal differences,
- Orographic lifting,
- Differences between the windward and leeward sides,
- Other climate characteristics you studied in this unit, and
- How people can help keep the "waters of Kāne" flowing on East Maui.

Basic parameters for evaluating the students' *mele* include:

- Accurate inclusion of the main water budget components (rainfall, fog drip, runoff, evapotranspiration, soil-moisture storage, and groundwater recharge),
- Accuracy in describing/including other concepts related to the hydrologic cycle, and
- Accurately locating places on Maui with respect to the hydrologic cycle.

You may also want to account for creativity, evidence of additional research, the range of additional information included beyond the six components of the water budget.


Water Budget for Windward Halea
Fog dri
Rainfall
Runoff
Evapot
Ground recharg
2000
1500
1000
500
0
-500
-1000
-1500
-2000
Water Budget Components, in Million Gallons per Day
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Month

Water in the Rain Forest--What Goes In and What Comes Out

Growing numbers of residents, tourists, and commercial developments mean an increasing demand for fresh water on Maui. Currently, the main source for water to supply most of the island's municipal uses is on West Maui, where wells pump water from the ʻĪao "aquifer" (an underground source of water). The ʻĪao aquifer is near its limit and cannot support much greater water withdrawals, so people are looking around for other sources of water for drinking, cooking, bathing, watering lawns and golf courses, filling pools, washing clothes and dishes, and all of our other daily activities that require fresh water.

One place people are looking is the windward side of East Maui, where large sources of ground water are still untapped. Sixty billion gallons of surface water per year from this part of East Maui already provide much of Upcountry and East Maui drinking water and most of the irrigation water that goes to the Hawaiian Commercial & Sugar Company in Central Maui. Some people, including the Board of Water Supply, want to tap the "ground water," too. (Ground water is the water that flows and is held in aquifers below the surface.) They look at that underground water as a key to providing fresh water for the entire island's future needs.

But the water that flows above the surface ("surface water") and the water that flows below it (ground water) are linked. Some people are concerned that pumping a lot of ground water and piping it off for use elsewhere on Maui would reduce the flow in the springs and streams that course down the flank of Haleakalā. They want more information about how the ground water and surface water interact on windward Haleakalā.

One effort to provide that information was a project completed in 1999 by the U.S. Geological Survey in partnership with the County of Maui Department of Water Supply and the State of Hawaiʻi Commission on Water Resource Management (Patricia J. Shade, *Water Budget of East Maui, Hawaii,* U.S. Geological Survey, Honolulu, 1999). Project investigators used existing data and models to calculate an average monthly "water budget" for East Maui. Part of that calculation focused specifically on the wet, windward side of East Maui between Māliko Gulch on the west and Makapipi Stream on the east, and from the shore to the north rim of the Haleakalā summit basin. (Figure 1, p. 46 shows the study area.)

A "water budget" is simply a model that estimates how much water enters and leaves a particular area, and through what mechanism. It is a first step in understanding a ground water system so that water resources can be managed well. Calculating a water budget is a complicated undertaking that involves many measurements, estimates, and calculations. The basic idea, however, is simple: What goes in must come out—or be stored somewhere within the system. Here is the basic equation:

$$G = P + F - R - ET - DSS$$

Where:

G = "ground water recharge"
P = rainfall
F = "fog drip"
R = "runoff"
ET = "evapotranspiration"
DSS = change in "soil-moisture storage"

(Figure 2, p. 47 illustrates the basic elements of the hydrologic cycle.)

Water Budget Equation Elements

Ground Water Recharge

This refers to the amount of water that filters into the soil, percolating through until it reaches

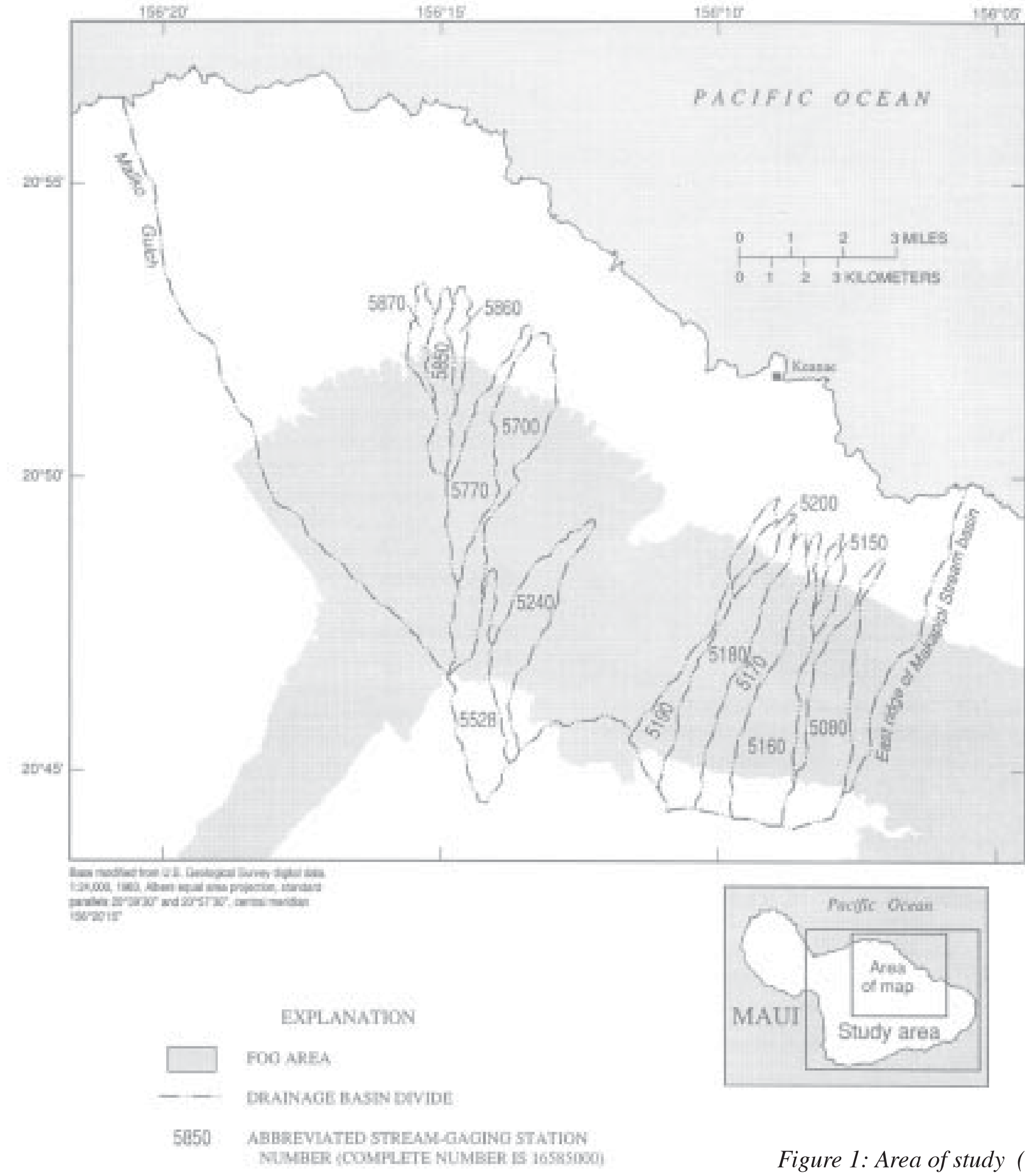


Figure 1: Area of study (Patricia J. Shade, Water Budget of East Maui, Hawaii, *U.S. Geological Survey, Honolulu, 1999, p. 13.)*

the underground reservoirs and flow-ways called aquifers. To calculate this amount, the other variables need to be known or estimated.

Rainfall

As you have learned in this unit, the rainfall distribution on windward Haleakalā is influenced by the orographic effect. Rainfall is abundant at most elevations as the prevailing trade winds are forced to rise and cool, condensing into clouds and rain. Monthly mean rainfall levels were calculated based on interpreting collected data to create maps denoting different rainfall levels across the study area.

Fog Drip

Also known as cloud-water interception, fog drip contributes water to the water budget

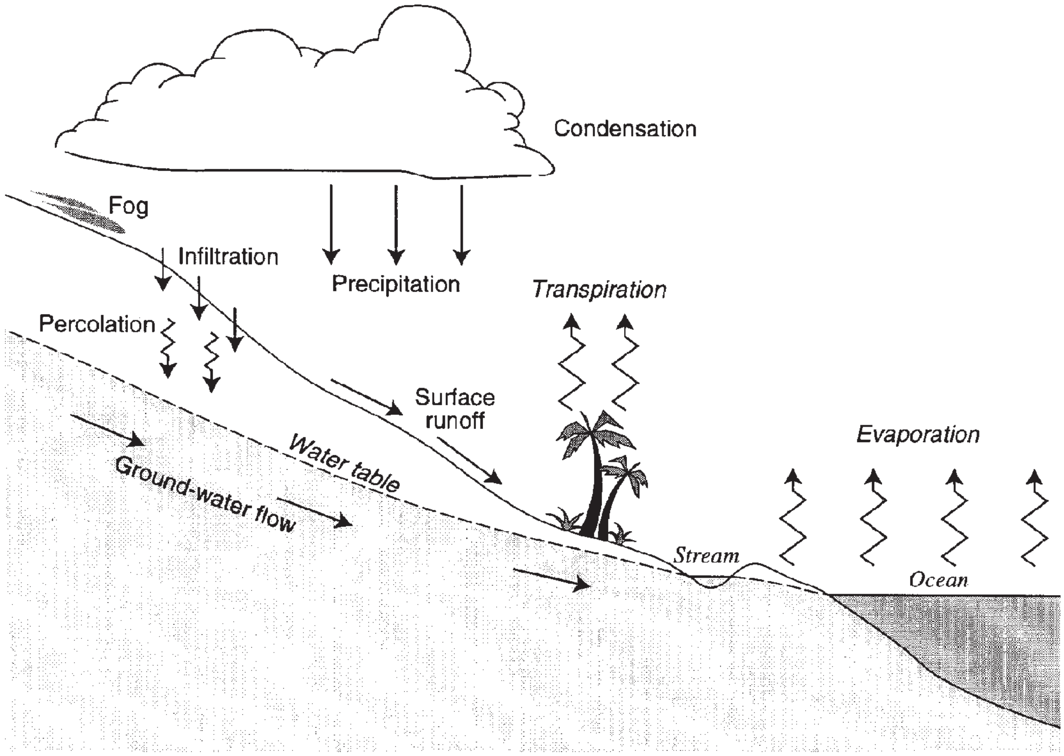


Figure 2: The hydrologic cycle (Patricia J. Shade, Water Budget of East Maui, Hawaii*, U.S. Geological Survey, Honolulu, 1999, p. 6.)*

through condensation that accumulates on the surfaces of plants and the ground. Limited data are available for calculating this part of the equation on East Maui. So its contribution was estimated based on research done on the windward slopes of Mauna Loa on the island of Hawai'i. As you have also learned in this unit, the cloud (or fog) zone on windward Haleakalā is influenced by the interaction of the orographic lifting effect and the trade wind inversion. In this area, fog drip makes a significant contribution to the water budget.

Runoff

Runoff is the water that flows across the land surface and into stream channels promptly after rainfall. It is calculated using data gathered about streamflow in fourteen different drainage basins on windward Haleakalā. Stream flow has two components: runoff and "base flow." Base flow is the part of stream flow that is sustained through dry weather by the discharge of ground water into the stream. So runoff can be estimated by subtracting the base flow from the total stream flow.

Evapotranspiration

This is the quantity of water evaporated from soil and water surfaces added to the amount of water evaporated as plants "transpire" (vaporize water through their leaf surfaces). For this study, evapotranspiration rates were estimated using two sets of data.

Soil characteristics

Soils of East Maui have been analyzed and mapped according to several characteristics that affect their ability to store moisture that would then be available to plants. These characteristics include "permeability rate" (how quickly water filters through the soil), how many inches of water each inch of soil can store, and the average depth of plant roots in that soil type. A maximum soil-moisture storage value was calculated for each soil type using these values, and the results were plotted on a soils distribution map. The maximum soil-moisture storage affects evapotranspiration because it can limit the amount of water available for plants to take up from the soil and transpire through their leaves.

Potential evapotranspiration

This is an estimate of the maximum evapotranspiration from an extensive area of well-watered, actively growing vegetation. It is estimated using data from standardized evaporating pans, which are easier to collect and have been shown to closely correspond with actual potential evapotranspiration. Where these data were not available, potential evapotranspiration was estimated based on research done on the windward slopes of Mauna Kea on the island of Hawai‘i.

Change in Soil-Moisture Storage

This variable is an estimate of the amount of water actually being stored in the soil across the study area. The volume of water stored in the soil changes from month to month and is approximated based on an estimated initial value, monthly changes in the other variables, and the maximum soil-moisture storage values.

Arriving At the Water Budget

Using this basic equation, a lot of complex modeling, and some well-calculated estimates, researchers produced a mean monthly water budget for East Maui. Table 1: "Mean Monthly Water Budget for Windward Haleakalā" shows the main results for windward Haleakalā. Use it to answer the questions that follow.

Table 1: Mean Monthly Water Budget for Windward Haleakalā

Water budget component	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Fog drip	70	77	89	174	129	103	316	322	241	161	237	183
Rainfall	1018	1090	1300	1261	881	713	897	917	671	792	1104	1228
Runoff	-475	-493	-598	-684	-378	-175	-286	-346	-193	-285	-509	-569
Evapotranspiration	-203	-230	-169	-185	-239	-272	-230	-222	-276	-238	-204	-177
Ground water recharge	-417	-445	-608	-571	-428	-394	-678	-667	-471	-417	-596	-651

Data in million gallons per day

Questions

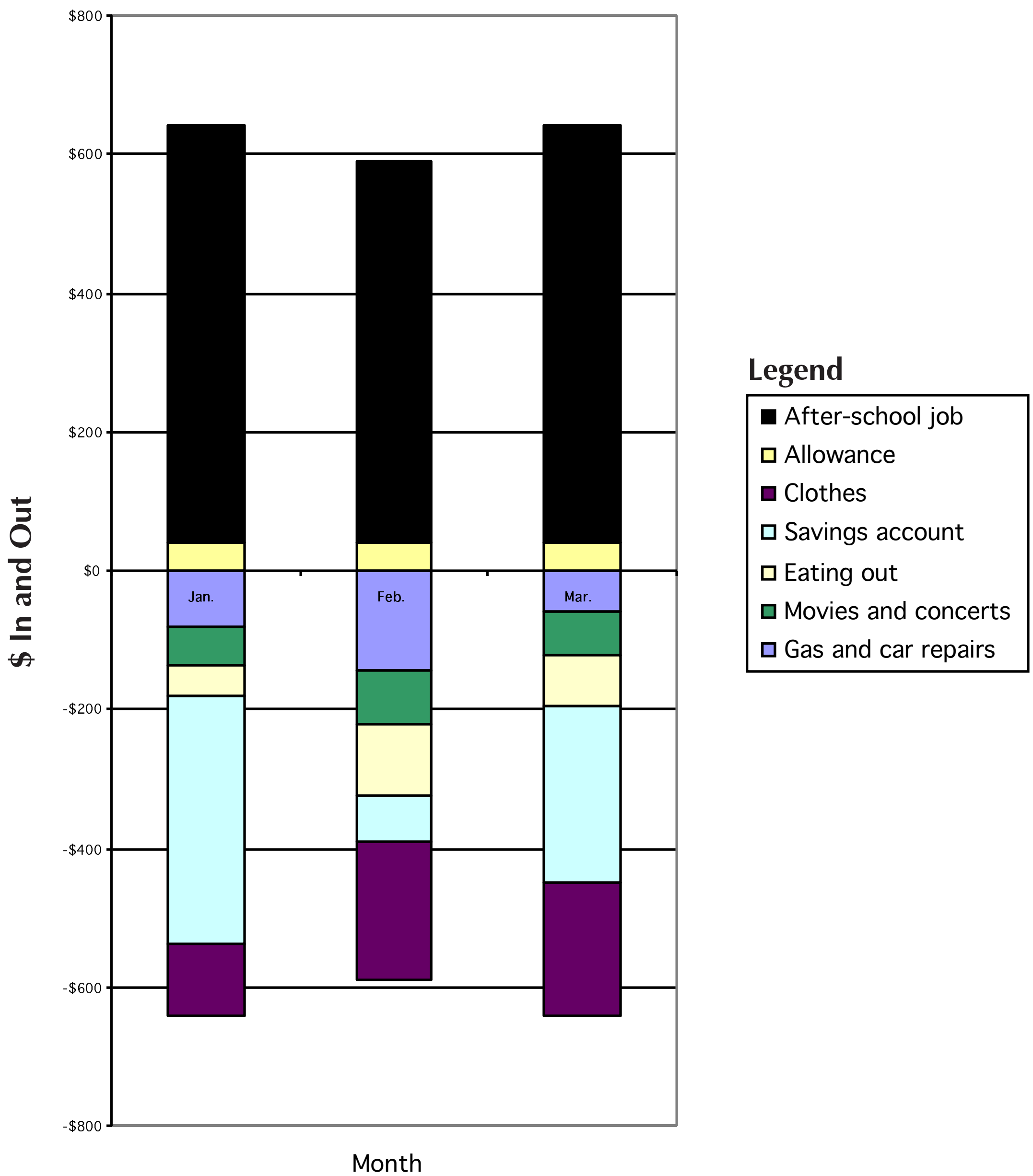
1) Using the data in Table 1: Mean Monthly Water Budget for Windward Haleakalā for your calculations, identify the three months in which the ratio of fog drip to rainfall is the highest. Below, list these three months and the contribution of fog drip to the water budget as a percentage of total moisture input (fog drip + rainfall). Express percentages using two decimal places.

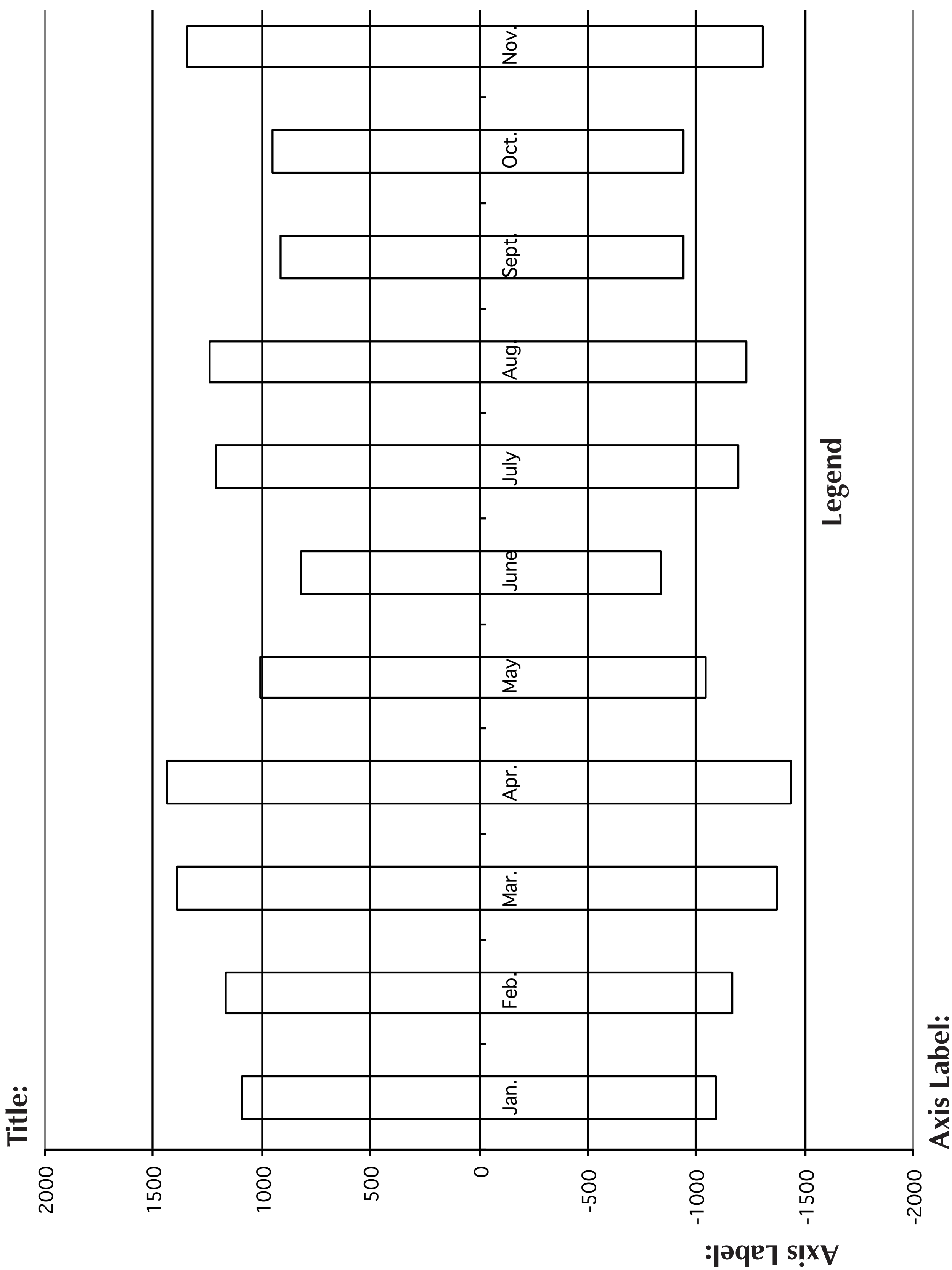
Top three months for fog-drip contribution	Percent of total moisture input
______________________________	________________
______________________________	________________
______________________________	________________

2) In the summer months, trade winds tend to be stronger and more reliable than at other times of the year. This pattern produces a well-developed trade wind inversion. How would this seasonally stronger atmospheric inversion help to explain the patterns in high fog-drip contribution you identified in question #1? Explain your reasoning.

3) Using the data in Table 1: Mean Monthly Water Budget for Windward Haleakalā and the blank chart on the following page, create a stacked-column chart representing the water-budget components for windward Haleakalā. A sample stacked-column chart is shown below.
Give your chart a title, labels for each axis, and a legend.

SAMPLE STACKED COLUMN CHART: Monthly Cash Flow

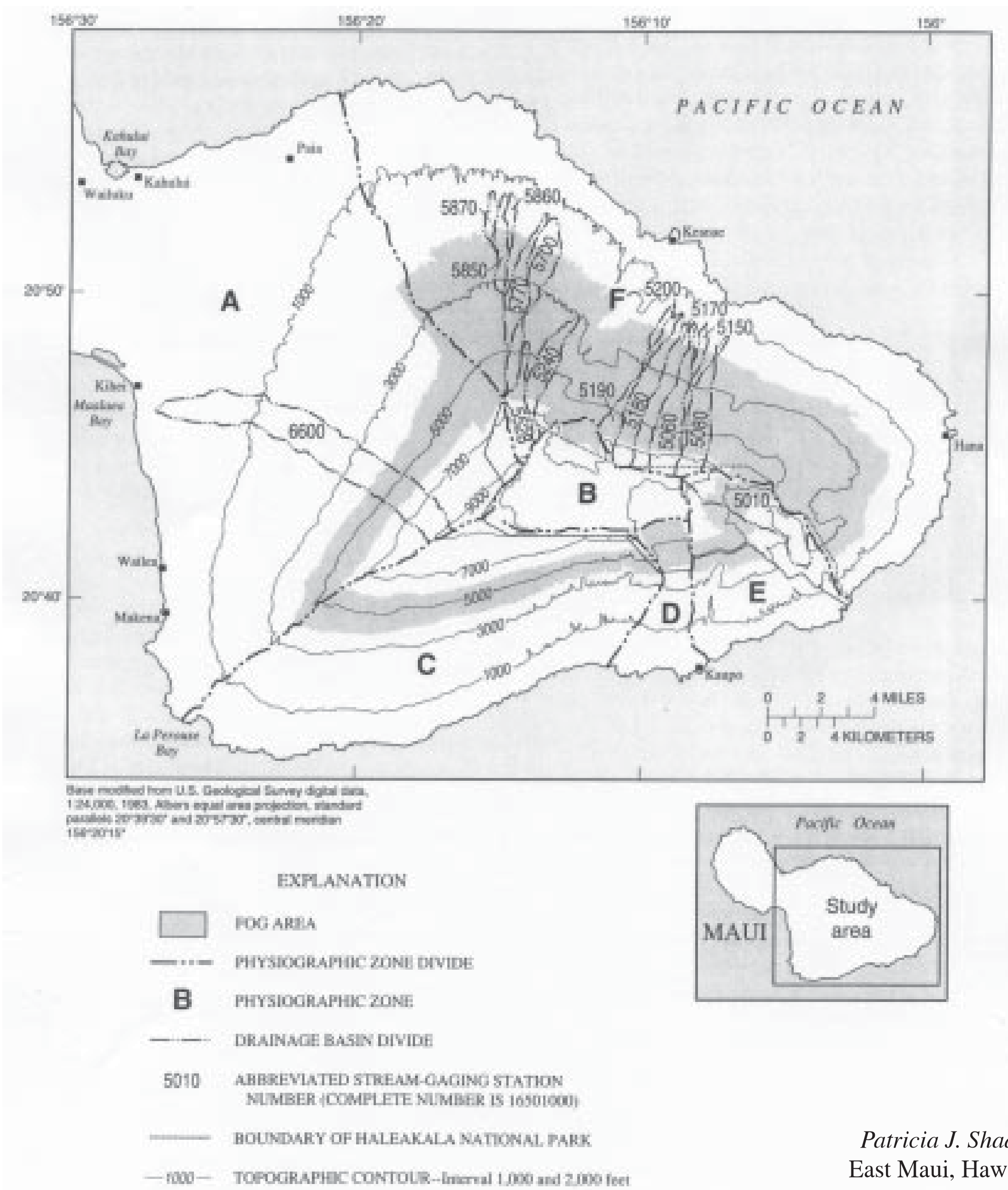



Title:
Legend
Axis Label:
Axis Label:
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
2000
1500
1000
500
0
-500
-1000
-1500
-2000

4) Using the following data, calculate the average contribution of rainfall and fog drip (in million gallons per day) to the water budgets of leeward Haleakalā (zone C on the map below) and windward Haleakalā (zone F on the map below). Show your calculations on the next page.

Water budget component	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Windward Haleakalā												
Rainfall	1018	1090	1300	1261	881	713	897	917	671	792	1104	1228
Fog drip	70	77	89	174	129	103	316	322	241	161	237	183
Leeward Haleakalā												
Rainfall	336	268	247	205	107	49	49	82	80	146	192	282
Fog drip	8	7	7	12	6	3	7	12	11	12	16	15

Data in Million Gallons per Day



This map shows where the windward and leeward fog zones are so you can picture the areas for which you are performing calculations. It is not used in your calculations.

Patricia J. Shade, Water Budget of East Maui, Hawaii, *U.S. Geological Survey, Honolulu, 1999, p. 13.*

4) (continued) Show calculations here.

5) Explain the difference in relative contribution of fog drip to total moisture input between the leeward and windward zones using the information on the map and what you know about the climate of windward and leeward Haleakalā.

6) A water budget is a model based on past averages. Some people believe that a series of extremely dry years in the late 1990s may be a sign that East Maui is entering into a prolonged period of reduced average rainfall. If East Maui is indeed beginning a long drought, do you think this estimated water budget should be used as a tool for determining how much surface or ground water can be safely withdrawn from the watershed? Explain your response.

The Waters of Kāne

On the following page is a translation of a *mele* from Kaua‘i that describes elements of the hydrologic cycle. It is entitled "*Ka Wai a Kāne*" or "The Waters of Kāne." (Kāne is one of the four major Hawaiian gods.)

Read "*Ka Wai a Kāne*." Then, on this page or a separate piece of paper, write your own *mele* that reflects the hydrologic cycle on windward Haleakalā. Be sure to include the water budget components you worked with in this unit.

Other ideas for your *mele* include:

- Rain forest alterations that can or have changed the water budget,
- Specific places on East Maui,
- Inversion layer and lifting-condensation levels,
- Seasonal differences,
- Orographic lifting,
- Differences between the windward and leeward sides,
- Other climate characteristics you studied in this unit, and
- How people can help keep the "waters of Kāne" flowing on East Maui.

Ka Wai a Kāne (The Waters of Kāne)

He ui, he ni nau,
E ui aku ana au iā ‘oe:
Aia i hea ka wai a Kāne?
Aia i ka hikina a ka lā,
Puka i Ha‘eha‘e
Aia i laila ka wai a Kāne.
E ui aku ana au iā ‘oe,
Aia i hea ka wai a Kāne?
Aia i Kaulanakalā
I ka pae ‘ōpua i ke kai,
Ea mai ana ma Nihoa
Ma ka mole mai o Lehua,
Aia i laila ka wai a Kāne.
E ui aku ana au iā ‘oe:
Aia i hea ka wai a Kāne?
Aia i ke kuahiwi, i ke kualono,
I ke awāwa, i ke kahawai,
Aia i laila ka wai a Kāne.
E ui aku ana au iā ‘oe:
Aia i hea ka wai a Kāne?
Aia i kai, i ka moana,
I ke Kaulau, i ke anuenue,
I ka pūnohu, i ka uakoko
I ka ‘ālewalewa
Aia i laila ka wai a Kāne.
E ui aku ana au iā ‘oe:
Aia i hea ka wai a Kāne?
Aia i luna ka wai a Kāne,
I ke ‘ōuli, i ke ao ‘ele‘ele,
I ke ao panopano,
I ke ao popolohua mea a Kāne la e!
Aia i laila ka wai a Kāne.
E ui aku ana au iā ‘oe:
Aia i hea ka wai a Kāne?
Aia i lala, i ka honua, i ka wai hu,
I ka wai kau a Kāne me Kanaloa
He waipuna, he wai e inu,
He wai e mana, he wai e ola,
E ola nō, ‘eā!

A question, a query
I put to you:
Where is the water of Kāne?
At the eastern gate
Where the sun comes in at Ha‘eha‘e
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
Out there with the floating sun
Where cloud-forms rest of the ocean
Uplifting their forms at Nihoa
This side the base of Lehua
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
There on the mountain peak, on the ridges steep,
In the valleys deep, where the rivers sweep,
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
There at sea, on the ocean
In the driving rain, in the rainbow arch,
In the misty spray, in the blood-red rainbow
In the ghost-pale cloud form,
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
High up is the water of Kāne,
In the heavenly blue, in the black-piled cloud,
In the thick dark cloud,
In the dark sacred cloud of the gods, indeed!
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
Deep in the ground, in the gushing spring
In the place of Kāne and Kanaloa,
A wellspring of water, water to drink
A water of power, the water of life!
Life indeed!

Rain Forest Unit 2

Rain Forest Relationships

Overview

In this unit, students learn about some of the main species in the rain forests of Haleakalā and how they are related within the unique structure of Hawaiian rain forests.

The primary canopy trees in the rain forest of Haleakalā and throughout the Hawaiian Islands are *ʻōhiʻa* (*Metrosideros polymorpha*) and *koa* (*Acacia koa*). At upper elevations, including the cloud forest zone within the rain forest, *ʻōhiʻa* dominates and *koa* is absent. In the middle and lower elevation rain forests, below about 1250 meters (4100 feet), *koa* dominates, either intermixed with *ʻōhiʻa,* or sometimes forming its own distinct upper canopy layer above the *ʻōhiʻa*.

These dominant tree species coexist with many other plants, insects, birds, and other animals. Hawaiian rain forests are among the richest of Hawaiian ecosystems in species diversity, with most of the diversity occurring close to the forest floor. This pattern is in contrast to continental rain forests, where most of the diversity is concentrated in the canopy layer.

Today, native species within the rain forests on Haleakalā include more than 240 flowering plants, 100 ferns, somewhere between 600-1000 native invertebrates, the endemic Hawaiian hoary bat, and nine endemic birds in the honeycreeper group.

Length of Entire Unit

Five class periods

Unit Focus Questions

1) What is the basic structure of the Haleakalā rain forest?

2) What are some of the plant and animal species that are native to the Haleakalā rain forest? Where are they found within the rain forest structure?

3) How do these plants and animals interact with each other, and how are they significant in traditional Hawaiian culture and to people today?

Unit at a Glance

Activity #1
Rain Forest Slide Show

Students learn about the Haleakalā rain forest by watching a slide show and writing about their feelings about the importance of preserving native rain forests.

Length
One-half to one period

Prerequisite Activity
None

Objectives
- Become familiar with the basic characteristics and structure of a native Hawaiian rain forest.
- Describe a personal perspective on the importance of native rain forests and efforts to preserve them.

DOE Grades 9-12 Science Standards and Benchmarks
None

Activity #2
Rain Forest Species Research

Students research a native rain forest species, finding and presenting information about it in an educational and attractive format.

Length
One period plus research time outside class

Prerequisite Activity
None

Objectives
- Use written and Internet resources to find basic information about a native rain forest species.
- Present the information visually and in written form.
- Describe the characteristics and habitat of a native rain forest species, as well as its relationship to other species, past or current use by humans, and/or significance in traditional Hawaiian culture.

DOE Grades 9-12 Science Standards and Benchmarks
LIVING THE VALUES, ATTITUDES, AND COMMITMENTS OF THE INQUIRING MIND: Students apply the values, attitudes, and commitments characteristic of an inquiring mind.
- HONESTY: Acknowledge references, contributions, and work done by others.
- SELF-DIRECTED: Use research techniques and a variety of resources to complete a report on a project of one's choice.

Activity #3
Rain Forest Species Presentations

Students present information about native rain forest species.

Length
Two class periods

Prerequisite Activity
Activity #2 “Rain Forest Species Research”

Objectives
- Make a two- to three-minute presentation based on research conducted on a native rain forest species.
- Create a visual representation of where in the rain forest structure different species are found.

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

Activity #4
Rain Forest Trivia

In teams, students demonstrate their knowledge of rain forest species.

Length
One class period

Prerequisite Activity
Activity #3 “Rain Forest Species Presentations”

Objectives
- Demonstrate knowledge of rain forest species.
- Demonstrate attentiveness to, and learning from, other student presentations.

DOE Grades 9-12 Science Standards and Benchmarks
None

Enrichment Ideas

- Following the instructions in Activity #2, research and create species cards for introduced species. Here is a list of some familiar introduced species.

Polynesian Introduced Plants

- *Kukui* or candlenut tree (*Aleurites moluccana*)
- *Wauke* or paper mulberry (*Broussonetia papyrifera*)
- *Mai'a* or banana (*Musa* x *Paradisiaca*)
- '*Ulu* or breadfruit (*Artocarpus altilis*)
- *Kalo* or taro (*Colocasia esculenta*)
- *'Awa* or kava (*Piper methysticum*)
- *'Ohe* or Hawaiian bamboo (*Schizostachyum glaucifolium*)
- *'Ōhi'a 'ai* or mountain apple (*Syzygium malaccense*)

Recent Plant Introductions

- *Kāhili* ginger (*Hedychium gardnerianum*)
- Strawberry guava and common guava (*Psidium cattleianum* and *Psidium guajava*)
- African tulip tree (*Spathodea campanulata*)
- *Liliko'i* or passionfruit (*Passiflora edulis*)
- Avocado (*Persea americana*)

Introduced Mammals

- Polynesian rat (*Rattus exulans*)
- Norway rat (*Rattus norvegicus*)
- Black rat (*Rattus rattus*)
- Pig (*Sus scrofa*)
- Cat (*Felis catus)*
- Axis deer (*Axis axis*)
- Small Indian mongoose (*Herpestes auropunctatus)*
- Domestic goat (*Capra hircus*)

- Use the rain forest species cards from Activity #2 to create a representation—such as a large drawing, a model, or a collage—of the Haleakalā rain forest. The representation should show the structure of the rain forest, where different species live, and some of the important relationships among species within the rain forest.

- Adapt the "Web of Life Game" using the rain forest species cards (Activity #2). This game builds knowledge about relationships among species. (See Alpine/Aeolian Unit 3, Activity #4 "Web of Life Game.")

- Make up and play different games using the rain forest species cards (Activity #2).

- Research native species that are endemic to Haleakalā. Some of the species cards from Activity #2, such as the one for Hawaiian lobeliads, encompass many species. Some of these are unique to Haleakalā.

Resources for Further Reading and Research

Hawai'i Audubon Society, *Hawaii's Birds*, 5th ed., Hawai'i Audubon Society, Honolulu, 1997.

Medeiros, Arthur C., and Lloyd L. Loope, *Rare Animals and Plants of Haleakalā National Park,* Hawai'i Natural History Association, Hawai'i National Park, 1994.

Moanalua Garden Foundation, *Forest Treasures* (CD ROM), 2000.

Stone, Charles P., and Linda W. Pratt, *Hawai'i's Plants and Animals; Biological Sketches of Hawai'i Volcanoes National Park*, Hawai'i Natural History Association, National Park Service, and University of Hawai'i Cooperative National Park Resources Study Unit, Hawai'i Volcanoes National Park, 1994.

Activity #1

Rain Forest Slide Show

● ● ● **Class Period One** *Setting the Stage*

Materials & Setup

- "Rain Forest Slide Show" (included with this curriculum)
- "Rain Forest Slide Show Script" (pp. 6-12)
- Slide projector and screen

Instructions

1) Show and narrate the slide show using the script.

2) As homework, or for the remainder of the class period, have students write responses to questions posed in the last segment of the slide show or the following questions:
   - What impact do you think the loss of native rain forests has had on native plant and animal species?
   - How about the ability to live and practice traditional Hawaiian culture?
   - Do you believe preserving rain forest habitat on Haleakalā is important? Why or why not?

Journal Ideas

- Have you ever been in the native rain forest? If so, what was it like? If not, what do you think it would be like?
- Do you believe the Hawaiian concepts of *wao akua* and *wao kanaka* are useful today? If so, how? If not, why not?
- Should the Hawaiian concepts of *wao akua* and *wao kanaka* be used in managing the Haleakalā rain forest today? If so, how? If not, why not? Be specific.

Assessment Tools

- Writing assignment
- Journal entries

Teacher Background

Rain Forest Slide Show Script

Slide #1
Upper rain forest

Welcome to *wao akua*, a place of mist, of clouds, and of spirits. In Hawaiian tradition, these upper reaches of the native forest are the realm of Kū, god of war, governance, and upright growth (such as trees). Humans could only enter this sacred area for specific purposes and with permission from the gods.

Before entering the forest, Hawaiians asked for permission from the forest to enter and work or take its resources. They also stated their good intentions before entering and asked for protection while they were in the forest. Here's a typical chant:

Noho Ana Ke Akua	**The Gods Dwell**
Noho ana ke akua i ka nāhelehele	The gods dwell in the forest
I ālai ʻia e ke kīʻohuʻohu	Hidden by the mists
E ka ua koko	By the low lying rainbow
E nā kino malu i ka lani	O beings sheltered by the heavens
Malu e hoe	Clear our paths (of all that may trouble us)
E hoʻoūlu mai ana ʻo Laka i kona mau kahu	Laka will inspire and enrich her devotees
ʻO mākou, ʻo mākou no a	That's us, us indeed

Slide #2
Lower rain forest

Below the *wao akua* is the *wao kānaka*, an area where people live and work and crop cultivation is extensive.

Slide #3
Rain forest aerial

Rain forests are characterized by high rainfall (exceeding 80 inches annually, but often much more) and no distinct dry period during the year. Rain forests have developed on the eastern flanks of Haleakalā as a result of the moisture-laden northeast trade winds received during most of the year.

Slide #4
Rain forest

The native rain forest of Haleakalā once extended from just above the coast up to approximately 2500 meters (8200 feet). These areas were home to many species of native birds, insects, and plants.

Slide #5
Researchers in rain gear

This area receives between 80 and 300 inches of rainfall annually. In some areas, sometimes called cloud forests, moisture comes more from plants intercepting moisture directly from low-lying clouds and fog. What do you think is the most rainfall ever measured in the Haleakalā rain forest? (In 1994, a rain gauge in Kīpahulu Valley in Haleakalā National Park recorded 575 inches of rain!)

Slide #6
Hāna Hwy. scene

The *wao kānaka* of today has been cultivated, logged, and invaded by nonnative plants introduced from all over the world. Although unrecognizable by ancient Hawaiians, this is probably the image most of us have of the rain forests on Maui.

Slide #7
Graphic?

What we might not realize is that the *wao akua* continues to thrive in the upper reaches of the rain forest in the place of mist, clouds, and spirits. As in earlier times, much of the remaining native rain forest is *kapu* or off-limits — it is protected and preserved.

Does anyone know how ancient Hawaiians used the rain forest? (Wait for answers, then continue with the slide show.) Here are some of the ways . . .

Slide #8
Featherwork

Among the people who were allowed to enter the *wao akua* in the times of old were the skilled *kia manu* (birdcatchers). Colorful feathers from native forest birds were fashioned into lei, capes, and ceremonial helmets for the *ali‘i*.

Slide #9
‘I‘iwi

The trained *kia manu* captured birds such as this *‘i‘iwi*, the *‘ō‘ō*, or *‘apapane*, plucked the desired feathers, and then released the bird. *‘I‘iwi* and *‘apapane* are still fairly common today; however, many native Hawaiian birds, like the *‘ō‘ō* are now extinct.

Slide #10
Koa tree or canoe

Traditionally, canoes were hewn from a single *koa* trunk harvested from the forest. The *kahuna kālai wa‘a* (expert of canoe-making) and the necessary work party would spend days preparing spiritually before venturing into the forest to search for the proper tree. Offerings of food and prayer preceded the tree cutting and rough shaping of the canoe. Guided by a spiritual protector, the canoe was then lowered down the mountain.

Slide #11
'Ama'u fern

The *wao kānaka* is where the *'ama'u* fern grows. In traditional Hawaiian culture, the *'ama'u* has many uses. Its trunk can be steamed and fed to pigs, and people ate it in times of famine. The fronds were cooked and eaten or used to thatch houses or mulch upland taro gardens.

Slide #12
Taro

Does anyone know what this plant is? (Taro) Taro or *kalo* was grown as a food staple. It was planted along streams and drainages, where it would grow naturally. It was cultivated in irrigated terraces. All parts of the *kalo* were harvested. The root was pounded into a paste called *poi* and the leaves were eaten as green vegetables. *Kalo* was a sacred food that could only be planted, harvested, and cooked by men. Women could only eat certain types. Today, *kalo* continues to be an important part of the culture of Hawai'i.

Slide #13
'Olonā

Other useful native plants from the rain forest include '*olonā.* Eight times stronger than hemp, *'olonā* is an endemic plant of Hawai'i and highly prized as a source of tough, durable fiber for ropes and fishing nets. In earlier times, it was commonly used as base material for ti-leaf cloaks and feather capes.

Slide #14
'Ie'ie

'Ie'ie is a woody vine that wraps itself around the trunks of trees. The long slender aerial rootlets were made into cordage for lashing house posts and for securing outriggers to canoes. The rootlets were also used in plaiting the framework for *mahiole* (helmets) and feather images such as *Kūlā'ikimoku,* the war image of *Kamahameha*, and in *hīna'i* (basket fish trap). The decorative flowering branches of *'ie'ie* were used on the *kuahu* (altar) in the *hālau hula* as a tribute to the goddess *Laka*.

Slide #15
Kapa

Bark from the *wauke*, a plant brought to Hawai'i with the Polynesians, was soaked and beaten into *kapa*, a paper-like cloth which was fashioned into soft, flexible attire. *Kapa* made in Hawaii displayed the greatest varieties of textures and colored designs found in Polynesia.

Slide #16
Māmaki

And *māmaki* was used for making firm, heavy *kapa* from the fibers of the mature stems. It is rougher and not as white as *kapa* made from *wauke* and was considered second in quality to it. The leaves are brewed into tea for use as a general tonic. You can still pick some up at Long's today! Though rather tasteless, the white fleshy mulberry-like fruit is eaten by people and birds, and has some medicinal uses.

Slide #17
Forest shot

The ancient Hawaiians depended on the rain forests for food, clothing, medicine, and transportation. They realized that their physical and spiritual well-being depended on perpetuating these resources and maintaining a high respect for the land.

Slide #18
Rain forest layers

The rain forests of Hawai‘i are typically multilayered, consisting of a continuous canopy tree layer over a lower subcanopy layer of trees and shrubs, and even lower understory and forest floor layer of smaller shrubs, herbs, and ferns. The dominant trees in the upper canopy filter but do not block the sun from the lower layers and forest floor.

Slide #19
Continental rain forest

Hawaiian rain forests are “upside down” in comparison to the tropical rain forests, such as the one pictured, of South America and Asia. Does anyone know why that is? (Wait for answers, then continue.) Continental tropical rain forests are known around the world as hotbeds of biological diversity. Huge numbers of plant and animal species live in these rain forest ecosystems.

Slide #20
Continental canopy

Most of the species diversity in these continental rain forests is concentrated in the canopy, which can include hundreds of species of trees that shelter a wide array of mammals, birds, insects, and epiphytes. Epiphytes are simply plants that grow supported by other plants. Almost any plant that grows in the rain forest can sometimes be seen growing as an epiphyte, for at least part of their life. In fact, a distinguishing rain forest feature is the abundance of epiphytes on tree trunks and branches.

Slide #21
Hawaiian canopy

By contrast, in Hawaiian rain forests, the canopy is dominated by just one or two species, usually *‘ōhi‘a* and *koa*, or both. Some forest birds and insects live primarily in association with these two species of canopy trees. Also, the only native mammal that lives in the Haleakalā rain forest is in these trees. Who knows what that mammal is? (The *‘ōpe‘ape‘a* or Hawaiian hoary bat. It may be found roosting in these trees during the day.)

Slide #22
Subcanopy

Greater diversity is displayed in the subcanopy or the second tree layer of the Hawaiian rain forests, where up to ten species form an open to closed canopy ranging in height from about 20 to 40 feet. *‘Ōlapa* is perhaps the most abundant tree species and is often seen growing ephiphytically on much larger *‘ōhi‘a* trees.

Slide #23
Understory

Most of the biological diversity in Hawaiian rain forests is contained in the understory, especially the ground-cover or forest floor layer. In this lowest layer of the forest, a profusion of shade-loving native plants that require cool, humid conditions thrive. This tapestry of plant life includes various ferns, herbs, shrubs, and saplings of canopy tree species. Chief among these are the ferns and fern allies; more than 100 species are found in the rain forests of Haleakalā. Some of the most abundant terrestrial ferns of the rain forest are *hāpu‘u* (tree fern), *palapalai,* and *‘ama‘u.*

Slide #24
Herb or shrub

Sharing the forest floor with the ferns are native herbs, shrubs, and saplings of canopy tree species. The most abundant herbaceous flowering plants of the rain forest floor are *‘ala‘ala wai nui*, weak-stemmed trailing members of the black pepper family. Shrub species most commonly encountered are the *‘ōhelo kau lā‘au*, *pūkiawe*, *kanawao* and young growth of trees such as *‘ōlapa, ‘ōhi‘a,* and *kōlea.*

Slide #25
Smilax (*hoi kuahiwi*)

Unlike many other tropical forests, Hawaiian rain forest do not support large numbers of climbing vines, also known as lianas. Nonetheless, several native vines are notable components of many forests. These include *‘ie‘ie*, a fibrous-stemmed, prickly-leaved climber in the screwpine family that was noted earlier as important to early Hawaiians, and *hoi kauhiwi* or smilax. This Hawaiian endemic vine has prominently veined, heart-shaped leaves and smooth or bumpy twining stems.

Slide #26
Mint

More rarely encountered are delicate vines in the mint family. Stenogyne, a small vine with oblong, scallop-margined leaves, is the most frequently seen Hawaiian mint. Hawaiian mints are often called “mintless mints.” Does anyone know why? (They lack the strongly scented oils most mints have . . . that give us peppermint, spearmint, etc.) They are highly palatable to non-native ungulates like cattle, goats, and pigs; thus, they have been eliminated or much reduced in pig-impacted forests.

Slide #27
Epiphyte

Common epiphytes include most species of mosses and lichens, the flowering *‘ala‘ala wai nui*, many small ferns, and larger plants such as the shrubby *‘ōlapa*, which often get their start in life by taking root in crevices of other trees. In these forests, epiphytes and trees may be so intertwined that it is difficult to identify the original host tree.

Slide #28
Endemic species

While Hawaiian rain forests are among the most species-diverse ecosystems on this isolated archipelago, they are relatively species-poor when compared to continental rain forests. Hawaiian rain forests, however, do support a large number of endemic species, found nowhere else in the world.

Slide #29
Drosophila

The rain forests of Hawai‘i support a large array of insects and spiders. This fly is one of over 500 species of flies in the Drosophilidae family that have been identified in Hawai‘i. Nearly one-quarter of the known species in this family are found in Hawai‘i, including many that are narrowly endemic. That means that they occur in only a very small area. Hawaiian *Drosophila* flies are an example of explosive adaptive radiation, an evolutionary process through which a large number of divergent and unique species arise from a single common ancestor species. Some researchers believe that Hawaiian rain forests offer a unique opportunity for studying evolution in action. Does anyone know how these flies attract mates? (The males compete with each other by doing a dance to attract females. The females select the best dancers.)

Slide #30
Cyanea horrida

Examples of endemic species known only from the rain forests of Haleakalā are *‘ōhā* or lobelias such as *Clermontia tuberculata* and *Cyanea horrida.*

Slide #*31*
Geranium multiflorum

Other endemic Haleakala species are two geraniums or *nohoanu.* This *Geranium multiflorum* is known only from East Maui. Since endemic species are often known from a limited area, it is not surprising that many, such as this one, are considered in danger of extinction.

Slide #32
Po‘ouli

The rain forests of Haleakalā also provide essential habitat for 13 endemic birds, eight of which are federally listed as Endangered Species. Early in 2001, there were only three known *po‘ouli* on the slopes of Haleakalā. This is one of them.

Slide #33
Degraded rain forest

Although rugged terrain and dense growth may seem to offer the Haleakalā rain forest some protection, these forests are under continuous pressure by feral pigs and goats, rats and mice, invasive alien plants, and diseases that threaten the native birds.

Slide #34
Fencing crew

Haleakalā National Park, the State of Hawai‘i, The Nature Conservancy and the East Maui Watershed Partnership have active management programs in the rain forests of Haleakalā including fencing, feral animal control, invasive plant control, and research.

Slide #35
Original rain forest extent

Like most other native ecosystems on Maui, the native rain forest has been significantly reduced in size since people came to this island. Originally reaching to the ocean in a broad band across the windward side of Haleakalā . . .

Slide #36
Today’s rain forest extent

Today the native rain forest covers a much smaller area and is cut off from the ocean by a swath of landscape altered by humans. The remaining intact native rain forests are by and large in higher elevations.

Slide #37
Forest shot

These rain forests of Haleakalā, considered *wao akua* by the early Hawaiians, continue to hold mysteries and unique flora and fauna that many people want to protect and value for this and future generations. Do *you* think it’s important to protect and value these forests? Why does it matter? What can you do about it? Think carefully about these questions—because they’re your homework assignment!

Activity #2

Rain Forest Species Research

● ● ● Class Period One *Species Cards*

Materials & Setup

- Research materials: at minimum the three listed in #3 below, and others that you can gather or check out of the library [See the Student Page "Rain Forest Species Cards" (pp. 36-41) for suggested resources.]

For each student

- Student Page "Rain Forest Species Cards" (pp. 36-40)
- One card from the "Rain Forest Species Assignments" (master, pp. 27-35)

Instructions

1) Hand out the Student Page "Rain Forest Species Cards" to each student. Also give each student one Species Assignment card—a different species for each student. There are 36 species total.

2) If you have a smaller class, you may select a representative sampling from the species cards, making sure you have a blend of invertebrates, birds, and plant species from the canopy, subcanopy, understory, forest floor, and vines categories. See the teacher background "Rain Forest Species Card Information Summary" for species that fit in each category (pp.15-26).

   OR

   You may offer extra credit to students who create more than one species card.

3) For the rest of this class, as homework, and during the next class period, students will create a card for the species assigned to them. The primary information resources available as part of this curriculum are:

   Hawai'i Audubon Society, *Hawaii's Birds*, 5th ed., Hawai'i Audubon Society, Honolulu, 1997.

   Medeiros, Arthur C., and Lloyd L. Loope, *Rare Animals and Plants of Haleakalā National Park,* Hawai'i Natural History Association, Hawai'i National Park, 1994.

   Moanalua Garden Foundation, *Forest Treasures* (CD ROM), 2000.

   Stone, Charles P., and Linda W. Pratt, *Hawai'i's Plants and Animals; Biological Sketches of Hawaii Volcanoes National Park*. Hawai'i Natural History Association, National Park Service, and University of Hawai'i Cooperative National Park Resources Study Unit, Hawai'i National Park, 1994.

   Additional sources of information can be found in the library and on the Internet. A beginning listing of resources is part of the student page.

4) Encourage students to create their own images for the species card rather than using the one on the Species Assignment card. Also encourage them to bring to the next class art supplies, reference books they have at home, and species information they photocopy from printed sources or download from the Internet so they can work on their species cards during class.

Note

If you have difficulty locating resources for student research or if you do not want students to research the species cards, give each student the relevant information from the teacher background (pp. 15-26). Students can create their species cards using this information.

● ● ● Class Period Two *Rain Forest Species Cards*

Materials & Setup

- Research materials (see Class Period One)
- Colored pens, pencils, scissors, glue and other supplies for student use in creating species cards

Instructions

1) Allow students to finish their species cards during this class period.

Journal Ideas

- Make up a chant or a poem about your rain forest species.
- What was the most interesting thing you learned about your species? Why?

Assessment Tools

- Rain forest species cards
- Journal entries

Teacher Background

Rain Forest Species Card Information Summary

The following summarizes some of the available information about each species. You may use these summaries to help check students' work. Note: Unless otherwise noted, "endemic" refers to the Hawaiian Islands, denoting species that today are thought to be unique to one or more of the Hawaiian Islands.

NATIVE INVERTEBRATES

Haleakalā flightless lacewing (*Pseudopsectra lobipennis*)

• Endemic to Haleakalā
• It no longer has lace wings. Its hardened and beetle-like front wings cup and protect its body and its rear wings are small and strap-like.
• In spite of alien rodent predators, this rare insect still survives in the dense rain forests of Kīpahulu Valley within the park.
• The adults hunt at night on tree trunks.

Hawaiian crickets
(Family Gryllidae, one indigenous genus [*Paratrigonidium*] and 3 endemic genera [*Leptogryllus, Thaumatogryllus,* and *Prognathogryllus*)

• All Hawaiian crickets are brown and flightless.
• Some are loud, strong "singers." A male cricket sings by rubbing his wings together to attract females of his species. Each species has a unique song.
• It lives in *'ōhi'a* and *koa* rain forests up to 1500 meters (4920 feet) in elevation. Within Haleakalā National Park, most are found in the rain forests of Kīpahulu Valley.
• Alien rodents (mice and rats) prey on these rare insects.
• The number of named, endemic Hawaiian crickets is over 200 species, twice the total known for the continental U.S. One species is named *kipahulu* after Kīpahulu Valley.

Hawaiian ground beetles (Family *Carabidae*)

• Ground beetles prey on arthropods and snails.
• Ground beetles are an example of adaptive radiation. The 215 endemic species of ground beetles on the Hawaiian Islands are believed to have evolved from as few as six original immigrants.
• Ground beetles are found in many different natural communities on Haleakalā including high-elevation shrublands, the alpine/aeolian zone, and the rain forest.
• In the late 1980s, scientists discovered and described two new species of ground beetles inside deep lava tubes in Kīpahulu Valley.

Hawaiian long-horned beetles (*Plagithmysus spp.*)

• Endemic genus (There are other genera of Hawaiian Long-Horned Beetles, as well.)
• The larvae of these wood-boring beetles feed within living, often damaged trees. Females lay their eggs in the bark of trees. On hatching, the larvae burrow into the wood, feeding there for a year or more before pupating into adult beetles.
• Most often, one beetle species has only one tree species as its host. *Plagithmysus cheirodendri* is endemic to East Maui and feeds exclusively on the wood of *kōlea* trees. Other long-horned beetles are associated with *koa*.
• Wood-boring beetles are an example of adaptive radiation. Over 136 species are believed to have evolved from a single ancestral species that arrived on the islands millions of years ago, probably from North America.
• Long-horned beetles are found in many different natural communities on Haleakalā. The most common is associated only with the *māmane* tree, some are found only in rain forests, and one species has adapted to feed only on the *ʻāhinahina* in the alpine/aeolian zone.
• The Maui parrotbill, a Hawaiian honeycreeper, uses its bill to tear apart plant stems in search of the pale larvae of these beetles, one of its primary foods. The naturalist R. C. L. Perkins found that the stomachs of the parrotbills he collected in 1894 were filled with long-horned beetle larvae.

Haleakalā weevil (*Oodemas spp.*)

• Endemic genus
• These weevils are also known as snout beetles, for their long snout. They have small (1/4-inch long), shiny, black, rounded bodies that resemble seeds.
• At least 15 species of *Oodemas* are known from Haleakalā, either in the deep rain forests or in native shrublands.
• The 58 species of small, rare *Oodemas* weevils are found only on the Hawaiian Islands. They seem to have no close relatives in the rest of the world.
• These weevils are a favorite food for birds. The adults hide under bark and in mosses and leaf litter during the day. They emerge under cover of darkness to feed on native plants and to mate.

Hawaiian carnivorous inchworm (*Eupithecia* spp.)

• Endemic genus
• The larvae of at least 18 species of Hawaiian moths have abandoned the usual vegetarian diet of caterpillars throughout the world. These caterpillars practice ambush predation, in which they settle on the edges of leaves or on plant stems waiting for a tiny spider or insect to approach.
• These carnivorous species are related to other *Eupithecia* moth species on Haleakalā that feed on flowers, seeds, leaves, and other plant parts.
• The first species of carnivorous inchworms was discovered in 1972.
• These inchworms are about 1.25 centimeters (.5 inch) long.
• There are at least 18 different species using different types of perch sites. They are colored and shaped to blend in with their favored hunting sites. Some that perch on moss-covered tree trunks even look mossy themselves!

Happy-face spider (*Theridion grallator*)

• Endemic
• These spiders are found in many of the rain forests of Hawai‘i, although they may be difficult to spot.
• Happy-face spiders are named for the bright patterns that appear on their abdomens. Some of these patterns resemble smiling faces.
• They are so small that you need a magnifying glass to really appreciate their markings. Including their legs, they are only 1.25-2 centimeters (about .5-.75 inch) long.
• They live under the leaves of rain forest trees and shrubs such as *kanawao* (*Broussaisia arguta*), *kawa‘u* (*Ilex anomala*), and *‘oha wai* (*Clermontia* spp.). They spin irregular-shaped webs in which they catch their prey.
• Females lay eggs on the underside of leaves. Once the tiny spiderlings hatch, the mother captures food for them, wrapping it in silken loops.

Pulelehua or Kamehameha butterfly (*Vanessa tameamea*)

• Endemic (One of only two butterflies native to Hawai‘i)
• A striking orange, black, and white butterfly that measures about five centimeters (two inches) across.
• Most commonly found in mesic woodlands and low- to mid-elevation wet forests. Higher-elevation rain forests and dry forests are less favored but still provide habitat for these butterflies.
• Larvae of this butterfly feed on the leaves of the *māmaki* (*Pipturus albidus*) and other native plants that, like *māmaki*, belong to the nettle family (*Urticaceae*). Parts of the caterpillar resemble *māmaki* flower clusters, and the chrysalis looks like a dead, curled-up leaf.
• Adult *pulelehua* feed on nectar from many native plants and are probably important pollinators for those plants.

Picture wing flies (Family Drosophilidae)

• There are more than 800 species of Hawaiian *Drosophila*. They are a premier example of adaptive radiation.
• *Drosophila* species now occupy a range of habitats. Different species feed on different food items, including rotting fruit and leaves, tree sap, and fungi.
• About 100 of the Hawaiian *Drosophila* species are “giant” picture wing flies. With wingspans up to 2.5 centimeters (one inch), these flies have ornate wing and body patterns that enable the different species to recognize each other.
• Male flies set up breeding territories called “leks” and attract females there. Males have evolved a wide array of courtship behaviors that have been recorded by scientists studying the role of sexual selection in the development of new species.
• Like many of the native arthropod species in Hawai‘i, most of these fly species are endemic to single islands, and even to very small areas on specific islands. Since their populations are often small and have a limited range, they are especially sensitive to habitat changes.

Flying earwig Hawaiian damselfly or *Pinao ʻula* (*Megalagrion nesiotes*)

• Endemic to East Maui and Hawaiʻi
• This species was recently rediscovered on Maui after 75 years with no specimens collected there. Originally known from both East Maui and Hawaiʻi, this damsefly is likely to be extinct on Hawaiʻi Island.
• "Flying earwigs" got their name from the pincer-like appendages on the tip of the male fly's tail.
• Adults tend to fly and perch low amidst the tangled vegetation of the rain forest understory. Unlike many other damselfly species, this species tends to live well away from ponds and streams.
• Observations suggest that breeding habitat is probably fern banks, steep and moist slopes, and scattered pockets of water, such as those collected in the leaves of rain forest plants.
• Away from the water, the *pinao ʻula* often makes its home in the *paʻiniu* plant.

Tree snails (*Partulina* spp.)

• Endemic
• Tree snails range from one to 7.5 centimeters (1/3 to three inches) in length. Their color ranges from white to brown to black, and many are banded. There is a great deal of variation in size, color, pattern, and shape.
• Graze on microscopic algae or fungi
• Various sources of introduced biota have had a negative impact on the snails and their habitat, among them the "cannibal snail" which was originally introduced to control the African snail. This predator eats the tree snail young and eggs. Rats are another chief predator on native tree snails.
• The "singing" tree snails were famous among European naturalists after early explorers brought specimens back from the Hawaiian Islands. It took about 50 years before crickets were found to be the source of the song!

NATIVE BIRDS

ʻIʻiwi (*Vestiaria coccinea*)

• Endemic
• A member of the Hawaiian honeycreepers, a group that at one time included some 52 species descended from one original finch species. The honeycreepers are an example of adaptive radiation.
• The *ʻiʻiwi* is about 15 centimeters (six inches) long, scarlet-orange in color, with a deeply curved, orange bill.
• The *ʻiʻiwi* prefers nectar but will sometimes eat insects and spiders, and feeds its young on insects. It is often found high in the canopy, feeding in flowering *ʻōhiʻa* trees. It can also be found lower in the rain forest dipping into the long, curved flowers of mints (*Stenogyne spp.*), other native plants, and introduced species.
• Its feathers were prized by Hawaiians for use in making feathered capes for royalty.
• It is not as common on Maui as the *ʻapapane* and the *ʻamakihi*, but is still widespread at upper elevations. (It is very rare or extinct on Oʻahu, Molokaʻi, and Lānaʻi.)
• *ʻIʻiwi* build their nests five meters (16 feet) or higher up in trees.

ʻApapane (*Himatione sanguinea*)

• Endemic
• This bird is a member of the Hawaiian honeycreepers, a group that at one time included some 52 species descended from one original finch species. The honeycreepers are an example of adaptive radiation.
• The red plumage of these 13-centimeter (five-inch) birds matches the color of the red *ʻōhiʻa lehua* blossoms perfectly. It is often found in the forest canopy searching for nectar from the *ʻōhiʻa*, but it also frequents flowering *koa* and *māmane* trees.
• The *ʻapapane* forages in the forest canopy for nectar and insects.
• This species often nests in the crowns of *ʻōhiʻa lehua* or in tree ferns, but its nests have also been found in lava tube skylights.
• The *ʻapapane* is among the most common honeycreepers in the state. Its range extends from the rain forests into upper-elevation shrublands and even into planted forests. Unlike many other honeycreepers, it is still found down to sea level in some areas.
• Its feathers were used in some Hawaiian featherwork.

ʻAmakihi (*Hemignathus virens*). Also, Maui *ʻAmakihi* (*Hemignathus virens wilsoni*) a Maui endemic subspecies

• Endemic
• This bird is a member of the Hawaiian honeycreepers, a group that at one time included some 52 species descended from one original finch species. The honeycreepers are an example of adaptive radiation.
• This yellow-green bird measures about 11 centimeters (4.5 inches) in length and has a downcurved bill, shorter than that of the *ʻiʻiwi*.
• The *ʻamakihi* feeds on nectar, insects, spiders, and fruit from forest trees and plants.
• It generally nests in uppermost tree branches.
• The *ʻamakihi* is among the most common honeycreepers in the state. Its range extends from the rain forests into upper-elevation shrublands and even into planted forests and higher elevation residential areas such as Kula and Kēōkea.

ʻAlauahio or Maui creeper (*Paroreomyza montana*)

• Endemic to Haleakalā (formerly also found on West Maui and Lānai)
• This bird is a member of the Hawaiian honeycreepers, a group that at one time included some 52 species descended from one original finch species. The honeycreepers are an example of adaptive radiation.
• Found on East Maui only, most commonly in the rain forest but also in the upper-elevation shrublands.
• Females of this small (11-centimeter or 4.5-inch) species of honeycreeper are green, the males yellow-green.
• They forage in pairs or small flocks, usually in the trees and shrubs of the rain forest understory, feeding on insects and spiders. Less often, they will feed on the nectar of *ʻōhelo* and *ʻōhiʻa* flowers.
• Often, an *ʻalauahio* will be seen high above the forest floor, gleaning insects from the bark of a *koa* tree.

ʻĀkohekohe or Crested honeycreeper (*Palmeria dolei*)

• Endemic and endangered
• Once found on both Maui and Molokaʻi but now restricted to East Maui
• This bird is a member of the Hawaiian honeycreepers, a group that at one time included some 52 species descended from one original finch species. The honeycreepers are an example of adaptive radiation.
• This primarily black bird sports a distinctive tuft of head feathers that range in color from light gray to light orange. It is one of the larger honeycreepers at 18 centimeters (seven inches) in length.
• It is an aggressive bird that often drives off other honeycreepers from flowering trees, enforcing the top end of a "pecking order" among nectar-sipping forest birds.
• It builds its nests in tree tops high in the upper canopy.
• It feeds primarily on the nectar of *ʻōhiʻa* blossoms. Its crest probably aids in pollinating the brush-like flowers of the *ʻōhiʻa*. *ʻĀkohekohe* will take nectar from other native plants, and it also eats insects such as caterpillars.

Poʻouli (*Melamprosops phaeosoma*)

• Endemic to Haleakalā (The *poʻouli* is endangered, with a population possibly numbering only three individuals in early 2001.)
• First described in 1973 on the upper northeastern slopes of Haleakalā
• This bird is a member of the Hawaiian honeycreepers, a group that at one time included some 52 species descended from one original finch species. The honeycreepers are an example of adaptive radiation.
• The name *poʻouli* means "dark-headed," which is an apt description of this small (14-centimeter or 5.5-inch-long) honeycreeper. Brown above and pale gray below, *poʻouli* wear a dark mask over the face and head.
• It builds its nest of twigs, lichens, mosses, and grasses high up in the *ʻōhiʻa* canopy.
• It forages in understory shrubs and trees tearing at bark, mosses, and lichens on branches looking for invertebrates such as native tree snails and wood-boring larvae.

Maui parrotbill (*Pseudonestor xanthophrys*)

• Endemic to Haleakalā and endangered.
• This bird is a member of the Hawaiian honeycreepers, a group that at one time included some 52 species descended from one original finch species. The honeycreepers are an example of adaptive radiation.
• Parrotbills are small birds (14 centimeters or 5.5 inches long) that are mostly olive green with yellow and brown markings, a bold eye stripe, and a large bill that resembles a parrot's.
• The Maui parrotbill is a flocking bird. With its low numbers, it is often seen in flocks with *ʻalauahio*.
• It is found in the shrubs and trees of the rain forest understory and subcanopy, foraging for insect larvae in woody branches and stems. It can be found in *ʻōhiʻa* and *ʻōhiʻa-koa* rain forests, as well as in *koa*-dominated forests.
• The Maui parrotbill uses its beak like a can opener to split and crack branches, prying out insect larvae with its tongue and upper mandible.
• There is no known Hawaiian name for this species.

Nukupu'u (*Hemignathus lucidus*)
Also, Maui *Nukupu'u* (*Hemignathus lucidus affinis*), a Maui endemic subspecies

• Endemic and endangered, possibly extinct. (The last birds were seen in the 1980s.)
• This bird is a member of the Hawaiian honeycreepers, a group that at one time included some 52 species descended from one original finch species. The honeycreepers are an example of adaptive radiation.
• Yellow and olive-green birds range from 11 to 14 centimeters (4.5-5.5 inches) long with a long, curved upper mandible.
• The *nukupu'u* uses its upper bill to search in bark crevices for spiders, caterpillars, *Oodemas* weevils, and other insects.
• Its preferred habitat, the *koa* forest, has been destroyed on a large scale, occupying only a small part of its original range. Now, with the *koa* forests dramatically decreased in size, and the presence of malaria-carrying mosquitoes at lower elevations, the *nukupu'u* is most commonly found in *'ōhi'a*-dominated forests above 1500 meters (4,920 feet).

NATIVE PLANTS

Canopy
'Ōhi'a (*Metrosideros polymorpha*)

• Endemic
• *Polymorpha* means "many forms." This species is found in a variety of forms, both within and outside the rain forest. Geographically speaking, its closest relatives occur in Australia.
• In the rain forest, it may grow straight and tall, reaching a height of 18 m (60 feet) or more. In the cloud forest zone, a part of the rain forest where most moisture comes from a nearly-constant cover of fog and clouds, the tree is smaller, with a gnarled and twisted trunk and leathery leaves. In the extreme wet of mountain bogs, *'ōhi'a* stands only a few inches high.
• This is the dominant tree in the wetter rain forests at middle and upper elevations. It forms a nearly continuous canopy in these areas.
• Although its flowers are adapted to wind pollination, native birds feeding on nectar also assist in pollination.
• It may begin its life as an epiphyte—a plant that grows using another plant for support, and taking nutrients from air and rainwater. Wind-blown seeds often lodge and germinate on tree fern trunks.
• *'Ōhi'a* wood is important in Hawaiian canoe-making, used for the gunwale (*mo'o*) of the canoe because it is hard enough to take the constant rubbing of the paddle. It was also used for the seats, spreaders, decking, and mast of the canoe, and for the ridgepoles, posts, rafters and thatching poles in houses.
• In Hawaiian tradition, it is believed that picking the blossoms causes rain.

Koa (*Acacia koa*)

• Endemic (Geographically speaking, its closest relatives occur in Australia.)
• *Koa* can reach heights of 30 meters (100 feet), piercing the *ʻōhiʻa lehua* canopy in places and towering above the rain forest.
• *Koa* may dominate the canopy in relatively drier parts of the rain forest. Sometimes it shares the canopy with *ʻōhiʻa*. In other places, the *koa* will grow taller and can form a distinct upper canopy layer above the *ʻōhiʻa.*
• *Koa* forests have been greatly diminished by logging and ranching. These trees are slow-growing and not easily renewable.
• *Koa* is the host to many rain forest insects.
• Its small, fuzzy, yellow flowers are important sources of nectar for native forest birds, although not as important as the red flowers of *ʻōhiʻa lehua*.
• *Koa* wood was prized by the Hawaiians, and was used to carve canoes, paddles, surfboards, spears, and calabashes (*ʻumeke laʻau*) to hold food, kapa and feathered garments. *Koa* was not used to store *poi*, as it imparted a bitter taste.
• Hulls of single (*kaukahi*) and double (*kaulua*) canoes were carved out of a single *koa* log.
• *Koa* bark was used as a dye for *kapa* and for timbers of grass houses.

Loulu or Fan palm (*Pritchardia* spp.). Also, (*Pritchardia arecina*), the species found in the Haleakalā rain forest

• Endemic (The members of this genus are the only fan palms native to Hawaiʻi. There are 19 endemic species, each of which is unique to a particular island.)
• These palms grow emerge above the canopy singly or in small patches.
• Fossil evidence suggests that *loulu* was more common in ancient times than it is now.
• These fan palms were used in the construction of *heiau loulu*, temporary *heiau* where offerings were made to the gods who presided over fishing.

Subcanopy

Hāpuʻu pulu or Tree fern (*Cibotium glaucum*) Also *Hāpuʻu iʻi* (*Cibotium chamissoi*)

• Endemic
• These large ferns can grow taller than three meters (ten feet) on a stocky "trunk," which is actually a network of interwoven aerial roots that absorb moisture.
• They can be very abundant in the shade created by rain forest trees such as *ʻōhiʻa lehua* and *ʻōlapa*. Where pigs range through the rain forest, however, these ferns are greatly diminished. They are recovering in areas that have been damaged by pigs in the past but are now fenced and patrolled to keep pigs out.
• *Hāpuʻu* are sometimes called "the mother of *ʻōhiʻa*" because their trunks make a good place for seedling germination.
• Tree ferns are covered with brown silky hairs called *pulu*. *Pulu* was traditionally used for stuffing pillows, dressing wounds, and embalming the dead.
• During times of famine, the pith of the trunk was cooked and eaten, and the fiddleheads were eaten, as well.

ʻŌlapa (*Cheirodendron trigynum*)

• Endemic
• This tree ranges in height from five to 15 meters (16 to 50 feet). *ʻŌlapa* is sometimes part of the understory and sometimes part of the canopy.
• In Hawaiian rain forests, *ʻōlapa* often grows intermixed with *hāpuʻu* tree ferns and *ʻōhiʻa*.
• This tree bears clusters of small, purplish fruits which are eaten by native birds.
• *ʻŌlapa* is one host plant for native *Drosophila* flies.
• The soft wood of *ʻōlapa* makes good habitat for the burrowing insects on which many birds feed.
• *ʻŌlapa* sticks were used by the *kia manu* (bird catchers). They covered the sticks with *kēpau* (sap) and placed them in the forest. The sap trapped birds that landed on these sticks. The wood burns when it is wet and was used by the *kia manu* for fires in the wet forest.
• In hula, *ʻōlapa* is the name given to dancers who are graceful enough to imitate the motions of *ʻōlapa* leaves fluttering in the breeze.

Māmaki (*Pipturus spp.*)

• Two Kauaʻi endemic species and two Maui endemics (*P. albidus* and *P. forbesii*)
• *Māmaki* grows as a shrub or small tree two to six meters (six to 20 feet) tall.
• It is in the nettle family. It is unusual because it lacks the stinging hairs associated with most nettle species.
• Birds eat the fruits of the *māmaki*, helping disperse the seeds.
• *Māmaki* was used to make a *kapa* similar to that made from *wauke* but coarser in texture.
• Rope and cordage were made from *māmaki* fibers.
• The leaves of *Pipturus albidus* are the primary food of the larvae of the *pulelehua* or Kamehameha butterfly (*Vanessa tameamea*).
• *Pipturus forbesii* is endemic to Haleakalā, found at upper elevations in the rain forest as well as in subalpine shrubland.

Kanawao or *Pūʻahanui* (*Broussaisia arguta*)

• Endemic
• A multibranched shrub 1.5-4.5 meters (five to 15 feet) tall, *kanawao* bears clusters of small flowers that produce small red-maroon fruits that mature to a blue-black color.
• It often grows in association with *ʻōhiʻa lehua* and *ʻōlapa*.
• This plant is a favored habitat for the happy-face spider.
• The soft wood of *kanawao* makes good habitat for the burrowing insects on which many birds, such as the Maui parrotbill, feed.
• *Kanawao* fruits were believed to aid conception.
• The cluster of fruits was used to symbolize an expansion in the number of chiefs in traditional Hawaiʻi.

Kōlea (*Myrsine* spp.)

• *Kōlea* is the collective name for most of the 20 endemic species of *Myrsine* found in Hawai'i. Only some of these species are found in the rain forest (such as *M. lessertiana* and *M. emarginata*).
• The 20 Hawaiian *Myrsine* species are thought to have evolved from one or two ancestral species, making this group an excellent example of adaptive radiation.
• Some *kōlea* grow as shrubs, while others are trees. *Kōlea* is a common understory tree.
• Dark-colored fruits are clustered along stems or branches.
• At least one *kōlea* species, *kōlea lau nui* (*Myrsine lessertiana*), provided wood for early Hawaiian house posts and beams as well as beaters for *kapa*. Red dye was made from the bark, and black dye was derived by burning the plant to make charcoal.

Understory

'Ōhelo (*Vaccinium* spp.)

• Three endemic species (*V. calycinum*, *V. dentatum*, and *V. reticulatum*)
• Related to blueberries and cranberries
• *'Ōhelo* grows as a shrub or tree, on the ground, or as an epiphyte using other plants for support. Depending on the species and the habitat, *'ōhelo* can range from several centimeters to several meters in height.
• All three *'ōhelo* species can be found in rain forest and bog areas on Haleakalā.
• Birds eat the small, usually red, fruits and help disperse seeds. When *'ōhelo* is in bloom, nectar-feeding birds favor it.
• The fruits of the *'ōhelo* were eaten by Hawaiians traveling to the uplands. They are still eaten by some people. Dried *'ōhelo* leaves are still used to make tea.
• *'Ōhelo* is considered to be sacred to Pele, the Hawaiian volcano goddess. Visitors to Kīlauea would customarily offer a branch bearing berries to Pele before eating themselves. This tradition lives on today when people offer a berry or two to Pele before eating. (Breaking branches off the plants is illegal in Haleakalā National Park.)

'Ōhā and *Hāhā* (and others), or Hawaiian lobelias (*Lobelia, Cyanea,* and *Clermontia* spp.)

• Four endemic Hawaiian genera and many endemic species are represented among Hawaiian lobelias. (*Lobelia* is not an endemic genus. *Clermontia* and *Cyanea* are among the four endemic genera.)
• Rats and pigs can cause serious damage to these flowering plants, although pigs can be—and are—excluded from parts of the rain forest.
• The four endemic genera (totaling nearly 100 species) all evolved from a single common ancestral species that arrived in Hawai'i millions of years ago. Among Hawaiian plants, this is the most prolific example of adaptive radiation.
• Hawaiian lobelias are shrubby species. Many of them have a characteristic lobeliad "rosette" growth form, in which leaves in circular formation grow at the end of single vertical stems (like palm trees). Others have branched trunks or vertical branches.
• The nectar of many lobelias is attractive to native honeycreepers. The flower shapes coevolved with the honeycreepers, so there is a correspondence between beak shape and flower shape.

Vines and Climbing Shrubs

'Ie'ie or Climbing screwpine (*Freycinetia arborea*)

• Indigenous
• This woody, climbing plant is found in the rain forest at lower and middle elevations up to about 1400 meters (4592 feet).
• Sometimes *'ie'ie* sprawls across the forest floor. It often wraps around and climbs the trunks of taller trees such as *koa* and *'ōhi'a*. It produces many aerial roots (*'ie*) that attach the plant to the host tree.
• *'Ie'ie* used to be pollinated by native honeycreeper species that are now extinct. Introduced birds such as the Japanese white-eye (*Zosterops japonicus*) now do the job.
• This plant was greatly diminished by pig damage. Rats are also major threats to *'ie'ie*. It is now rare to find flowers that have not been eaten by rats. Rat predation on flowers impairs reproduction.
• The fibers in the stem were used to make cordage to tie together house rafters and bind the outrigger (*ama*) to the canoe (*wa'a*).
• Aerial roots were woven into very fine and durable baskets and funnel-shaped traps to catch fresh-water shrimp and fish as well as helmets (*mahiole*) which were worn by chiefs going into battle.
• *'Ie'ie* was sacred to early Hawaiians. The plant was dedicated to the forest god, Kū. In a *hālau hula, 'ie'ie* represented the demigoddess Lauka'ie'ie.

Maile (*Alyxia oliviformis*)

• Endemic
• A climbing shrub or vine with glossy, leathery leaves, tubular yellow flowers, and purple-black fruits shaped like olives
• There are many varieties of *maile*, distinguished by differences such as leaf size and shape, and scent. Different Hawaiian names reflect these differences (e.g., *maile ha'i wale* or brittle *maile*, and *maile pākaha* or blunt-leaved *maile*) and illustrate ancient Hawaiians' acute observation skills.
• *Maile* is woven into a fragrant, open-ended lei that symbolizes respect for the wearer.
• *Maile* is dedicated to the *hula* goddess, Laka. It has inspired many songs, chants, and dances.

Hawaiian mints (*Stenogyne* spp.)

• Endemic
• Of eight *Stenogyne* species known from East Maui, five are thought to be extinct. Unlike most other mint species found elsewhere in the world, Hawaiian mints are "mintless"—they do not have aromatic foliage that deters browsing, because they evolved in an environment in which there were no browsing animals. So they are vulnerable to grazing by introduced cattle, pigs, and goats.
• Rat predation is a significant problem for these plants.
• *Stenogyne kamehamehae*, with its clusters of long, curved red or white flowers, is found in rain forests on both Moloka'i and Maui. *Stenogyne rotundifolia* is a Maui endemic that still survives in the upper reaches of Haleakalā rain forests in areas not disturbed by feral pigs.
• Deep, curved *Stenogyne* flowers attract native nectar-sipping bird species whose beak shapes co-evolved with the mint flower shapes. These birds pollinate the flowers.

Forest Floor and Epiphytes

Uluhe or False staghorn fern (*Dicranopteris linearis*)

• Indigenous
• A shrubby, vining fern that forms densely tangled mats on the rain forest floor
• Thickets of *uluhe* can quickly take over when openings are created in the forest canopy, but they do not do well in deep shade. This dense growth can overtake other vegetation and prevent the growth of other plants, including most alien weed species. *Uluhe* can form vegetative mats as much as six meters or 20 feet deep!
• *Uluhe* is often found growing in association with *ʻōhiʻa lehua*.
• In traditional Hawaiian medicine, the bitter juice of this plant was taken as a laxative or emetic.

ʻAlaʻala wainui (*Peperomia* spp.)

• *ʻAlaʻala wainui* is the Hawaiian name for all the plants in this genus, most of which are endemic.
• These plants, which are members of the pepper family, are succulent herbs that range in height from seven or eight centimeters (three inches) to just over a meter.
• *ʻAlaʻala wainui* may grow on the ground or as epiphytes, perched on trees or rocks.
• This plant is extremely susceptible to pig damage, as its fragile stems are easily trampled.
• The sticky fruit are probably dispersed on birds' feet and feathers.
• Many plants in this group were used to make medicines for a variety of health problems and to produce a gray dye for *kapa*.

Paʻiniu (*Astelia* spp.) or *Kaluaha* (*Astelia menziesiana*)

• Endemic
• The long, silvery leaves of *paʻiniu* form rosettes from the center of which grow flowering stalks that bear a cluster of small, bright-orange fruits.
• It is an herbaceous plant that may grow as an epiphyte, using native tree trunks or branches for support, or it may be rooted in the ground.
• This species is used as an indicator of the presence or absence of pigs. If you find *paʻiniu* growing on the ground, you know there have not been pigs in the area.
• This is a favored home for *pinao ʻula*, the Hawaiian Damselfly.
• Birds eat the *paʻiniu* fruit, assisting in seed dispersal.
• The silvery skins of the leaves were woven into flower garlands called *lei paʻiniu*.

Limu or Mosses and Liverworts

• *Limu* refers to many forms of algae, as well as mosses, lichens, and liverworts.
• Numerous species of mosses (*limu kele*) and liverworts live in the rain forests. They form a spongy, blanket-like cover on some native trees, rocks, and other surfaces.
• These fragile plants are easily destroyed by browsing and trampling pigs, goats, and deer.
• The "sponge" of *limu* absorbs water, providing a source of additional moisture during dry spells and helping prevent erosion caused by rapid runoff.

Rain Forest Species Assignments

Cut along dashed lines

Invertebrate
Haleakalā flightless lacewing
(*Pseudopsectra lobipennis*)
Order Neuroptera,
Family Hemerobiidae

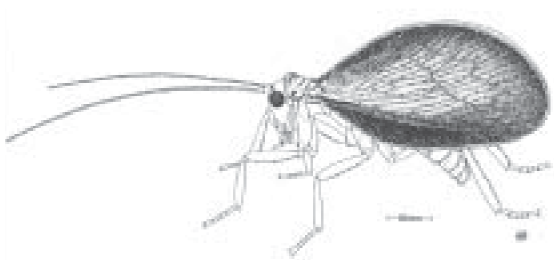


Illustration: Nanci Sidaras

Invertebrate
Hawaiian crickets
(One indigenous genus [*Paratrigonidium*] and 3 endemic genera [*Leptogryllus*, *Thaumatogryllus*, and *Prognathogryllus*])
Order Orthoptera, Family Gryllidae
(*Paratrigonidium* and *Leptogryllus* are most common on East Maui.)

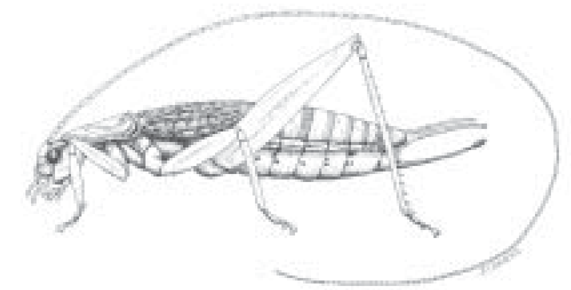


Illustration: Nanci Sidaras

Invertebrate
Tree snails
(*Partulina spp.*)
Order Pulmonata,
Family Achatinellinae

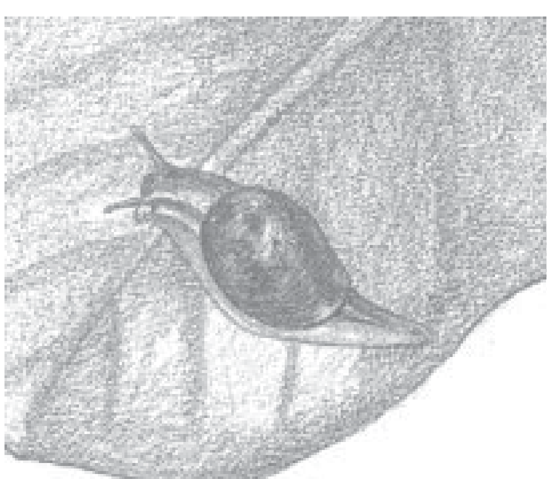


Illustration: Joan Yoshioka

Invertebrate
Hawaiian ground beetles
(Family Caribidae)
Order Coleoptera
(The genus *Mecyclothorax* is most common on East Maui.)

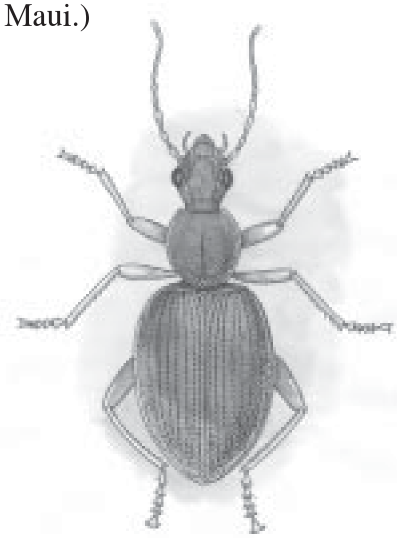


Illustration: Nanci Sidaras

Cut along dashed lines

Invertebrate
Hawaiian long-horned beetles
(*Megopis reflexa* and
Plagithmysus spp.)
Order Coleoptera,
Family Cerambycidae

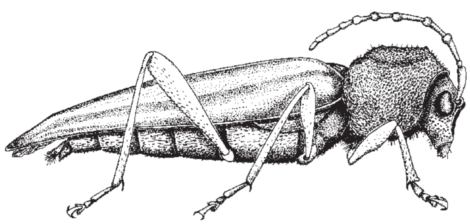
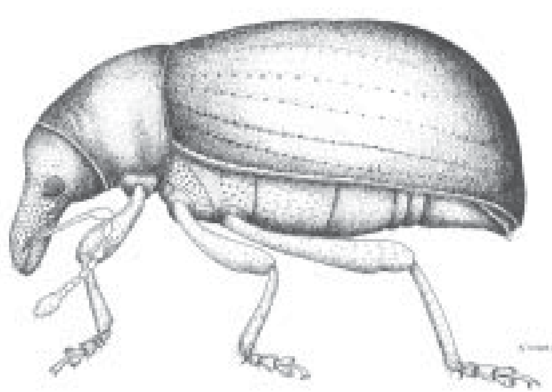


Illustration: Nanci Sidaras

Invertebrate
Haleakalā weevil
(*Oodemas* spp.)
Order Coleoptera,
Family Curculionidae



llustration: Nanci Sidaras

Invertebrate
Hawaiian carnivorous inch-worm (*Eupithecia* spp.)
Order Lepidoptera,
Family Geometridae
(The green grappler, *Eupithecia orichloris*, is a common East Maui species.)

Illustration: Nanci Sidaras

Invertebrate
Happy-face spider
(*Theridion grallator*)
Order Araneae, Family Theridiidae

Illustration: Nanci Sidaras

Cut along dashed lines

Invertebrate

***Pulelehua* or Kamehameha butterfly**

(*Vanessa tameamea*)

Order Lepidoptera,
Family Nymphalidae

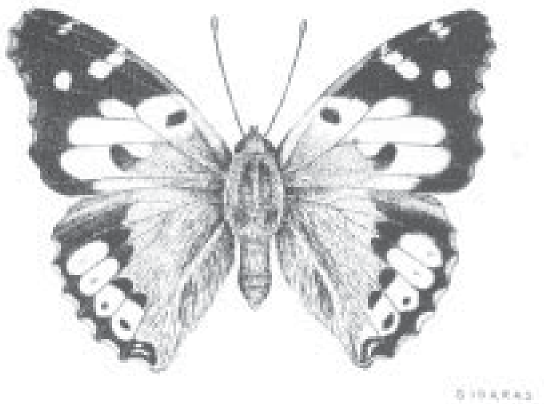


Illustration: Nanci Sidaras

Invertebrate

Picture wing flies

(Family Drosophilidae)

Order Diptera

Illustration: Joan Yoshioka

Invertebrate

Flying earwig, Hawaiian damselfly or *Pinao ʻula*

(*Megalagrion nesiotes*)

Order Odonata,
Family Coenagrionidae

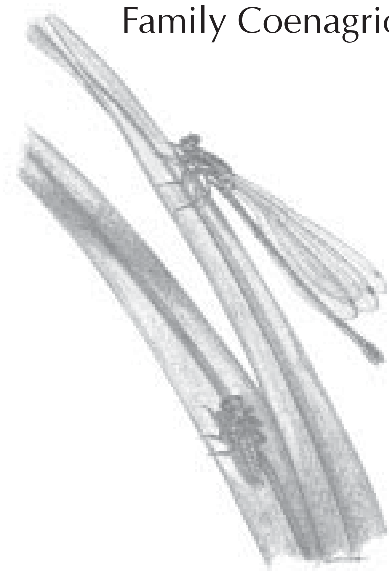


Illustration: Joan Yoshioka

Bird

Nukupuʻu

(*Hemignathus lucidus*)

Order Passeriformes, Family Fringillidae, Subfamily Drepanidinae

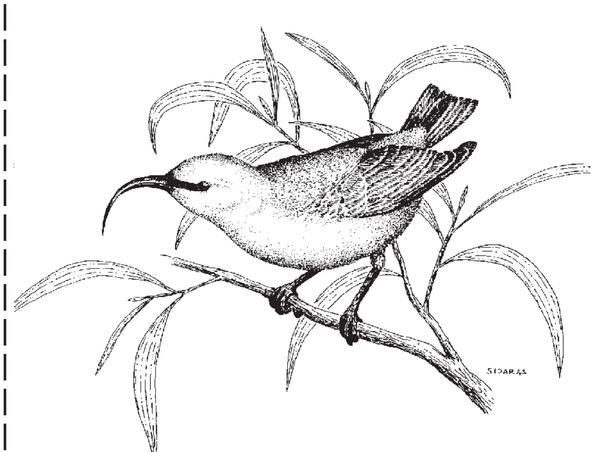


Illustration: Nancy Sidaras

Cut along dashed lines

Bird
ʻIʻiwi (*Vestiaria coccinea*)
Order Passeriformes,
Family Fringillidae,
Subfamily Drepanidinae

Photo: Eric Nishibayashi

Bird
ʻApapane (*Himatione sanguinea*)
Order Passeriformes,
Family Fringillidae,
Subfamily Drepanidinae

Photo: Eric Nishibayashi

Bird
ʻAmakihi (*Hemignathus virens*)
Order Passeriformes,
Family Fringillidae,
Subfamily Drepanidinae

Photo: Eric Nishibayashi

Bird
Maui *ʻAlauahio* or Maui creeper
(*Paroreomyza montana*)
Order Passeriformes,
Family Fringillidae,
Subfamily Drepanidinae

Photo: Eric Nishibayashi

Cut along dashed lines

Bird
***ʻĀkohekohe* or Crested honeycreeper** (*Palmeria dolei*)
Order Passeriformes, Family Fringillidae, Subfamily Drepanidinae

Photo: Eric Nishibayashi

Bird
Poʻouli
(*Melamprosops phaeosoma*)
Order Passeriformes, Family Fringillidae, Subfamily Drepanidinae

Photo: Paul Baker, Maui Forest Bird Recovery Project

Bird
Maui parrotbill
(*Pseudonestor xanthophrys*)
Order Passeriformes, Family Fringillidae, Subfamily Drepanidinae

Photo: Eric Nishibayashi

Plant
***Limu* or Mosses and Liverworts**
Class Musci (Mosses),
Class Hepaticae (Liverworts)

Limu *growing on tree trunks (Photo: Steve Anderson)*

Cut along dashed lines

Plant
ʻŌhiʻa lehua
(*Metrosideros polymorpha*)
Order Myrtales, Family Myrtaceae

Illustration: Joan Yoshioka

Plant
Koa (*Acacia koa*)
Order Fabales, Family Fabaceae

Illustration: Joan Yoshioka

Plant
***Loulu* or Fan palm**
(*Pritchardia spp.*).
Order Arecales, Family Arecaceae
(*Pritchardia arecina* is a common East Maui species.)

Illustration: Joan Yoshioka

Plant
***Hāpuʻu pulu* or Tree fern**
(*Cibotium glaucum*)
Also ***Hāpuʻu iʻi***
(*Cibotium chamissoi*)
Order Filicales, Family Dicksoniaceae

Illustration: Joan Yoshioka

Cut along dashed lines

Plant
ʻŌlapa
(*Cheirodendron trigynum*)
Order Apiales, Family Araliaceae

Illustration: Joan Yoshioka

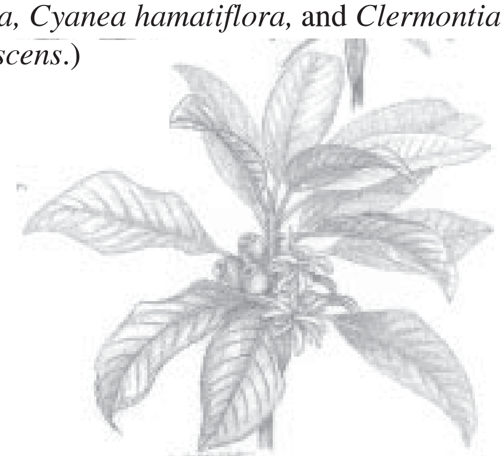
Plant
Māmaki (*Pipturus* spp.)
Order Urticales, Family Urticaceae

Illustration: Joan Yoshioka

Plant
ʻŌhelo (*Vaccinium* spp.)
Order Ericales, Family Ericaceae
(*Vaccinium calycinum* is a common East Maui species.)

Illustration: Joan Yoshioka

Plant
***ʻŌhā* and *Hāhā* (and others) or Hawaiian lobelias** (*Lobelia, Cyanea,* and *Clermontia* spp.)
Order Campanulales,
Family Campanulaceae,
Subfamily Lobelioideae
(Common East Maui species include *Lobelia grayana*, *Cyanea hamatiflora*, and *Clermontia arborescens*.)



ʻŌhā (Clermontia parviflora) (Illustration: Joan Yoshioka)

Cut along dashed lines

Plant
Kanawao* or *Pū'ahanui
(*Broussaisia arguta*)
Order Rosales, Family Hydrangeaceae

Photo: Steve Anderson

Plant
Kōlea (*Myrsine* spp.)
Order Primulales, Family Myrsinaceae
(*Myrsine lessertiana* is a common East Maui species.)

Illustration: Joan Yoshioka

Plant
***'Ie'ie* or Climbing screwpine**
(*Freycinetia arborea*)
Order Pandanales,
Family Pandanaceae

Photo: Carol Gentz

Plant
Maile (*Alyxia oliviformis*)
Order Gentianales,
Family Apocynaceae

Illustration: Joan Yoshioka

Cut along dashed lines

Plant
Hawaiian mints (*Stenogyne* spp.)
Order Lamiales, Family Lamiaceae
(*Stenogyne rotundifolia* is a common East Maui species.)

Illustration: Nanci Sidaras

Plant
***Uluhe* or False staghorn fern**
(*Dicranopteris linearis*)
Order Filicales, Family Gleicheniaceae

Illustration: Joan Yoshioka

Plant
ʻAlaʻala wainui
(*Peperomia* spp.)
Order Piperales, Family Piperaceae
(*Peperomia cookiana, lilifolia,* and *waikamoiana* are common East Maui species.)

Photo: Kim Martz and Forest Starr

Plant
Paʻiniu (*Astelia* spp.) or
Kaluaha (*Astelia menziesiana*)
Order Liliales, Family Liliaceae

Illustration: Joan Yoshioka

Rain Forest Species Cards

Species card instructions

Based on your research, fill in your blank species card using the following suggestions and questions as guidance. The answers to all of these questions are not readily available for every species, so work with the information you can find.

Species type and names
These appear on your species assignment card. Include common, Latin, and Hawaiian names, where appropriate.

Status
Is this an endemic or indigenous species? Where else in the world is this species found? Is it common, rare, threatened, or endangered? Why? Is it threatened by alien species? If so, how?

Description and characteristics
What does the species look like? How does it behave? What could you tell others about this species that would help them identify it?

Where in the rain forest?
Where does it fit in the structure of the rain forest? If it's a plant, is it a canopy species? Subcanopy? Understory? Ground cover or forest floor? Epiphyte, vine, or climbing shrub? If it's an invertebrate or bird, where would you be most likely to find it?

Rain forest relationships
How does this species interact with other rain forest species? What is its habitat?

Think about it…
A thought-provoking question about this species

Did you know?
A fun fact about this species (This could be a native Hawaiian cultural use, a unique characteristic, or something else that interesting.)

Sources of information
Citations for the information source(s) you used in creating this species card

Species image
An image of the plant or animal that you draw, colorize, or photocopy

A Beginning List of Resources for Research

Available through your teacher

Hawai‘i Audubon Society, *Hawaii’s Birds*, 5th ed., Hawai‘i Audubon Society, 1997.

Medeiros, Arthur C., and Lloyd L. Loope, *Rare Animals and Plants of Haleakalā National Park,* Hawai‘i Natural History Association, Hawai‘i National Park, 1994.

Moanalua Garden Foundation, *Forest Treasures* (CD ROM), 2000.

Stone, Charles P., and Linda W. Pratt, *Hawai‘i’s Plants and Animals; Biological Sketches of Hawaii Volcanoes National Park*, Hawai‘i Natural History Association, National Park Service, and University of Hawai‘i Cooperative National Park Resources Study Unit, Hawai‘i National Park, 1994.

Websites

Bishop Museum Natural Sciences Department at <www.hbs.bishopmuseum.org>. Click on Natural Sciences Department under the Research and Collections icon.

College of Tropical Agriculture and Human Resources at <www.ctahr.hawaii.edu>. Click on “forests” under “environment,” or the “ornamentals and flowers” subsection.

Hawai‘i Biological Survey at <www.hbs.bishopmuseum.org/hbsl.html>.

Hawaiian Ecosystems at Risk at <www.hear.org>.
Contains links to many other informative websites

Native Hawaiian Plant Society at <www.philipt.com/nhps>.

The Nature Conservancy at <www.tnc.org/hawaii>.

University of Hawai‘i Botany Department, “Hawaiian Native Plants” at <www.botany.hawaii.edu/faculty/carr/natives.htm>.
Includes photos of many native Hawaiian plants

U.S. Fish and Wildlife Service, Pacific Islands Ecoregion, “Hawaiian Endangered Species” at <pacificislands.fws.gov/wesa/endspindex/html>.

Also, try doing Internet searches through a search engine, using the common or Latin name of your species.

Check the library or friends and family for these additional resources

Abbott, Isabella Aiona, *Lāʻau Hawaiʻi: Traditional Hawaiian Uses of Plants,* Bishop Museum Press, Honolulu, 1992.

Hadfield, Michael G., "Extinction in Hawaiian Achatinelline Snails," in E. Alison Kay (ed.), *A Natural History of the Hawaiian Islands; Selected Readings II,* University of Hawaiʻi Press, Honolulu, 1994, pp. 320-334.

Howarth, Francis G., and William P. Mull, *Hawaiian Insects and Their Kin,* University of Hawaiʻi Press, 1992.

Krauss, Beatrice H., *Native Plants Used as Medicine in Hawaiʻi,* Harold L. Lyon Arboretum, Honolulu, 1991.

Polhemus, Dan and Adam Asquith, *Hawaiian Damselflies: A Field Identification Guide*, Bishop Museum Press, Honolulu, 1996.

Pratt, H. Douglas, *A Pocket Guide to Hawaiʻi's Trees and Shrubs*, Mutual Publishing, Honolulu, 1998.

Wagner, Warren Lambert, and S. H. Sohmer, *Manual of the Flowering Plants of Hawaiʻi*, University of Hawaiʻi Press, Honolulu, 1999.

Sample Species Card

ʻŌpeʻapeʻa or Hawaiian hoary bat (*Lasiurus cinereus semotus*)
Order Chiroptera, Family Vespertilionidae

Status

- Endemic subspecies to the Hawaiian Islands (Other members of this species are found in temperate areas of North and South America, and several island groups including the Galapagos archipelago.)
- Hawaiian hoary bat populations were probably never very large, and there are now approximately a few thousand left. They are less common on Maui than on Kauaʻi and Hawaiʻi.

Description and characteristics

- This small reddish-gray bat weighs just over half an ounce.
- A nocturnal animal, the bat hunts at night and roosts during the day.
- It uses high-pitched cries and sonar to locate its food—flying insects.

Where in the rain forest?

- It clings to tree branches or rocks to roost upside down during the daytime.

Rain forest relationships

- It feeds on flying insects.
- It can be found in native *ʻōhiʻa* and *koa* forests. It has also adapted to human-altered landscapes, sometimes roosting in nonnative macadamia and eucalyptus trees.

Think about it…

One hundred years ago, there were proposals to introduce nonnative bat species to the Hawaiian Islands to help keep insect pests in check. If they'd been successfully introduced, what effects might these nonnative species have had on the native Hawaiian bat?

Did you know?

The Hawaiian name, *ʻōpeʻapeʻa*, may come from the Hawaiian word *peʻa* which means "cross-shaped" or "sail-shaped."

Sources of information

Medeiros, Arthur C., and Lloyd L. Loope, *Rare Animals and Plants of Haleakalā National Park.* Hawaiʻi Natural History Association, Hawaiʻi National Park, Hawaiʻi, 1994, pp. 3-5.

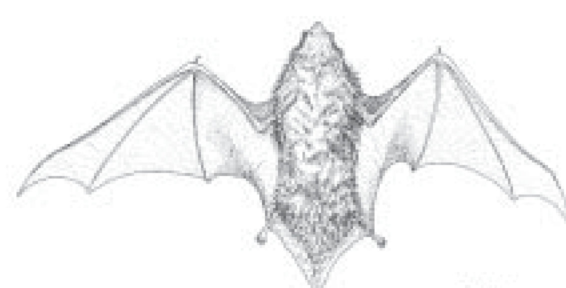


Illustration: Nanci Sidaras

Blank Species Card

Species type

Species name (common and scientific)

Status

Description and characteristics

Where in the rain forest?

Rain forest relationships

Think about it…

Did you know?

Activity #3

Rain Forest Species Presentations

● ● ● **In Advance** *Preparing for Class Presentations*

- Using the species cards they created in Activity #2, have students prepare for a two- to three-minute in-class presentation using the Student Page “Presentation Preparation” (p. 44). Each student should also write down two questions they think other students should be able to answer after listening to the presentation, as well as the answers to those questions.

- Use colored markers to draw a rain forest scene on two long strips of newsprint taped together—long enough to cover the longest section of open wall that you have available in your classroom. Your scene doesn’t need to be artistic, but it does need to show the distinct sections of the rain forest structure: canopy, subcanopy, understory, and ground cover or forest floor. See “Hawaiian Rain Forest: General Structure and Composition” (p. 43) for an explanatory diagram. Students will place species cards on this representation to show where species fit in the rain forest.

- Prepare for Activity #4: “Rain Forest Trivia” if you wish to use it as an assessment tool after the presentations.

● ● ● **Class Periods One and Two** *Rain Forest Species Presentations*

Materials & Setup

- Newsprint rain forest representation (see “In Advance,” above)
- Masking tape for posting the newsprint
- Scotch tape for posting species cards on the newsprint rain forest representation

For each student

- Student Page “Presentation Preparation” (p. 44)

Instructions

1) Have students do two- to three-minute species presentations. Monitor their times, and give them signals when they have 30 seconds left. Make it clear that these presentations must not exceed three minutes. Sometimes we only have a limited amount of time to convey information, so we need to learn to speak clearly and succinctly.

   Do the presentations in the following order:
   1) Plants: Canopy and subcanopy first, then other plants
   2) Invertebrates
   3) Birds

2) Prior to each presentation, the student should give you his or her two questions. Monitor the presentations to make sure students cover the answers to these questions during their presentations.

3) At the end of each presentation, have the student tape his or her species card to the large rain forest drawing in the part of the rain forest where it is most likely to be found.

Journal Ideas

- Was it easy or difficult to keep your presentation to two or three minutes? Describe another situation in which it was important for you to keep your communication brief and to-the-point.

Assessment Tools

- In-class presentations
- Leave about ten minutes at the end of each class period to give a quiz using the questions about the day's presentations. Have students write down their responses and hand in their quizzes. Use the student question and answer sheets to grade the quizzes.

Hawaiian Rain Forest: General Structure & Composition

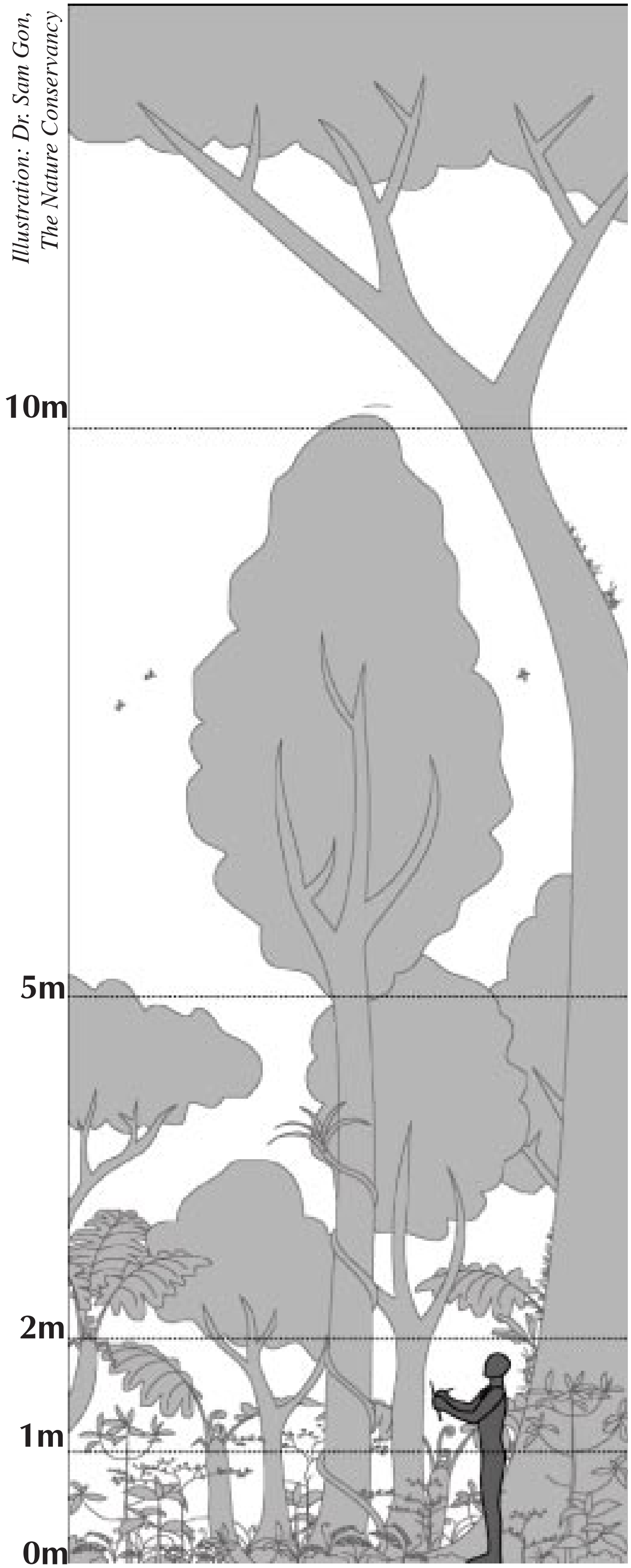


Illustration: Dr. Sam Gon, The Nature Conservancy

Canopy

Height above five meters (16 feet) This layer includes the majority of trees, primarily consisting of *Acacia koa* and *Metrosideros polymorpha*. The height of the main canopy layer is usually under ten meters (33 feet). In some places, taller trees emerge above the prevailing canopy height.

Epiphytes and Climbing Plants

Epiphytes are present in all layers, increasing in cover and diversity closer to the ground. Epiphytes include mosses and liverworts, lichens, a variety of ferns, and flowering plants. Vines and climbing plants are most abundant in lower layers, but may extend to the canopy.

Subcanopy Trees and Shrubs

Height, two to five meters (6.5-16 feet)
In this layer, large tree ferns, shrubs, and saplings of canopy trees are present.

Understory

Height, one to two meters (three to 6.5 feet)
Typically, present here are tree ferns, shrubs, and saplings of subcanopy and canopy trees.

Groundcover or Forest Floor

Height, to one meter (to three feet)
Here are found small ferns, small shrubs, herbs, sedges and grasses, mosses and liverworts, and seedlings from all layers.

Presentation Preparation

In class, you will make a two- to three-minute presentation about your species, using the information you gathered as you did research for the species card. Your presentation may be no longer than three minutes, so plan carefully.

As you plan your presentation, think of two important things you want your classmates to learn from your presentation. Write these two things in question-and-answer format. You will hand these in to your teacher before you make your presentation.

In addition to these two points, consider topics such as the following in planning your presentation:

- Where does this species fit in the structure of the rain forest? (Is it a canopy species, subcanopy species, understory species, or ground cover/forest floor species? Is it an epiphyte or climbing species?)
- Is it a native species? (Indigenous? Endemic?) Is it a Polynesian introduction, or an alien species more recently introduced?
- Is it rare? Endangered? Why?
- What are its basic characteristics?
- How is it related to other species in the rain forest?
- Is/was it used or significant in Hawaiian culture? If so, how? (Many of the native plant species cards contain notes about traditional significance. You may research other uses of these plants, specific details or examples of their use, or stories, songs, or chants that mention these plants.)
- Is it still used today?
- Is there current research being done on this species? If so, what are scientists trying to learn?

Activity #4

Rain Forest Trivia

● ● ● In Advance *Preparing for the Game*

1) You may use this activity to assess student learning from Activity #3 "Rain Forest Species Presentations." To do this, hand out one copy of the student page "Rain Forest Trivia Questions" to each student in advance of the in-class presentations. Students should write on the Student Page the two questions they think other students should be able to answer after listening to the presentation, as well as the answers to those questions.

2) Label each of three large envelopes with one of the following categories: Native Invertebrates, Native Birds, Native Plants.

3) Prior to each presentation, the student should give you his or her two "Rain Forest Trivia Questions." Monitor the presentations to make sure students cover the answers to these questions during their presentations. Then place the questions into the appropriate envelope (Native Invertebrates, Native Birds, Native Plants).

● ● ● Class Period One *Rain Forest Trivia*

Materials & Setup

For each student

- Student Page "Rain Forest Trivia Questions" (p. 47)

- Students' Rain Forest Trivia cards, categorized into the three labeled envelopes

Instructions

1) Go around the class, asking each student a question drawn from one of the envelopes. Rotate among categories for variety, or have each student select a category.

2) Draw a card from that category, read the question, and have the student answer it. If the student cannot answer it correctly, open the question to the rest of the class. Allow time for clarification and explanations from the student who wrote the question, after other students have answered (or attempted to answer) each question.

3) You may make this activity competitive by dividing the class into teams and scoring a point for each correct answer. In this competitive version, the student who wrote the question is not allowed to answer it until someone else has offered an answer, even if s/he is on the team receiving the question.

Journal Ideas

- What was the most interesting thing you learned about native Haleakalā rain forest species? Why?

Assessment Tools

- Student Page "Rain Forest Trivia Questions"
- Participation in Rain Forest Trivia game and student recollection of answers to trivia questions s/he wrote
- Journal entries

Rain Forest Trivia Question #1

Your name

The name of your species (common, Hawaiian, and Latin, if applicable)

Question

Answer

– – – – – – – – – – – – – – – – Cut or tear here – – – – – – – – – – – – – – – –

Rain Forest Trivia Question #2

Your name

The name of your species (common, Hawaiian, and Latin, if applicable)

Question

Answer

Rain Forest Unit 3

Rain Forest Birds: A Study in Adaptation

Overview

Between the native species living today and the fossil record still being unearthed, there is plenty of evidence for the remarkable diversity of bird life that evolved on the Hawaiian Islands. By looking at rain forest birds, students explore how that diversity of life may have evolved, including the process of adaptive radiation. They also learn about the effects of human pressure on species survival and ongoing threats to native bird species, and they conduct independent research projects on native rain forest birds.

Length of Entire Unit

Three class periods, plus optional research and presentation time

Unit Focus Questions

1) What is adaptive radiation and how has this process influenced the evolution of species in Hawaiian rain forests?

2) What are historic and current threats to native rain forest bird species?

Unit at a Glance

Activity #1
Win, Lose, or Adapt Game

Students play a game to develop a basic understanding of the process of adaptive radiation, the effects of habitat loss and competition for food, and the concepts of feeding "specialists" and "generalists."

Length
One class period followed by homework

Prerequisite Activity
None

Objectives
- Evaluate and describe the effects of habitat loss and competition for food on native birds.
- Apply the concepts of "specialization" and "generalization" to discuss species survival under changing conditions.
- Hypothesize about the comparisons between the simulated adaptive radiation in the game and evolution in nature.

DOE Grades 9-12 Science Standards and Benchmarks
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 effects of large and small disturbances on systems in the natural world.

BIOLOGICAL EVOLUTION: Students examine evidence for the evolution of life on earth and assess the arguments for natural selection as a scientific explanation of biological evolution.
- Explain the basic idea behind biological evolution.

Activity #2
Adaptive Radiation in Rain Forest Birds

Through a homework reading, questions, and class discussion, students learn about adaptive radiation in Hawaiian honeycreepers.

Length
One class period, preceded by homework

Prerequisite Activity
None

Objectives
- Define and adaptive radiation.
- Describe factors that are thought to have influenced adaptive radiation among Hawaiian honeycreepers.

DOE Grades 9-12 Science Standards and Benchmarks
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 effects of large and small disturbances on systems in the natural world.

BIOLOGICAL EVOLUTION: Students examine evidence for the evolution of life on earth and assess the arguments for natural selection as a scientific explanation of biological evolution.
- Explain the basic idea behind biological evolution.

Activity #3

Rain Forest Birds Research Projects

Students select a topic related to native Haleakalā rain forest birds and conduct an independent research project on that topic.

Length
One class period, plus optional class time for research and presentations

Prerequisite Activity
None

Objectives

- Research and report on one topic related to native birds of the rain forest on Haleakalā.

DOE Grades 9-12 Science Standards and Benchmarks
LIVING THE VALUES, ATTITUDES, AND COMMITMENTS OF THE INQUIRING MIND: Students apply the values, attitudes, and commitments characteristic of an inquiring mind.

- QUESTIONING: Ask questions to clarify or validate purpose, perspective, assumptions, interpretations, and implications of a problem, situation, or solution.
- SELF-DIRECTED: Use research techniques and a variety of resources to complete a report on a project of one's choice.

Enrichment Ideas

- Research and accurately color line drawings of native rain forest birds. Use the *Forest Jewels of Hawai'i* coloring book (Hawai'i Department of Land and Natural Resources, Division of Forestry and Wildlife, Honolulu, 1996) along with the images of birds in Arthur C. Medeiros, and Lloyd L. Loope, *Rare Animals and Plants of Haleakalā National Park*, Hawai'i Natural History Association, Hawai'i National Park, Hawai'i, 1994.

- Produce original drawings, watercolor or oil paintings, or other artistic and accurate representations of Hawaiian rain forest birds.

- Design a bird to fit different types of food sources. Collect samples or drawings of potential food sources for birds and draw or construct a model of a bird head and beak (or an entire bird) that is adapted to the food source(s). Potential food sources:
    - Flowers of different sizes and shapes,
    - Seeds and nuts of different sizes and shapes,
    - Tree branches or trunks with different types of bark (look for variations such as smooth surfaces on which insects crawl, crevices that shelter insects, or different thicknesses of bark that birds would peel or pry off to reach larvae burrowed underneath),
    - Fruits of various sizes, shapes, and textures, and
    - Insects of different sizes and shapes that have different life histories (e.g., larval stages that burrow in leaf buds, roots, or woody plant stems).

- Make research presentations (Activity #3) to the rest of the class.

Resources for Further Reading and Research

Carlquist, Sherwin, *Hawaii: A Natural History*, Pacific Tropical Botanical Garden, Lawai, Kauai, Hawai‘i, 1980.

Chapter 11, “The Honeycreepers and Other Birds,” includes many photographs and line drawings of honeycreepers along with notations about their food sources.

Freed, L. A., S. Conant, and R. C. Fleisher, “Evolutionary Ecology and Radiation of Hawaiian Passerine Birds,” in Kay, E. A. (ed.), *A Natural History of the Hawaiian Islands, Selected Readings II*, University of Hawai‘i Press. Honolulu, 1994, pp. 335-345.

Givnish, T. J., K. J. Sytsma, J. F. Smith, and W. J. Hahn, “Molecular Evolution, Adaptive Radiation, and Geographic Speciation in *Cyanea (Campanulaceae, Lobelioideae)*,” in Wagner, W. L., and V. A. Funk (eds.), *Hawaiian Biogeography: Evolution on a Hot Spot Archipelago*, Smithsonian Institution, Washington, DC, 1995, pp. 288-337.

Juvik, James O., “Biogeography,” in Juvik, Sonia P., and James O. Juvik (eds), *The Atlas of Hawai‘i*, 3rd ed., University of Hawai‘i Press, Honolulu, 1998, pp. 103-106.

Medeiros, Arthur C., and Lloyd L. Loope, *Rare Animals and Plants of Haleakala National Park*, Hawai‘i Natural History Association, Hawai‘i National Park, Hawai‘i, 1994.

Smith, T. B., L. A. Freed, J. K. Lepson, and J. H. Carothers, “Evolutionary Consequences of Extinctions in Populations of a Hawaiian Honeycreeper,” *Conservation Biology*, Vol. 9, No. 1, 1995, pp. 107-113.

Activity #1

Win, Lose, or Adapt Game

● ● ● Class Period One *Win, Lose, or Adapt Game*

Materials & Setup

- "Food Competition Action Chart," for your reference (master, p. 12)
- "Scenario Cards" (master, pp. 13-16)

For each student

- Student Page "Win, Lose, or Adapt: Questions About the Game" (pp. 17-18)

For each group of six to eight students

- Two decks of playing cards
- "Game Instructions" (master, p. 9)
- "Beak-Type Wheel" (master, p. 10)
- "Bird/Player Identification Cards"—Eight each of four beak types (master, p. 11)
- "Food Competition Action Chart," one copy (master, p. 12)

Instructions

1) Divide the class into groups of six to eight students, and give each group the materials listed above.

2) You are the "master of ceremonies" for this game, making sure players understand and follow instructions and reading the "Scenario Card" that precedes each round of competition. Begin the game by reviewing the "Game Instructions" with students. Make sure that everyone understands that they are looking for any three-of-a-kind, regardless of suit.

3) Begin each round by reading the appropriate "Scenario Card." End each round by asking groups to tally the number of food items each player collected and following the instructions on the "Food Competition Action Chart."

4) Use the question on the final "Scenario Card" to begin a class discussion about the game and its results. Other discussion questions include:
   - Which kind of bird was most successful? Why?
   - What does this game tell us about adaptation and evolution in the natural world?
   - How many honeycreeper species do you think actually evolved in the islands?

   If you are continuing with Activity #2, students will be able to answer these questions better, based on their homework reading.

5) Assign the Student Page "Win, Lose, or Adapt: Questions About the Game" as homework (or discuss in class).

Assessment Tools

- Student participation in the game.
- Student Page "Win, Lose, or Adapt: Questions About the Game" (teacher version, pp. 7-8)

Teacher Version

Win, Lose, or Adapt: Questions About the Game

1) In the game, the "jacks" had to get three of a kind of any card, while the specialized birds only had to get a pair but in a certain numeric range. How do you think this division of food items parallels what happens in nature?

   Well-reasoned responses are acceptable. The specialized birds have a limited range of food items and are well-adapted for that kind of food. The "jacks" have a wider range of food sources, but they may have lower feeding efficiency than the specialists for each one, making it slightly more difficult for them to obtain food from particular sources.

2) What effect do you think declining food sources would have on overall population size of native birds? Why? What would you need to know in order to predict the effects on different types of birds (i.e., nectar sippers, etc.)?

   Any well-reasoned response is acceptable. The basic line of reasoning is likely to be that declining food sources would support a smaller number of birds. In order to gauge the effects on the different types of birds, one would probably need to know how different types of habitat were changing, whether a species of plant that bird is dependent on is declining, whether the birds have substitute food sources in other habitats, etc.

3) If all food sources are declining equally rapidly, which of the four types of birds do you think would have the advantage? Why?

The likely response is the jacks, because they can exploit all food sources and would likely be able to shift between food sources, depending on what's available. (Again, any well reasoned response is acceptable.)

4) List and explain at least two ways in which you think this game is similar to/different from the actual process of evolution and adaptation.

Well-reasoned responses are acceptable. Examples of responses include:

- In the game, the direction of evolution in beak shape/food specialization is determined by a chance roll of the die. In nature, environmental conditions and genetic characteristics determine the direction of natural selection.
- In the game, populations of the most successful species increased without evolving. This probably is the case most often in nature as there is less selective pressure on successful species.
- In the game, it may seem as though adaptation and evolution are happening to individual birds, when in reality the process takes place over many, many generations and entire species.
- In the game, we lumped all nectar eaters together into one group and did the same with the other types of birds. In reality, bird species can be even more specialized to specific sources of food, and changes in the abundance and type of food sources will create selective pressures that are different among species that fall into the same general category.

Win, Lose, or Adapt Game Resources

Win, Lose, or Adapt

Game Instructions

1) Play in groups of six to eight with two decks of playing cards randomly mixed and facedown in a central pile. These cards represent your food source. Each player has a Bird/Player identification card that specifies your beak type and particular food source (a combination of playing cards).

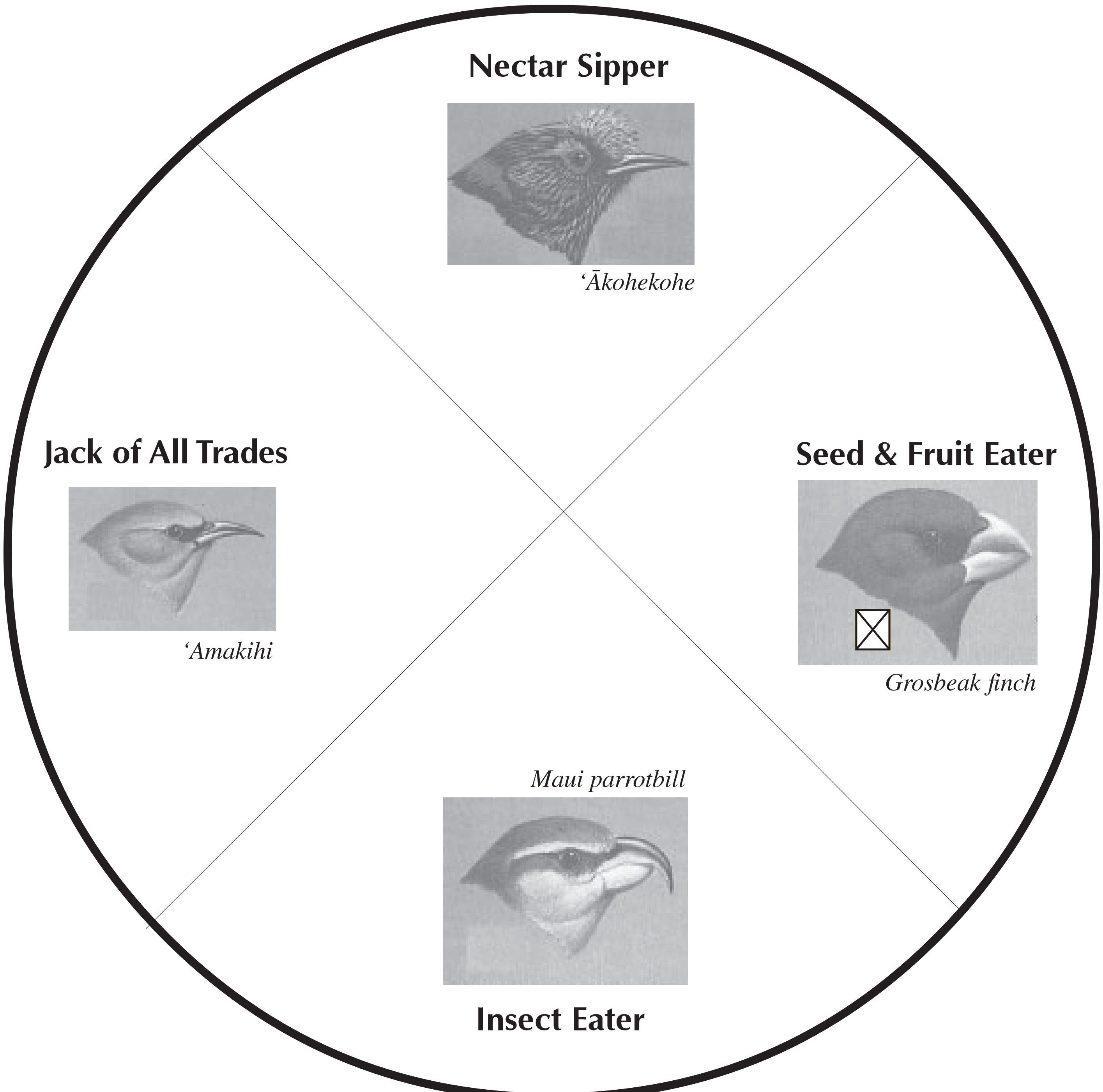
2) Your instructor will begin each of the five rounds of this game by reading a "Scenario Card" with instructions about how many cards each player is to draw and information concerning the beginning of the round.

3) In each two-minute round, you must try to collect as much of your food source as possible.
   - Draw the specified number of playing cards from the central pile. When the two-minute round begins—
   - Draw one playing card at a time, and decide whether to keep it. (Do not take turns drawing playing cards. All players will draw and return playing cards simultaneously, racing each other to collect your food source.)
     If you keep the card, discard one playing card from your hand facedown on the pile.
     If you do not keep the card, return it facedown on the pile.
   - Draw another playing card and continue.
   - Place the food source you collect faceup on the table in front of you, and draw enough playing cards from the central pile to replace the playing cards you put down.
   - Always maintain the original number of playing cards in your hand.
   - Continue playing in this fashion until the two-minute round is up.

4) At the end of each round, tally up the number of food sources each player collected, and follow the instructions on the "Food Competition Action Chart" to determine the winners of the round and the appropriate actions for each player. Ties are resolved by drawing a playing card from the central pile. The high playing card wins the tie. Aces are low.

5) In preparation for the next round, return your playing cards to the central pile and mix them up.

Beak-Type Wheel



Illustrations: H. Douglas Pratt, Jr.

Bird/Player Identification Cards

For each group of eight students, make eight copies of this sheet, for a total of eight cards that represent each beak type. Use card stock or another heavy paper. Cut apart on the dotted lines.

Jack of All Trades

Your beak shape allows you to prod, nip, and probe, taking advantage of all food sources. But since your beak is not specifically adapted to any one source of food, you're at a bit of a disadvantage when specialized birds are around.

Your food source
Three-of-a-kind of any cards, Ace through King, any suit

Collect as many as you can in each round!

Seed & Fruit Eater

Your beak crushes, slices, and pries to get through the husks, pods, and fleshy fruits surrounding the seeds you eat.

Your food source
Pair of cards, 6 through 9, any suit

Collect as many as you can in each round!

Nectar Sipper

Your tubular tongue and petal-probing beak is well-suited to sipping nectar from flowers. Your probing beak and feathers also transfer pollen from one flower to another, providing a function important to plant reproduction.

Your food source
Pair of cards, Ace through 5, any suit

Collect as many as you can in each round!

Insect Eater

Your beak probes the nooks and crannies of shrubs and trees, sometimes probing beneath the bark, to search out insects that hide there.

Your food source
Pair of cards, 10 through King, any suit

Collect as many as you can in each round!

Food Competition Action Chart

Ties are resolved by drawing a card. The player with the higher card wins. Aces are low.

Winner or Loser	Players	Action
The Winners These birds were the most successful at feeding and successfully reproduced, multiplying their numbers significantly.	The two birds that collected the MOST food	These birds thrived and so did their young, so each of these players “recruits” one of the players that died. The recruited player takes a matching bird identification card, representing the new generation.
The Unsuccessful These birds were not successful at feeding, and they died.	The two birds that collected the LEAST food	These birds “die” by turning in their identification cards. They then join the population of one of the birds that successfully reproduced by taking a bird identification card that matches one of the successful players.
The Survivors These birds were successful at feeding to keep themselves and some of their young alive, but they were at a definite disadvantage in the competition for food.	All other birds	These birds survived, but did not thrive. Each of these players draws a card to evolve to a new beak type, enabling them to exploit a different food source. • **Red suit** = Trade in your I.D. card for the next bird type in a CLOCKWISE direction on the beak-type wheel. • **Black suit** = Trade in your card for the next bird type COUNTER-CLOCKWISE.

Scenario Cards

Round 1 Scenario and Instructions

1) Each player takes one “jack of all trades” player identification card.

2) Each player draws **five** playing cards from the central pile.

3) Read Scenario #1:

   This game loosely follows what scientists believe to be the story of a small flock of finches and their descendants, which eventually evolved into at least 52 species of endemic birds collectively known as the Hawaiian honeycreepers.

   The scene: The island of Kaua‘i, three to four million years ago—or so. You are part of a small flock of finch-like birds that are blown by a great hurricane to this island, more than 2,500 miles from your North American or Asian continental homeland. On Kaua‘i, you and the other members of your flock find a variety of food sources: nectar from flowering plants, seeds, fruit, and insects. Your beak shape allows you to take advantage of all of these food sources—you are a “jack of all trades” or a “generalist,” probably similar to today’s *‘amakihi*.

   Important to the survival of any individual within a species—and, more broadly, any species—is its ability to acquire enough food to live, reproduce, and feed its young. Your ability to compete for food will determine whether you survive and reproduce.

   In each round of this game, the playing cards represent your food source. Look on your bird identification card to see what you are trying to collect.

   You’ll try to collect as many of the food items listed on your identification card as you can during each round. Each round lasts two minutes—Wait until I say “begin” before you start collecting your food, and stop collecting as soon as I say “stop.”

Round 2 Scenario and Instructions

1) Each player draws **five** playing cards from the central pile.

2) Read Scenario #2:

An eon passes—maybe a million or two million years—and the original flock of birds produces generation after generation. Some birds survive and reproduce, passing along their genetic information and characteristics to their young. Over time, birds with certain characteristics, such as slightly different beak shapes, were able to successfully exploit certain food types, and the birds with those characteristics thrived and reproduced, passing these characteristics along to future generations. Today, we know this process as “natural selection.”

As time went on, these characteristics became so pronounced that different species emerged from the original flock of birds, which were all basically the same. These species are represented on your “Beak-Type Wheel.”

So we come to this point, where we have species of birds with different beak shapes exploiting different types of foods. The birds and species that are generalist feeders, like the original “founder flock,” compete with other birds and species that are adapted to specialized food sources.

Begin Round 2.

Round 3 Scenario and Instructions

1) Each player draws **five** playing cards from the central pile.

2) Read Scenario #3:

Another eon passes—another couple million years—and evolution continues. During this time, descendant species of the original founder flock find their way to the newly emerging island that we call Maui, flying from island to island in search of food.

On Maui, about a million years ago today, the competition for food continues . . .

Begin Round 3.

Round 4 Scenario and Instructions

1) Each group removes approximately one-third of the playing cards remaining in their central food pile before beginning this round, and sets them aside for the remainder of the game.

2) Each player draws **four** playing cards from the central pile.

3) Read Scenario #4:

   Another eon passes—a shorter one this time—and evolution continues. Late in this time frame, Polynesian settlers arrive on Maui. Over time, these original Hawaiians cleared land for their farms and villages and took trees from the forest for building. As their numbers multiplied, their impact on the land increased, and many of the food sources for the species that descended from the original Hawaiian finches were in shorter and shorter supply.

   Begin Round 4.

Round 5 Scenario and Instructions

1) Each group again removes approximately one-third of the playing cards remaining in their central food pile before beginning this round, and sets them aside for the remainder of the game.

2) Each player draws **three** playing cards from the central pile.

3) Read Scenario #5:

   A few hundred years pass, and Europeans "discover" Hawai'i. Over time, forests are cut down for sale overseas, cattle and other domestic livestock graze forests and shrublands, destroying even more habitat for native Hawaiian birds. Feral pigs and goats damage the native forests, and introduced species compete with native birds for food. Rats and mongoose prey on native bird eggs and chicks. Many native birds are forced to live exclusively at upper elevations because mosquitoes carrying bird diseases inhabit lower elevations.

   Begin Round 5.

Final Scenario

1) At the end of Round 5, read the following passage:

   That brings us to today. Out of the 52 species of Hawaiian honeycreepers, the descendants of finch-like ancestors that arrived on the Hawaiian Islands before Maui even existed, only 22 survive today. Of these, 14 are classified as endangered or may already be extinct. Only eight surviving species are not classified as endangered. What do you think could be happening to these native species?

Win, Lose, or Adapt: Questions About the Game

1) In the game, the “jacks” had to get three of a kind of any card, while the specialized birds only had to get a pair but in a certain numeric range. How do you think this division of food items parallels what happens in nature?

2) What effect do you think declining food sources would have on overall population size of native birds? Why? What would you need to know in order to predict the effects on different types of birds (i.e., nectar sippers, etc.)?

3) If all food sources are declining equally rapidly, which of the four types of birds do you think would have the advantage? Why?

4) List and explain at least two ways in which you think this game is similar to/different from the actual process of evolution and adaptation.

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Activity #2

Adaptive Radiation in Rain Forest Birds

● ● ● **In Advance** *Student Reading*

- Assign the Student Page "Adaptive Radiation in Hawaiian Honeycreepers" (pp. 22-26) as homework.

● ● ● **Class Period One** *Adaptive Radiation Discussion*

Materials & Setup

For each student

- Student Page "Adaptive Radiation in Hawaiian Honeycreepers" (pp. 22-26)
- Student Page "Adaptive Radiation in Hawaiian Honeycreepers: Questions on the Reading" (pp. 27-28)

Instructions

1) Have students complete the Student Page "Adaptive Radiation in Hawaiian Honeycreepers: Questions on the Reading" in class.

2) Spend the remainder of the class discussing adaptive radiation and the homework reading, beginning with student responses to the questions.

Journal Ideas

- Many native birds are not found in low-elevation areas on Maui. Do you think that native birds once occupied these lowland areas? How would you go about finding out?
- Do you think anything should be done to protect the remaining Hawaiian honeycreepers? Why or why not?
- Keeping in mind the different human-caused pressures that have led to declines and extinctions among Hawaiian honeycreepers, what do you think can be done to protect the species that remain?
- Imagine being a traditional Hawaiian bird catcher, collecting thousands of feathers over your lifetime. What do you think it would have been like to work mostly alone in the forests of the gods?

Assessment Tools

- Student Page "Adaptive Radiation in Hawaiian Honeycreepers: Questions on the Reading" (teacher version, pp. 20-21)
- Participation in class discussion
- Journal entries

Teacher Version

Adaptive Radiation in Hawaiian Honeycreepers: Questions on the Reading

1) Define adaptive radiation, and explain its relationship to endemic species. Give one example of adaptive radiation in Hawaiian species other than honeycreepers.

Adaptive radiation is the evolution of many species from a single ancestor.

Well-reasoned responses about the relationship between adaptive radiation and endemism are acceptable. Possible relationships include:

- Adaptive radiation results in many endemic species (species that evolved here and are found nowhere else in the world) that are closely related to each other because of their common ancestor, and
- Because species are evolving in response to local conditions, adaptive radiation may result in species that are "narrowly endemic," or restricted to a small range or a single island.

Examples include Hawaiian *Drosophila* flies and Hawaiian lobeliads. There are many others that students may have learned about outside this unit, including the silversword alliance which includes the *ʻāhinahina* or Haleakalā silversword.

2) Why are fossil records valuable sources of information to scientists studying the evolution of native bird species?

Well-reasoned responses are acceptable. Fossil records enable scientists to identify previously unknown species and establish their relationships with existing species. Among Hawaiian honeycreepers, for example, 18 species are known only from fossil records. That's 35 percent of all known honeycreeper species. Our understanding of the scope of adaptive radiation among honeycreepers would be much narrower if not for the fossil record.

3) Is the shift in the size of *ʻiʻiwi* bills over the last 100 years an example of adaptive radiation in action? Explain your answer.

Well-reasoned responses are acceptable. Two possibilities:

- The shift in *ʻiʻiwi* bill size is probably not adaptive radiation in action because it is likely to be taking place across the entire species, so the changes that are taking place are probably not going to result in the creation of a new species. The extinction of the *ʻōʻō* probably affected the *ʻiʻiwi* across much of its range, as did the decline of the preferred food source, Hawaiian lobeliads.
- If there are islands or large stretches of habitat in which Hawaiian lobeliad populations are protected or restored and other places where they are not, then we may be seeing adaptive radiation in action, as the habitat for some populations of *ʻiʻiwi* would favor their existing bill size, and the habitat for others would favor a shorter bill, possibly leading to species differentiation over a long period of time.

4) Using what you have learned about evolution and adaptation, explain why extinctions of rain forest bird species have happened—and continue to occur—so rapidly in the face of human-caused changes to native Hawaiian rain forests.

Well-reasoned responses are acceptable. Two possibilities:

- Human-caused changes such as habitat destruction, pressures by introduced species, and introduced diseases are altering conditions for native birds so quickly that evolution cannot keep up. The honeycreepers took millions of years to evolve, but humans have caused dramatic changes in their environment within hundreds of years.
- Human activity has contributed to many different pressures on native birds including habitat destruction, predation and competition by introduced species, and disease. A species that might be able to adapt and survive in the face of a single human-caused pressure may not fare so well when there are multiple pressures working against its survival.

Adaptive Radiation in Hawaiian Honeycreepers

The Hawaiian Islands are the most isolated archipelago on the planet. Here, we are more than 2,000 miles away from the nearest continent and some 1,000 miles away from the closest Pacific atolls. Because of this isolation, over millions of years, relatively few plant and animal species arrived on the islands. The “three Ws” (wind, waves, and wings) are used to describe the means by which species arrived here. From a small collection of “founding species” descended all of the animals and plants that are native to Hawai‘i. The Hawaiian rain forest is a hotbed of “endemism.” Of its native inhabitants, a large proportion are unique to these islands.

In contrast to “indigenous” species, Hawaiian endemic species evolved into a new species after arriving here from somewhere else. Indigenous species have remained relatively unchanged since their arrival and are not unique to Hawai‘i. Among the endemic forest birds, most species belong to a group known as the Hawaiian honeycreepers. All of the honeycreeper species are thought to have evolved from a single finch species that arrived on the islands more than 15 million years ago. This process of “adaptive radiation” has, over time, resulted in honeycreepers that are very different from each other and adapted to many different environments.

The oldest of today’s main islands, Kaua‘i, is only about five million years old. So much of the early evolution of the honeycreepers probably happened on other, older islands in the chain. Through a process called “interisland dispersal,” the ancestors of the honeycreeper species we know today colonized the new islands, even as their old homelands were being slowly eroded away. These new islands may have offered different habitat for the birds, which over time could have further radiated into new species.

In the 1970s, paleontologists began in earnest to collect partially fossilized bird remains from sand dunes, lava tubes, caves, and sinkholes in the Hawaiian Islands. This fossil record revealed many species of honeycreepers that were already extinct by the time Western scientists had started identifying and describing Hawaiian birds. Most of these extinctions were most likely a result of the impacts of the Hawaiian people: competition or predation by Polynesian introductions, conversion of lowland habitats into agricultural areas, and killing of birds for food and other human uses.

Hawaiian Honeycreepers at a Glance

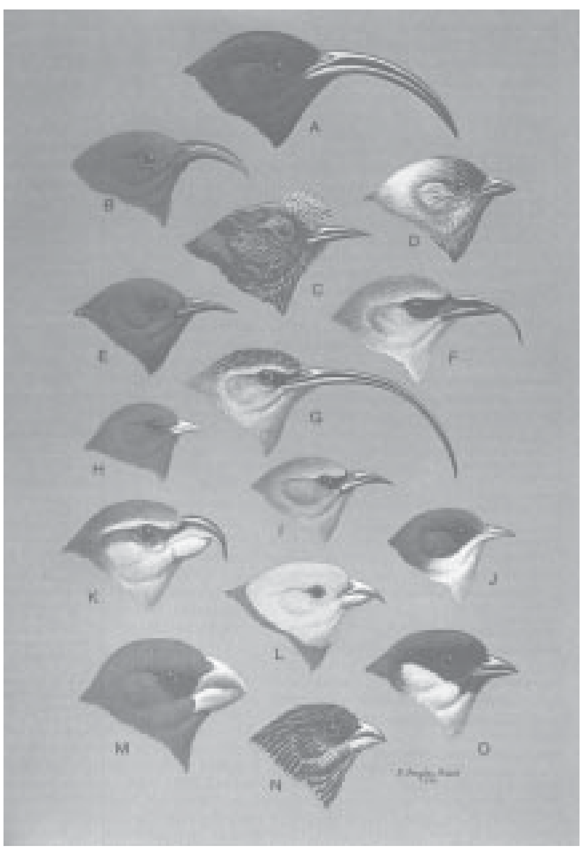
- Thought to have evolved from a single species of finch.
- Fifty-two species are thought to be part of the Hawaiian honeycreeper subfamily.

Eighteen species, known only from fossil record, were probably extinct by 1778.	35 percent
Twelve species have gone extinct since 1778.	23 percent
Fourteen surviving species are classified as endangered, some may already be extinct.	27 percent
Eight surviving species are not classified as endangered.	15 percent

In addition to uncovering evidence of bird extinctions, fossil research has helped to shed new light on the true extent of adaptive radiation in Hawaiian honeycreepers. From the single ancestral finch species, at least 52 honeycreeper species are known to have evolved. What caused this remarkable formation of new species?

Adaptive Radiation

Adaptive radiation is often thought of as being driven by the need or opportunity for plants or animals to live in habitats other than the ones to which they are best adapted. It is easy to see how such needs and opportunities could arise for birds arriving on the Hawaiian Islands from other parts of the world. The Hawaiian honeycreepers evolved into species with different primary food sources: nectar, hard seeds, soft fruit, and insects and larvae. Some honeycreeper species have diets made up of combinations of these food sources.



Variations in bill morphology of selected Hawaiian honeycreepers
(Illustration: H. Douglas Pratt, Jr.)

Their beak structure and even their leg and facial muscles reflect their diet and how they forage for food.

Some nectar-eating honeycreepers have beaks that are shaped to fit specific flowers. This is evidence of coevolution, in which honeycreepers and flowering plants evolved together, the birds feeding on the nectar and in turn spreading pollen from flower to flower. Birds and flowers evolved specialized relationships, of which the *'i'iwi* and Hawaiian lobeliad plants are an excellent example. The long, curved bill of the *'i'iwi* is perfectly suited to gathering nectar from the long, tubular, curved flowers of many lobeliad species.

Many factors are thought to have influenced adaptive radiation in Hawaiian honeycreepers, including the following:

Isolation and Dispersability

Populations of a bird species that remain isolated from each other can, over time, evolve into separate species. In general, birds can easily disperse from one place—or island— to another by flying. But the pattern of species and island-specific subspecies of honeycreepers suggests that some species were more likely to do so than were others.

Some scientists believe that insect-eating honeycreepers have a more reliable source of food than do species that feed on fruit or nectar. They hypothesize that "frugivorous" (fruit-eating) and "nectivorous" (nectar-feeding) birds are more likely to fly between islands looking for food in lean years. Because the "insectivores" (insect-feeders) had less reason to move around, they remained more isolated and developed into more species and subspecies.

Other scientists believe that there is not such a clear link between eating habits and interisland dispersal. Instead, they distinguish between common "generalists" such as the *'apapane* and *'amakihi* that are widespread across the islands on the one hand, and specialized seed eaters and nectivores on the other hand. Generalists are able to feed on a variety of food types. The more specialized eaters, some scientists maintain, would have been more likely to stay where their food source was and further evolve in that place. The generalists would have been more likely to fly from island to island.

Adaptation to Food Resources

Birds can rapidly adapt to new types of food or changes in the abundance of food sources. Over time, these adaptations (physical or behavioral changes) can result in the emergence of new species. In 1984 and 1985, studies of endangered Laysan finches that had been introduced in 1967 to Pearl and Hermes Reef, showed significant differences had already developed between the Pearl and Hermes finches and their ancestors on Laysan. The differences appeared to be a response to differences in food availability. If those differences turn out to be genetically linked, then evolutionary change had occurred among these birds in fewer than 20 generations.

Intraspecies Food Competition

Competition for food among members of the same species can lead to "adaptive shifts" or changes. Less competitive members of the species may shift to feeding on a different size or type of food, and over time this division of food can lead to bills that are specialized to this available food source.

ʻIʻiwi (Photo: Eric Nishibayashi)

Other Rain Forest Examples of Adaptive Radiation

- The Hawaiian *Drosophila* flies: Over 500 species of flies in the Drosophilidae family have been identified in Hawaiʻi, all of which evolved from a single common ancestor species. Nearly one-quarter of the known species in this family are found in Hawaiʻi, including many that are "narrowly endemic." That means that they occur in only a very small area.

- Hawaiian lobeliads: Six of seven genera of this group of plants are endemic to Hawaiʻi. The 98 species in the genera *Cyanea, Clermontia, Delissea,* and *Rollandia* are considered by many scientists to be the largest group of Hawaiian plants to have evolved from a single immigrant species.

Evolution is Not Over

Evolutionary changes in Hawaiian honeycreepers did not end at some time in the past. In fact, there is evidence that rapid evolutionary changes have occurred within the past 100 years, in response to human-induced extinctions and habitat changes. Given the fact that the honeycreepers evolved over *millions* of years, to measure significant changes in *one hundred* years indicates rapid natural selection.

Here is an example of such a rapid shift:

In the early 1990s, a group of biologists compared body measurements of live *ʻiʻiwi* with museum specimens collected prior to 1900 (Smith, et al., 1995). Early studies of the *ʻiʻiwi*—prior to 1900—reported that the long, curved flowers of Hawaiian lobeliads were this bird's preferred food. Now, however, *ʻiʻiwi* feed mainly on the open flowers of *ʻōhiʻa*, which do not have tubular, curved flowers.

What might have caused this change in diet? Researchers point to two factors. The first is that the lobeliads, once a prominent part of the understory of Hawaiian rain forests, are now rare. During the 20th century, habitat degradation and grazing by feral ungulates induced the extinction of 25 percent of Hawaiian lobeliad species. Most of the species that remain are rare or endangered. So the preferred food of the *ʻiʻiwi* is greatly reduced.

Researchers suggest the second factor influencing this dietary shift was the extinction of the *ʻōʻō*. The *ʻōʻō* was a Hawaiian honeyeater, another native Hawaiian bird not related to the honeycreepers. This bird was behaviorally dominant over the *ʻiʻiwi*, keeping the *ʻiʻiwi* from feeding heavily in the favored trees of the *ʻōʻō*: the *ʻōhiʻa*. By 1900, the *ʻōʻō* was extinct, and as the lobeliads declined over the course of the 1900s, the *ʻiʻiwi* shifted its foraging emphasis to *ʻōhiʻa* flowers.

Birds that feed most efficiently on *ʻōhiʻa* flowers, such as the *ʻapapane* and the *ʻākohekohe*, have short bills to exploit this food source. Researchers hypothesized that a shift in diet away from the long, tubular, curved lobeliad flowers to the open *ʻōhiʻa* flowers would have resulted in selective pressures which favored shorter bills over longer bills.

The biologists tested this hypothesis by comparing bill measurements and other body measurements of live *ʻiʻiwi* with museum specimens collected prior to the extinction of the *ʻōʻō*. Evaluating the data they collected, they found that the upper mandible (beak portion) became shorter, while overall body size stayed the same. The results of their analysis suggest "the longer billed birds, presumably due to lower feeding effiencies on *ʻōhiʻa,* were lost over time as selection favored shorter and possibly straighter bills."

As human-induced extinctions and declines of native species continue, the structure of Hawaiian natural communities is changing rapidly. These changes open the possibility for rapid evolutionary shifts, such as the one that appears to be happening with the *ʻiʻiwi*.

Ongoing Threats

Of the 22 known surviving species of Hawaiian honeycreepers, 14 are considered endangered, and some of these may already be extinct. What is contributing to this loss of species today?

- Habitat destruction: The Maui parrotbill is an illustrative example of the impact of habitat destruction. By the 1890s, it was already rare in the remaining *koa*-dominated rain forests. These *koa* forests were destroyed, largely by wildfires, browsing by introduced animals, and logging. Today, the parrotbill survives only in higher-elevation *ʻōhiʻa* forests, where it is an extremely rare bird.

- Avian malaria and other diseases: Like many Hawaiian honeycreepers, the rare *ʻākohekohe* is thought to be highly susceptible to avian malaria, a disease introduced early this century with nonnative birds. The disease is transmitted by a nonnative mosquito and is believed to prevent honeycreeper populations from surviving in lower-elevation forests. Mosquitos rarely occur above 1200 meters (3936 feet) elevation. Many native birds escape infection only while they remain in upper-elevation forests.

- Predation by cats, mongooses, and rats: These animals eat native bird eggs and chicks, and sometimes even adult birds, especially those tending their young.

These pressures are happening at a rapid rate, much more quickly than many bird species can adapt. The honeycreepers that are faring the best tend to be those that can adapt to a broad range of habitats. The most common honeycreepers on Maui and in Hawaiʻi are the *ʻapapane* and the *ʻamakihi*. Both of these birds range from the rain forests into upper-elevation shrublands and even into planted forests. As the *ʻiʻiwi* shows, however, rapid evolutionary shifts are possible, and that possibility—along with efforts at habitat protection, feral animal control, and research into avian diseases—may spell survival for some of the remaining Hawaiian honeycreeper species.

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Adaptive Radiation in Hawaiian Honeycreepers: Questions on the Reading

1) Define adaptive radiation, and explain its relationship to endemic species. Give one example of adaptive radiation in Hawaiian species other than honeycreepers.

2) Why are fossil records valuable sources of information to scientists studying the evolution of native bird species?

3) Is the shift in the size of *'i'iwi* bills over the last 100 years an example of adaptive radiation in action? Explain your answer.

4) Using what you have learned about evolution and adaptation, explain why extinctions of rain forest bird species have happened—and continue to occur—so rapidly in the face of human-caused changes to native Hawaiian rain forests.

Activity #3

Rain Forest Birds Research Projects

● ● ● Class Period One *Discussion and Research Topics*

Materials & Setup

For each student

- Student Page "Rain Forest Birds Research Projects: Topics and Resource List" (pp. 30-35)

Instructions

1) Students will be doing independent research projects on topics related to birds in Hawaiian rain forests, including the rain forest on Haleakalā. Brainstorm a list of topics or questions students find interesting. Students may select topics from that list or come up with another of their own choosing. Use the Student Page "Rain Forest Birds Research Projects: Topics and Resource List" in class to help spark students' thinking, or hand it out to students at the end of class.

2) You will need to set the parameters for these research projects, such as:
   - How long students will have to do their research;
   - When they will need to hand in a research plan, including the question they are researching and sources of information (this research plan will help keep their projects on track and enable you to help students target their efforts);
   - How students will present their findings (options include a research paper, class presentation, poster display, or multimedia presentation); and
   - How research and presentations will be evaluated.

Note

- Depending upon the needs of your students, you may need to schedule some class time to help students refine their research questions, identify more sources of information, or develop reports.

Assessment Tools

- Research plans
- Research reports or presentations

Rain Forest Birds Research Projects: Possible Topics and Resource List

There are many interesting research topics having to do with native birds in Hawaiian rain forests. This background sheet suggests a handful of topics for which information is readily available. Then it lists many written and internet resources for research, linking them with these topics. It also lists useful sources of general background information.

Possible Research Topics

1) **Basic biology and natural history of a particular family, genus, or species of birds**
   Several species and families of native Hawaiian birds have been thoroughly studied. You could select one or more species, a genus, or even the whole family of honeycreepers, and learn about them in depth. You may also learn about topics such as co-evolution, in which native plant and bird species evolved together with special adaptations that are beneficial to both.

2) **Human-caused changes: Habitat alteration and introduced species**
   From the time that Polynesians first settled on the Hawaiian Islands, people have been changing the environment in which native Hawaiian birds live. You could study how humans have changed bird habitat—or specific habitats such as the *koa* forest—and what has happened to native bird species as a result. Or you could study the threats that introduced species pose to native birds.

3) **Avian (bird) malaria as a threat to native bird species**
   Early in the 1900s, nonnative birds that carried a disease called avian malaria were brought to the Hawaiian Islands by people. Avian malaria is transmitted to native birds by a nonnative mosquito. You could learn more about this disease, how and why it threatens native birds, how it is spread, and the possible relationship between pig rooting, mosquito reproduction, and the spread of avian malaria. You could also explore why native birds seem to escape infection at elevations above 1200 meters (3936 feet), and how this might change because of global warming.

4) **Bird catching and hunting and the cultural significance of birds in traditional Hawaiian society**
   In Hawaiian society, birds were hunted and captured for a variety of reasons, including as a source of food and feathers. Bird catchers played an important role in this culture. You could learn more about how and why Hawaiians caught birds, which species were prized, and what is known about the effects of bird hunting and catching on populations of native birds. You could also learn about the cultural significance of different bird species to native Hawaiians.

5) Extinction of Hawaiian bird species

Throughout the Pacific Islands, it is estimated that more than 2000 species of land birds became extinct after human settlement. You could learn more about what scientists know about extinct native birds based on historical records and the recovery of partially fossilized bird remains from sand dunes, lava tubes, caves, and sinkholes. You could also explore causes of extinction and why native Hawaiian birds were so susceptible to the pressures that came along with human settlement of the islands.

6) Efforts to protect or revive threatened and endangered native bird species

Today, there are many efforts to protect native bird species that are in danger of extinction. You could learn about how species are classified as threatened or endangered, which Hawaiian species are so classified, and what is being done to protect one or more of these species.

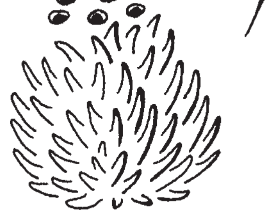
Resources for Research: A Beginning List

Sources of Information (Print)	General Information	Bird Biology and Natural History	Human-cause changes	Avian malaria	Bird catching & cultural significance	Extinction	Protecting bird species
Berger, A. J. , *Hawaiian Birdlife*, 2nd ed., University of Hawai'i Press, Honolulu, 1981. This is an extensive resource; common Maui birds are covered on pp. 127-170.	•	•	•	•	•	•	•
Berger, A. J. , *Bird Life in Hawai'i*, Island Heritage Publishing. Aiea, Hawai'i, 1996. This book gives a one- to two-page description and color drawing for each bird and discusses habitat alteration and non-native birds on pp. 7-8, 42-70.		•	•		•	•	
Carlquist, Sherwin, *Hawai'i, A Natural History*, Pacific Tropical Botanical Garden, Kaua'i, Hawai'i, 1980. In chapter 11 (p. 190-212) a section on the honeycreepers and other birds covers life history, diet, nest descriptions, threats such as avian malaria, and sketches.		•					
Hawai'i Audubon Society, *Hawai'i's Birds*, Hawai'i Audubon Society, Honolulu, 1997. For each bird species there is a one- to two-page description about the bird's distribution, description, voice, and habits. The introduction talks about dispersal to the Hawaiian Islands, evolution, extinction, and other notes.	•	•			•		
Juvik, S. P., and J. O. Juvik (eds.), *Atlas of Hawai'i*. 3 rd ed., University of Hawai'i Press, Honolulu, 1998. "Birds" section by Sheila Conant (pp. 130-134) includes basic background, an insert on extinction, a discussion of honeycreepers and adaptation to food sources, and an overview of human impacts (avian malaria, non-native organisms). "Alien Species and Threats to Native Ecology" section by F. R. Warshauer (pp. 146-149) provides an overview of species introductions, including a look at the rate of introduction, types of organisms, and impact. "Biogeography" section by J. O. Juvik (pp. 103-106) provides an overview of means of dispersal of land plants and animals to Hawai'i.	•		•	•		•	
Medeiros, A. C., and L. L. Loope, *Rare Animals and Plants of Haleakala National Park*, Hawai'i Natural History Association, Hawai'i National Park, Hawai'i, 1994. Overview about birds in Hawai'i includes rare birds found in Haleakalā National Park, extinctions, and adaptive radiation. Provides specific information on three birds in the rain forest: the crested honeycreeper, parrotbill, and *nukupu'u*.	•	•				•	

Sources of Information (Print)	General Information	Bird Biology and Natural History	Human-cause changes	Avian malaria	Bird catching & cultural significance	Extinction	Protecting bird species
Stone, C. P., and L. W. Pratt, *Hawai'i's Plants and Animals: Biological Sketches of Hawai'i Volcanoes National Park*, University of Hawai'i Press, Honolulu, 1994. For the common forest birds, this book gives one to two pages of information including life history, description, distribution, value to Hawaiians, current threats, and drawings. Addresses avian malaria on pp. 214-215, 271.		•		•	•	•	•
Kepler, A. K. , *Hawaiian Heritage Plants*, Oriental Publishing Co., Honolulu, 1984. Discusses lobelias and bird catching, pp. 80-83; bird catching, chants, feather capes, pp. 107-111; *'elepaio* pp. 69-73; and *palila* pp. 86-88					•		
Pukui, M. K., and S. H. Elbert, *Hawaiian Dictionary*, University of Hawai'i Press, Honolulu, 1986. Definitions of different types of bird catchers and methods used: *kau manu, kia manu, kapili manu, kono manu, la au kia*					•		
Kamehameha Schools Bernice Pauahi Bishop Estate, *Life in Early Hawai'i: The Ahupua'a*, 3rd ed., Kamehameha Schools Press, Honolulu, 1994. Bird catching is addressed on pp. 16, 28, 43.					•		
Kepler, C. B., and A. K. Kepler, *Haleakala: A Guide to the Mountain*, Mutual Publishing, Honolulu, 1988. Common birds seen at Hosmer Grove, pictures & brief descriptions, pp. 33-34		•					
Freed, L. A., S. Conant and R. C. Fleisher, "Evolutionary Ecology and Radiation of Hawaiian Passerine Birds," in Kay, E. A. (ed.), *A Natural History of the Hawaiian Islands, Selected Readings II*, University of Hawai'i Press. Honolulu, 1994, pp. 335-345. This is a summary of research and findings on adaptive radiation in Hawaiian passerine birds, focusing on Hawaiian honeycreepers.	•	•					
Attenborough, D., *The Life of Birds*, BBC Books, London, England, 1998. This is a general reference book on bird behaviors and biology, including flightlessness, feeding, mating and rearing young. Although not specific to Hawaiian species, this book provides background, context and examples from all over the world.	•						

Sources of Information (Internet)	General Information	Bird Biology and Natural History	Human-cause changes	Avian malaria	Bird catching & cultural significance	Extinction	Protecting bird species
U.S. Geological Survey, "Status and Trends of the Nation's Biological Resources: Hawai'i and the Pacific Islands" at <biology.usgs.gov/s+t/SNT/noframe/pi179.htm>.	•	•	•	•		•	
U.S. Geological Survey, "Hawaii's Environment Benefits from Geographic Isolation" at <hvo.wr.usgs.gov/volcanowatch/1999/99_03_18.html>.				•			
"Hawaii's Endangered Species" at <naalehuel.k12.hi.us > Student pages include a site about endangered species created by students.		•		•		•	•
U.S. Fish and Wildlife Service, "Threatened and Endangered Species" at <pacificislands.fws.gov/wesa/endspindex.html>. Site about threatened and endangered species in the Pacific, including Hawaiian plants and animals	•	•				•	•
"Researchers at Zoo Work to Save Hawaiian Birds from Extinction," (*Molecular Genetics: Research Reports* No. 93, Summer 1998) at <www.si.edu/researchreports/9893/birds.htm>.	•		•	•			
"Searching for Hope in the Family Tree," (*National Wildlife*, April/May 1998) at <www.nwf.org/natlwild/1998/honey.html>.				•			
Hawai'i Biological Survey at <hbs.bishopmuseum.org/hbsl-navbar-0.html>. Includes information about endangered and threatened species						•	
Bryant, Peter J., "Islands, Chapter 12 in Biodiversity and Conservation, A Hypertext Book" at <darwin.bio.uci.edu/~sustain/bio65/lec12/b65lec12.htm# Diseases>.	•		•			•	
"Extinction and Biodiversity" at <www.teaching-biomed.man.ac.uk/bs1999/bs146/biodiversity/Extinction.html>. Not Hawai'i or bird-specific	•					•	
Hawai'i Natural Heritage Program at <www.abi.org/nhpl/us/hi/iiwi.htm> (*'i'iwi* life history) < www.abi.org/nhpl/us/hi/pbill.htm> (Maui parrotbill life history)		•					

Sources of Information (Internet)	General Information	Bird Biology and Natural History	Human-cause changes	Avian malaria	Bird catching & cultural significance	Extinction	Protecting bird species
Smithsonian Institution, "*'I'iwi* Life History" at <www.si.edu/organiza/museums/zoo/zooview/exhibits/birdhs/iiwi.htm>.		•					
"Hawaii's Endemic Birds" at <biology.usgs.gov/s+t/noframe/t018.htm>.	•	•	•	•		•	•
"National Geographic On-Line Index" at <www.nationalgeographic.com/publications/explore.html>.	•						

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 ʻĀINA" 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 *hāpuʻu*) 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 intro-duced 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 *'ōhi'a (Metrosideros polymorpha)* also occur in bogs. Within the bog, shrubs such as *'ōhelo* (*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 Kaua'i, O'ahu, Moloka'i, Hawai'i 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 Pu'u 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

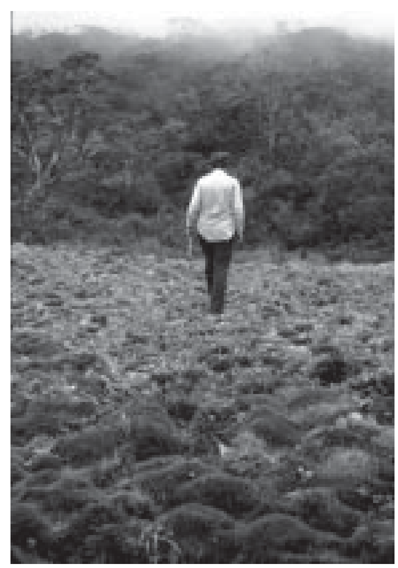
Bog plants are adapted to a unique set of environmental conditions. The montane bogs in the Hāna rain forest are located in an extremely wet area. Clouds cover the bogs almost continually, precipitation is high, and drainage is poor. Here are some other features of the bog environment:

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.

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)

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.

'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.

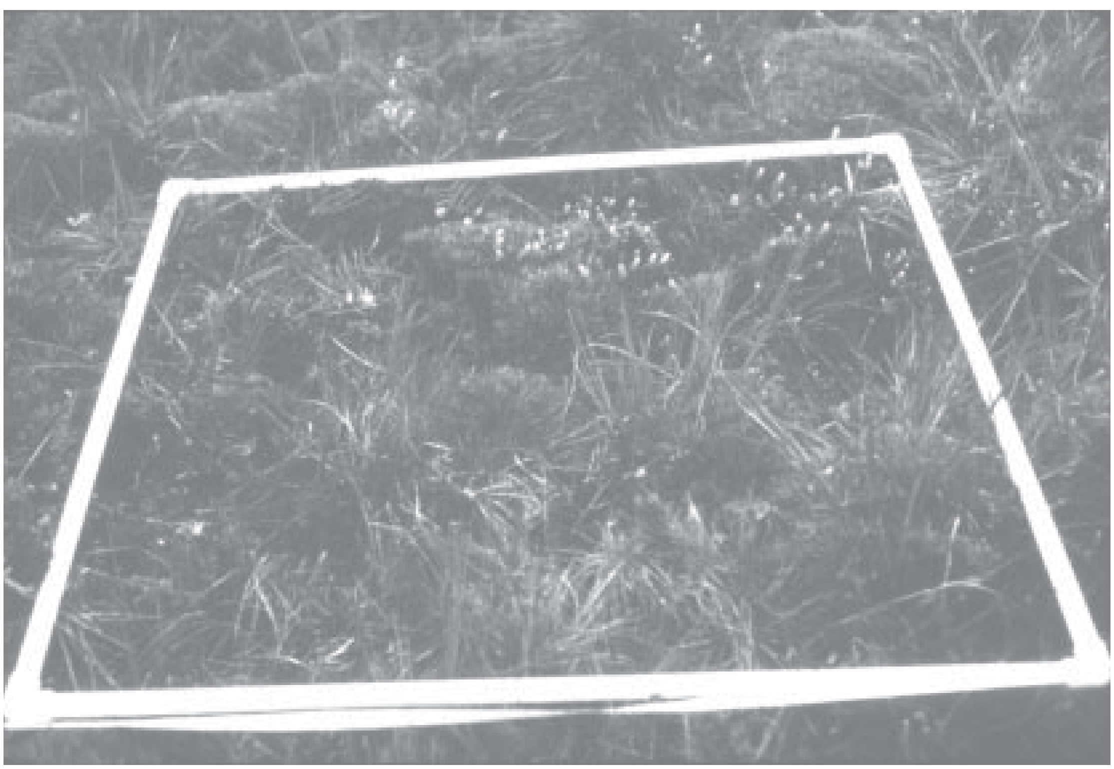
3) Analyzing data

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

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 areCgroundRdeadCvegetation	%g	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

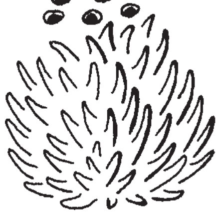
Plot #:

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

Rain Forest Unit 5

Weed Warriors



Overview

Invasive plants are a top concern of resource managers on Maui and the other Hawaiian Islands. The islands are highly vulnerable to invasion by nonnative (sometimes called "alien") plants and animals because native island species have evolved in isolation from pressures routinely encountered by plants and animals on continents. The Hawaiian Islands currently have more than 10,000 introduced plant species, most of which grow only in cultivation. Over 1000 of these introduced plants now have reproducing populations in the wild. At least 100 of these nonnative plant species are considered by scientists and resource managers to pose a threat to native Hawaiian ecosystems because of their potential to displace native species and modify the ecosystem.

But some people see certain nonnative plants in a different light than do resource managers. In this unit, students explore the role of values and perspectives in making decisions involving nonnative plant species. They also learn about why some introduced plants are invasive while others are not and apply that knowledge in a management scenario.

Length of Entire Unit

Five and one-half class periods

Unit Focus Questions

1) What are some different values and perspectives that people hold about nonnative plant species?

2) How do values and perspectives influence decisions about nonnative plant species?

3) What characteristics make some plant species invasive?

4) What threats do invasive plant species pose to native ecosystems?

5) What are some of the invasive plants of most concern to resource managers on East Maui?

6) How can resource managers set priorities for invasive plant management?

Unit at a Glance

Activity #1
Kāhili Ginger Values and Perspectives

Students role-play different perspectives about a nonnative plant species and a proposal to ban the propagation and sale of this plant in Hawai‘i. They explore different types of values and consider how those values might affect people's decisions and actions.

Length
Two class periods

Prerequisite Activity
None

Objectives
- Recognize that different perspectives exist and affect the way people think about nonnative species in Hawai‘i.
- Identify and articulate several perspectives about nonnative species in Hawai‘i.
- Communicate persuasively about a perspective.
- Differentiate among intrinsic and instrumental value.
- Articulate and examine personal perspectives.

DOE Grades 9-12 Science Standards and Benchmarks
LIVING THE VALUES, ATTITUDES, AND COMMITMENTS OF THE INQUIRING MIND: Students apply the values, attitudes, and commitments characteristics of an inquiring mind.
- OBJECTIVITY: Evaluate various perspectives and their implications before drawing conclusions.

Activity #2
What Makes a Plant Invasive?

Students learn about invasive plant characteristics and how those characteristics influence management decisions by completing homework reading, questions, and a class discussion.

Length
One and one-half class periods

Prerequisite Activity
None

Objectives
- Identify six invasive nonnative plant species of concern to Maui resource managers.
- Identify and explain factors that influence the invasiveness of nonnative plant species.
- Assess the implications of invasiveness characteristics on management approaches.

DOE Grades 9-12 Science Standards and Benchmarks
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.

LIVING THE VALUES, ATTITUDES, AND COMMITMENTS OF THE INQUIRING MIND: Students apply the values, attitudes, and commitments characteristics of an inquiring mind.
- CRITICAL-MINDEDNESS: Evaluate the logic and validity of evidence, conclusions, and explanations against current scientific knowledge.

Activity #3

Managing Invasives on Survivor Island

Students apply knowledge and information about invasive plants to a management scenario.

Length
Two class periods

Prerequisite Activity
Activity #2 “What Makes a Plant Invasive?”

Objectives
- Use critical reasoning skills to prioritize control activities in a hypothetical management scenario.

DOE Grades 9-12 Science Standards and Benchmarks
LIVING THE VALUES, ATTITUDES, AND COMMITMENTS OF THE INQUIRING MIND: Students apply the values, attitudes, and commitments characteristic of an inquiring mind.
- OPEN-MINDEDNESS: When appropriate, modify ideas, explanations, and hypotheses, based on empirical data or evidence

RELATING THE NATURE OF TECHNOLOGY TO SCIENCE: Students use the problem-solving process to address current issues involving human adaptation in the environment.
- Evaluate alternative solutions for effectiveness based on appropriate criteria.

Enrichment Ideas

- Research efforts among members of the East Maui Watershed Partnership to control invasive plants. The partnership is a collaborative effort among six public and private landowners and Maui County to protect the 100,000-acre rain forest core of this critical watershed. Online information about the partnership can be found at <ice.ucdavis.edu/~robyn/mauimgt.html>. Students may also want to contact the major partners directly: The Nature Conservancy, East Maui Irrigation Company, Hawai‘i Department of Land and Natural Resources, National Park Service, Haleakalā Ranch, Hāna Ranch, and Maui County.

- Conduct library and Internet research on the six invasive nonnative species highlighted in this unit (Activities #2 and #3) to find additional biological information or control strategies that would assist in developing management priorities.

- Research existing public education and awareness campaigns about invasive nonnative species. Design a program, poster, or educational flyer for a species that is not covered in existing educational efforts or make suggestions for improving current campaigns.

- Participate in volunteer efforts to control invasive nonnative plants in the rain forest. (See field trip notes in unit introduction for ideas.)

- Research the efforts of the Maui Invasive Species Committee (MISC) to prevent and control invasive nonnative plant and animal species on the island. Find beginning information about MISC at <www.hear.org>.

Resources for Further Reading and Research

Hawai‘i Ecosystems at Risk at <www.hear.org>.
This site is a central repository of information about invasive nonnative plants and nonnative animals in Hawai‘i, including links to databases and other sites. It includes information about the Maui Invasive Species Committee, Coordinating Group on Alien Pest Species, and other state, national, and regional groups concerned with invasive species.

Moanalua Gardens Foundation, *Forest Treasures* (CD-ROM), Moanalua Gardens Foundation, Honolulu, 2001.
CD-ROM includes images of several invasive nonnative plants, as well as tools for students to create multimedia presentations.

Smith, Clifford W., “Impact of Alien Plants on Hawai‘i’s Native Biota” at <www.botany.hawaii.edu/faculty/cw_smith/>.
This article describes nonnative plants in Hawai‘i and the impacts associated with them, as well as strategies to ameliorate problems.

Stone, Charles P., Clifford W. Smith, and J. Timothy Tunison, *Alien Plant Invasions in Native Ecosystems of Hawai‘i: Management and Research*, University of Hawai‘i Cooperative National Park Resources Studies Unit, Honolulu, 1992.

Activity #1

Kāhili Ginger Values and Perspectives

● ● ● **Class Period One** Kāhili *Ginger Perspectives*

Materials & Setup

- One copy of the "Perspectives" acetates (master, pp. 8-9)
- Overhead projector and screen

For each group of three to four students

- *One* perspective card from "*Kāhili* Ginger Perspectives" (master, pp. 10-11)
  Be sure that at least one group has each of the four perspective cards. More than one group may have each perspective.

For each student

- Student Page "*Kāhili* Ginger Information Sheet" (p. 12)
- Student Page "What's Your Perspective?" (pp. 13-14)

Instructions

1) Show the whitetip reef shark acetate to the class. Engage students in a brief discussion:
   - Ask:
     "What is this?"
     "What's your reaction to it?"
     "What would your reaction be if you were snorkeling or diving and you saw one?"
   - Observe: Different people have different *perspectives* about sharks. Some people think they're neat, some think they're scary, some are so fascinated that they spend their whole lives studying them, some want to kill them, and some think they should be left alive.

2) Ask students for ideas about what can change people's perspectives. Write a list on the board or overhead. Here are some ideas to insert:
   - Perspectives can vary in different situations,
   - Having more information can sometimes change a person's perspective, and
   - Listening to other people's point of view can change our opinion, bring up questions we may not have thought of before, or give us a broader perspective. People who speak especially passionately or articulately may be able to change the way other people think or feel about a topic because of their strong beliefs, ability to speak convincingly, or well-constructed arguments.

3) Show the *kāhili* ginger acetate to the class, showing only the photo and covering up the printing at the bottom of the page. Ask, "What is this?" Make sure everyone knows it's *kāhili* ginger, but do not go into more detail.

4) Divide the class into groups of three to four. Give each student a copy of the Student Page "*Kāhili* Ginger Information Sheet" and each group *one* of the perspective cards from "*Kāhili* Ginger Perspectives."

5) Uncover the bottom of the *kāhili* ginger acetate, so students can read the proposal. Each group's assignment is to develop a short, compelling, persuasive response to that proposal, from the perspective given on its role card.

6) Give groups 15-20 minutes to develop their responses. Then ask a spokesperson from each group to present the group's response, making it as dramatic, full of feeling, and persuasive as possible.

7) If there is time at the end of class, discuss with students how well they were able to take on another person's perspective. Did they agree or disagree with the perspective they had to work with? Which of the group responses seemed most compelling? Why?

8) As homework, assign the Student Page "What's Your Perspective?"

● ● ● Class Period Two *Values and Perspectives*

Instructions

1) Ask students to define the word "values." Values are commonly defined as things (such as principles or qualities) that have inherent worth or desirability. Ask students to come up with some examples of values and write them on the board or overhead. Some examples of Hawaiian values include *mālama* (caring), *laulima* (working together), *ho'omanawanui* (patience), *'ohana* (family), and *lokomaika'i* (generosity).

   If students have difficulty generating a list of values, ask a few students to volunteer to tell the class something that's really important to them. If it doesn't seem basic enough to be a value, ask the student why that's important, and keep asking the question until you get to the level of basic values.

2) Tell students that there is a different but related way of using the concept of value. Write the phrases "intrinsic value" and "instrumental value" on the board or overhead. Briefly discuss what the terms mean by first asking students for their ideas. Then bring in the following definitions and write some examples on the board or overhead:

   Intrinsic value — Worth or desirability that is ascribed to something simply because it exists. This type of value is also known as "existence value." Intrinsic value systems include spiritual and aesthetic perspectives.

   Instrumental value — Worth or desirability that is ascribed to something because of what it can do for people (or a person). Instrumental value systems include cultural, ecological, economic, educational, personal, legal or recreational perspectives.

3) Brainstorm some examples of how these different types of values would affect someone's actions or preferences. For example, someone who saw a fish as having intrinsic value might prefer to leave the fish living in the ocean. Someone who saw the fish as having primarily instrumental value might prefer to catch it and eat it.

4) Ask for a show of hands from students who believe Hawai‘i should enact a law banning the propagation, sale, and distribution of *kāhili* ginger. Then ask for a show of hands from those who disagree. Finally, ask for students who aren't sure to raise their hands.

5) Have students divide into three groups: those who support the law, those who oppose the law, and those who aren't sure. If no students raised their hands for one group, then have only two groups. Give groups 15 minutes to identify and make a list of the beliefs and values that underlie their positions.

6) Now have the three groups reassemble. Have a spokesperson from each group read the list of beliefs and values. After each list is read, discuss the types of values (intrinsic and instrumental) and the value systems (e.g., aesthetic, cultural, economic) that each group expressed.

7) Wrap up the class by asking students to discuss the importance of values in decision making. Did the values of the three groups seem similar or different? If they seem different, do students think that explains the different positions of each group? If they seem similar, what else do students think could explain the differences among the groups' positions?

Journal Ideas

- Think of an important decision you've made and discuss why you decided the way you did. What values influenced your decision? Did anyone try to get you to change your mind? Did it work? Why or why not?
- Discuss how protecting native rain forests could be important to someone who ascribes primarily intrinsic value to the forest *and* by someone who ascribes primarily instrumental value to the forest.
- Do you think the fact that a nonnative plant such as *kāhili* ginger has been given a Hawaiian name changes people's perspective about the plant? Why or why not?
- Can the value of *kāhili* ginger be weighed against the value of intact native rain forests? How would you compare or evaluate the two? Why?

Assessment Tools

- Student Page "What's Your Perspective?": Evaluate on the basis of the quality of student reasoning and articulation.
- Participation in class discussions and group work
- Journal entries

Perspectives Acetates

#1 Whitetip Reef Shark or *Manōlālākea*

(Triaenodon obesus)

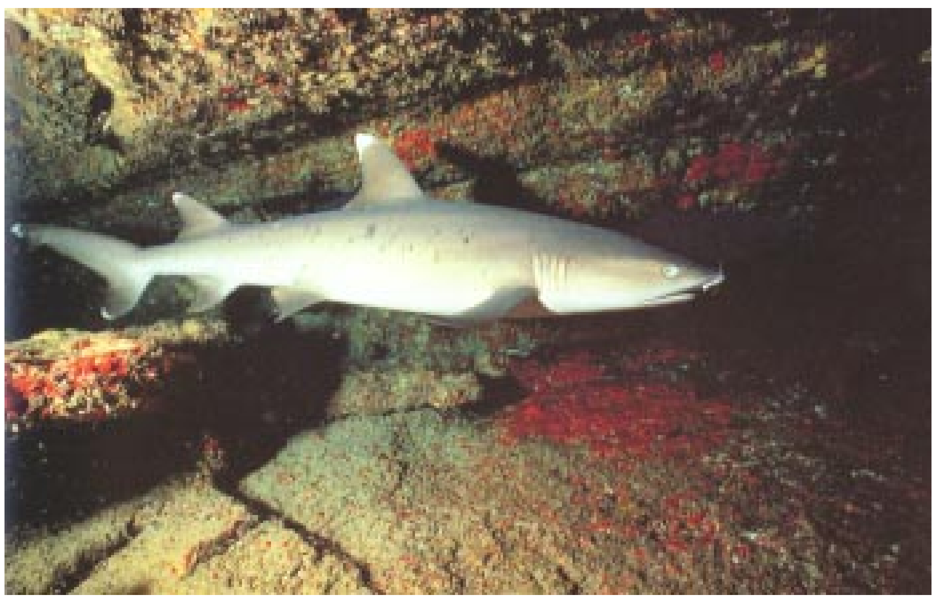


Photo: David R. Schrichte in John Hoover,
Hawaii's Fishes*, Mutual Publishing*

#2 *Kāhili* Ginger

(Hedychium gardnerianum)

Photo: The Nature Conservancy

In New Zealand, *kāhili* ginger is a locally common plant often seen along river bottoms and valley floors. This nonnative species has started to appear in New Zealand's native forests and is predicted to pose a significant threat to many of New Zealand's native forest ecosystems, as well as areas recovering from disturbances such as logging. This species forms vast colonies, choking out native vegetation almost completely and preventing growth of new trees, shrubs, and forest floor plants. *Kāhili* ginger may permanently displace rare plants or cause serious losses to populations of uncommon plants and entire natural communities. To guard against this possibility, New Zealand law prohibits the propagation, sale, and distribution of *kāhili* ginger.

Should Hawai'i adopt a similar law? Why or why not?

Using the information on the "*Kāhili* Ginger Information Sheet" as well as your group's perspective card, develop a compelling, persuasive answer to this question.

Kāhili Ginger Perspectives

Cut along dashed lines

Perspective #1
Nursery Owner

Your nursery grows *kāhili* ginger and sells it to landscapers and home gardeners. Other nurseries and mail order catalogs sell this plant, and if your customers couldn't buy it from you, they'd get it somewhere else. People love this plant because of its fragrant and beautiful flowers. *Kāhili* ginger is the showiest of all of the ginger varieties, with giant flower heads of brilliant yellow flowers with protruding dark orange stigmas (flower parts that receive pollen grains) that give the flowers a dramatic look.

People like how easy these plants are to grow. Once they've become established, *kāhili* ginger plants easily spread throughout an area and require little weeding because the hearty, dense ginger growth crowds out other plants. *Kāhili* ginger helps prevent erosion and its deep green leaves form an attractive planting even when the flowers are not in bloom.

Perspective #2
Hiker

You love to walk in the forest, and your favorite time of year is August and September, when the *kāhili* ginger is in bloom. The yellow flower heads blooming along the trail fill the air with a sweet, sharp, unique fragrance. On your way out of the forest, you love to pick a few flowering stalks to take home with you. The delicate flowers don't last long, but that's a good excuse to go for another hike to pick more! The ginger fruits also provide food for birds, which you love to watch along your hikes.

Although it is not native to Hawai'i, you appreciate this plant's interesting connection to Hawaiian culture. It is named for the *kāhili*, the feathered standard that symbolized Hawaiian royalty. On its stout stalk, the flower head looks like the feathered head of the *kāhili*.

Cut along dashed lines

Perspective #3
Natural Preserve Manager

Your job is to preserve the native Hawaiian rain forest. Nonnative plant species like *kāhili* ginger make that job difficult and expensive. *Kāhili* ginger is an "invasive" plant, which means that it grows quickly and reproduces rapidly, aggressively taking over new areas and outcompeting other plants for light, water, and nutrients. That's bad news for native plants, many of which are important in traditional Hawaiian culture. Especially threatened are the rare plants that are found only in Hawaiʻi and the native animals that depend on these plants.

Eradicating ginger in an area is a labor-intensive and expensive task that requires systematic attention. Young seedlings may be pulled out, but larger, established plants must be uprooted. Large clumps can be eliminated only by cutting down the vegetation with a cane knife and then applying herbicide to the cut surface of the rhizome. These sites must be monitored for regrowth, and all of the areas of the preserve that are likely habitat for ginger must be patrolled regularly to detect new populations established by birds or rats dispersing seeds that may come from cultivated ginger around homes and businesses.

Perspective #4
Native Insect Researcher

Your studies of native *Drosophila* flies are adding to the scientific community's understanding of evolution and island ecology. You estimate that over 800 species of flies in the family Drosophilidae have evolved here on the Hawaiian Islands over about 70 million years, all of them the descendants of just one or two ancestral species. Because they are a prime example of adaptive radiation and because their behavior and its connection to evolution is relatively easy to study, these flies are a resource of international importance.

Many of these 800 species are found only in tiny patches of habitat offering specific foods and mating sites. Since their habitat is so small, these species can easily be reduced to small numbers or eliminated by anything that degrades the forest, including invasion by aggressive plants such as *kāhili* ginger, which can completely displace all native plants in the understory. From discussions with your colleagues, you know that other researchers share your concern over the potential for *kāhili* ginger and other invasive plants to destroy critical habitat for other unique Hawaiian species.

Kāhili Ginger Information Sheet

Kāhili Ginger

Hedychium gardnerianum, Family Zingiberaceae
Native to India, Himalayan region
Introduced to the Hawaiian Islands as an ornamental plant

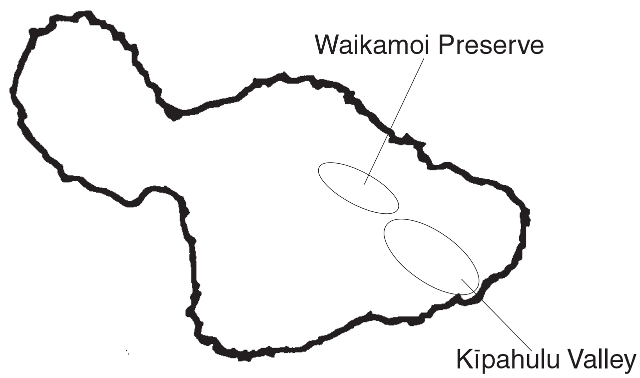
Description

This is a large, showy ginger that can reach heights of up to six feet. It bears large heads of fragrant, bright golden-yellow and red flowers. The flower head turns into a cluster of large, fleshy, bright orange-red fruits. The fruits split open exposing bright red seeds that are very attractive to birds.

Growth Habit

Grows in dense clusters that spread by runners that extend from the base of the plant and sprout new plants

Distribution on East Maui



Kāhili ginger is grown in home gardens and landscape plantings, especially in cool, moist, sunny to partially shaded areas. It also has spread beyond cultivated areas and is now found in protected rain forest areas such as Waikamoi Preserve (managed by The Nature Conservancy) and Kīpahulu Valley (a part of Haleakalā National Park). *Kāhili* ginger is also found in Koʻolau Gap between 600-900 meters (1968-2932 feet) elevation and has displaced thousands of acres of native rain forest in the East Maui watershed. (Distribution is not fully known because only small areas of the Haleakalā rain forest are being actively managed and monitored for the presence of ginger.)

How Spread

Kāhili ginger may be intentionally propagated by transplanting "rhizomes" (thickened, underground plant stems that produce shoots above and roots below). Rhizomes that are dug up can also resprout—for example, in compost piles—if they are not dried and thoroughly burned. *Kāhili* ginger can also be dispersed, sometimes long distances, by birds that eat the fruits and excrete the seeds or carry them to other parts of the forest. Fruits of streamside plants can be carried downstream by running water.

Potential Effects on Native Forests

Because of its bird-dispersed seeds, *kāhili* ginger is capable of spreading to remote forests. Once established, this ginger may spread by growth of its rhizome mass. In time, this species may completely dominate the ground cover and shrub layer of invaded forests, replacing the natural understory plants and preventing the growth of young native trees.

What's Your Perspective?

1) Think back to the class activity. Can you identify any perspectives about banning or not banning *kāhili* ginger that were not presented during the activity? If so, what are they?

2) What is *your* perspective on the question your group worked on during class? Here is that question again:

In New Zealand, *kāhili* ginger is a locally common plant often seen along river bottoms and valley floors. This nonnative species has started to appear in New Zealand's native forests and is predicted to pose a significant threat to many of New Zealand's native forest ecosystems, as well as areas recovering from disturbances such as logging. This species forms vast colonies, choking out native vegetation almost completely and preventing growth of new trees, shrubs, and forest floor plants. *Kāhili* ginger may permanently displace rare plants or cause serious losses to populations of uncommon plants and entire natural communities. To guard against this possibility, New Zealand law prohibits the propagation, sale, and distribution of *kāhili* ginger.

Should Hawaiʻi adopt a similar law? Why or why not?

3) What is your opinion based on? What intrinsic and instrumental values are involved in your opinion?

4) Should companies that sell nonnative plants in Hawai‘i be required to provide information to customers about their potential effects on native ecosystems? Why or why not? Would it make any difference whether the plants are potentially invasive (capable of spreading out of cultivation and disrupting native ecosystems)? Why or why not?

5) Some companies sell plants through the Internet or mail order catalogs, shipping them around the world from a central nursery instead of through locally based nurseries. If companies selling nonnative plants in Hawai‘i were required to provide information about their potential effects on native ecosystems to customers, how could this be set up and enforced for nurseries that do business over the Internet?

Activity #2

What Makes a Plant Invasive?

● ● ● In Advance *Collecting Weeds*

- Have students bring to class examples of plants they think of as weeds. Challenge students to look for plants that seem particularly invasive (capable of rapidly taking over large areas and inhibiting the growth of other plants).

● ● ● Class Period One *Characteristics of Invaders*

Materials & Setup

For each student

- Student Page "Invasive Plants in Hawaiʻi" (pp. 22-30)
- Student Page "Invasive Plants in Hawaiʻi: Questions on the Reading" (pp. 31-34)

Instructions

1) Have students display their plants in front of the class. As the class observes the plants, ask whether there seem to be any similarities among them. (If they need ideas, prompt students to look at characteristics such as leaf size, flower size and structure, the form in which plants grow, root shape and size, and so forth.)

2) Divide the class into groups of four to five students. Tell students that there are eleven characteristics that make some plants highly successful invaders. Have student teams work together to identify as many of these as they can, using the plants on display for ideas. Each group should make a list of the characteristics it identifies and explain their reasoning for each one.

3) Now tell students that there are seven main "dispersal mechanisms" that spread invasive plants into the Haleakalā rain forest. A dispersal mechanism is a means by which plant seeds are spread around, which enables the plant to become established in a new area. Challenge student teams to think of as many of the seven dispersal mechanisms as they can, write down their ideas, and explain their reasoning.

4) Give each student a copy of the Student Page "Invasive Plants in Hawaiʻi." Have students read pages 22-25, stopping before the subsection entitled "Six Invaders of Concern." When students have finished reading, have groups go back to their lists and use the information in the reading to determine the characteristics and dispersal mechanisms they missed. Groups should note these on their lists and place check marks by the ones they identified correctly.

5) As a class, discuss the similarities and differences between student lists and the ones given in the reading.

6) As homework, assign the rest of the Student Page "Invasive Plants in Hawaiʻi" as well as "Invasive Plants in Hawaiʻi: Questions on the Reading."

● ● ● Class Period Two *Invasives Identification Quiz*

Materials & Setup

- "Correct Responses for Invasive Plant Identification Quiz" acetate (master, p. 21)
- Overhead projector and screen

For each student

- Student Page "Invasive Plant Identification Quiz" (pp. 35-36)

Instructions

1) Hand out the Student Page "Invasive Plant Identification Quiz," and have students complete it.

2) Go over correct answers, using the acetate of correct responses. Discuss student questions.

3) Optional: Discuss the homework assignment with the class, using the questions on the Student Page "Invasive Plants in Hawai'i: Questions on the Reading" as a guide.

Journal Ideas

- How would you define a "weed"? Does invasiveness potential have anything to do with your definition? How about whether the plant is native?
- When talking about nonnative plants in Hawai'i, people often distinguish between "Polynesian introductions" brought here by early Polynesian settlers, and nonnative plants that were introduced later, after European contact. Does this division make sense to you? Why or why not?

Assessment Tools

- Participation in group work and class discussion
- Student Page "Invasive Plants in Hawai'i: Questions on the Reading" (teacher version, pp. 17-20)
- Student Page "Invasive Plant Identification Quiz" (teacher version, p. 21)
- Journal entries

Teacher Version

Invasive Plants in Hawai'i: Questions on the Reading

1) From the reading, select three of the characteristics that invasive plants may possess, and explain why each one could give these plants an advantage over native plants.

Characteristic	Advantage
• Quick growth to reproductive maturity	Rapidly maturing plants would start producing seed or reproducing vegetatively more quickly than slower native species, thus adding more plants to their populations more quickly.
• Profuse reproduction by seeds and/or vegetative structures such as root runners	Crowding out more slowly reproducing native plants
• Long seed life in the soil	The ability to build up a massive number of seeds in the soil from which new plants can continuously sprout puts native plants with shorter-lived seeds at a disadvantage.
• Seeds that can lie dormant through unfavorable conditions and sprout when conditions are ideal for rapid growth	Dormancy adds to the number of seeds in the soil from which new plants may sprout under favorable conditions. Not sprouting during unfavorable conditions means that these plants may have a reduced risk of seedling mortality compared to native plants that do not have this characteristic.
• Seeds that are adapted to be easily spread by wind, animals, water, and/or humans	The ability to establish new populations in areas that are not directly adjacent to existing ones may give invasive plants an edge in colonizing new areas.
• Production of "biological toxins," substances that suppress the growth of other plants	A form of direct competition which may suppress the growth of nearby native plants
• Spines, thorns, and other structures that cause physical injury and repel animals	Most native Hawaiian plants have evolved without these mechanisms which can be an important protection against introduced predators such as goats, pigs, and cattle.

Characteristic	Advantage
• The ability to "parasitize" or live on other plants.	Parasitic plants can weaken native plants by using nutrients and energy from the host plant.
• Roots or "rhizomes" (underground plant stems that sprout roots below and plant stems above) containing large food reserves	Large food reserves may enable invasive plants to survive longer through drought and other adverse environmental conditions than native plants.
• Survival and seed production under adverse environmental conditions	May enable invasive plants to thrive where and when more sensitive native plants die back or lose vigor
• High photosynthetic rates or large leaves that allow them to tolerate low-light conditions and to grow quickly	May enable invasive plants to become established in shady areas where many native plants cannot live and give juveniles of an invasive species that forms dense thickets an advantage over native species that need more light to survive or thrive

2) If the goal is to control or eliminate invasive plants, why would it be important to identify and remove new populations before they reach reproductive maturity?

Once a population matures, it may rapidly reproduce, growing very quickly in size and density. A smaller population will be easier to treat or remove and have less impact on native vegetation in the area. Also, once an invasion is widespread, there is a much larger area to patrol to find new populations.

3) One job of field crews in protected areas is to look for previously undiscovered populations of invasive plants. If you were in charge of field crews at Waikamoi Preserve or Kīpahulu Valley, which of the plant species covered in the "Matrix of Factors That Influence Invasiveness" would you have field crews look for most frequently? Use the information in the matrix to explain your answer.

Clidemia—this species rapidly reaches reproductive maturity in six months, unlike other species in the matrix that take at least two years.

4) Give two reasons why it would be important for field crews to reinspect areas where they have already manually removed a population of invasive plants and/or treated it with herbicides.

- To determine whether their treatment worked,
- To monitor whether any seeds stored in the soil have sprouted into new plants, and
- To prevent more fruit or seed from being produced by plants that may have survived or been missed in the initial treatment.

5) How long would you have crews return to a treated site to monitor it? Use the information in the matrix to explain your answer.

Depending upon the species, four to six years, since that's how long seeds can stay viable in the soil. (Responses may also address the fact that seed longevity in the soil is unknown for some plant species. In these cases, students may suggest additional research, long-term monitoring that becomes less frequent over time, and other alternatives.)

6) Imagine that you are in charge of controlling invasive plants in Waikamoi Preserve or Kīpahulu Valley. Use the information provided in the last two columns of the invasiveness matrix ("Vegetative Layers Impacted" and "Potential Displacement of Natives in Layers") to determine the potential threat each plant poses to native rain forest plants. Rank the six plant species in order of the threat they pose to the native rain forest, with "1" indicating the greatest threat and "6" indicating the least threat. (If there is a tie between two species for a given ranking, use other information in the matrix to determine your ranking.) Explain why you ranked the plants the way you did.

Here is one logical ranking (there may be others, which are acceptable as long as they are based primarily on the information in the last two columns in the matrix and well-reasoned).

1. Strawberry Guava
   May fully displace all vegetative layers and reaches reproductive maturity more quickly than Miconia
2. Miconia
   May fully displace all vegetative layers but reaches reproductive maturity more slowly than strawberry guava, so it may be easier to find and control populations before they reproduce
3. Australian Tree Fern
   May partially to completely displace three of four vegetative layers in the rain forest
4. *Kāhili* Ginger
   May completely displace the ground and shrub layers
5. Pampas Grass
   May partially to completely displace the ground and shrub layers
6. Clidemia
   May partially displace the ground and shrub layers

7) Use the other columns of the invasive matrix to double-check your ranking. Would you change anything based on this additional information? If so, what would you change and why? If not, why not?

Here is one logical response (there may be others, which are acceptable as long as they are based primarily on the additional information in the matrix and well-reasoned).

1) Miconia
May mature more slowly than strawberry guava but is of higher concern because it produces such huge numbers of small seeds that are highly dispersable

2) *Kāhili* Ginger
Its ability to completely displace the ground and shrub layers means that it could disrupt the new growth of any kind of vegetation in the forest. Since pigs are controlled in much of Waikamoi Preserve and Kīpahulu Valley, this plant is a greater threat than strawberry guava, which is primarily spread by pigs.

3) Strawberry Guava
May fully displace all vegetative layers and reproduces quickly

4) Australian Tree Fern
Dispersal by wind is a big concern with this plant since it can be easily spread long distances.

5) Pampas Grass

6) Clidemia

8) How can knowing the potential elevation range help a resource manager plan a control strategy for a particular plant species?

Possible responses include:

For plants that are restricted by elevation, managers can target control efforts to the elevational range in which the plants may be found, rather than spreading efforts to elevations where these plants are unlikely to survive or reproduce.

Also, a broad elevational range can add up to greater destruction because there is a greater amount of habitat that this plant may invade. This potential may increase the priority placed on controlling a given plant.

Frost and cold tolerance means that plants may invade the upper-elevation habitats, which tend to be less altered by human activity, with a more intact native ecosystem. This potential may increase the priority placed on controlling a given plant.

Correct Responses for Invasive Plant Identification Quiz

Photo: The Nature Conservancy

Kāhili Ginger

B. A popular flowering plant in gardens and landscaping

1. Birds are one of the main dispersal mechanisms for this plant, which produces bright red seeds.

Photo: The Nature Conservancy

Miconia

E. Originally brought to the Hawaiian Islands as an ornamental tree because of its dark green and purple leaves

2. Is capable of completely displacing native plants in all vegetative layers of the rain forest

Photo: Steve Anderson

Clidemia

A. A densely branching shrub that is thought to have been introduced to the Hawaiian Islands unintentionally

3. Restricted to elevations below 1300 meters (4264 feet) because it cannot tolerate cooler temperatures or frost

Photo: Steve Anderson

Australian Tree Fern

D. Nurseries sell more of these plants than the native *hāpu‘u,* which could serve the same function in landscaping.

4. A dense infestation of this plant in Kīpahulu Valley is thought to have originated from nurseries in the Hāna area, 12 kilometers (7.4 miles) away.

Photo: Kim Martz and Forest Starr

Strawberry Guava

C. Originally introduced to the Hawaiian Islands as a food source because it bears edible purple or yellow fruit

5. Is spread by pigs and can completely displace native plants in all vegetative layers of the rain forest

Photo: Kim Martz and Forest Starr

Pampas Grass

F. A popular ornamental plant with saw-toothed leaves and white to pink flower plumes

6. Is capable of invading many habitats including grasslands, mesic forests, wet forests, shrublands, and bogs

Invasive Plants in Hawai'i

Oceanic islands such as Maui and the other Hawaiian Islands are highly vulnerable to invasion by "alien" (nonnative) plants and animals. These biological invasions are often successful because native island species have evolved in isolation from pressures routinely encountered by plants and animals on continents. These forces include browsing and trampling by herbivorous mammals, ant predation, many types of diseases, and frequent and intense fires. Native island species evolved without the need for mechanisms to protect against predators and consequently, have reduced ability to compete against introduced species.

Scientific estimates of the rate at which the native biota of the Hawaiian Islands arrived here vary. One estimate puts the average rate at one new species every 35,000 years over a span of 70 million years. Over time, some of these original immigrant species evolved into the endemic plants and animals found on the islands. After the arrival of the Polynesians in the fifth century A.D., the arrival rate for new species increased to about three or four species each century. European contact in the 18th century further accelerated the immigration rate. Over the past 200 years, new insect species have been arriving on the Hawaiian Islands at a rate of 15 to 20 *per year* and plants have been introduced at an average rate of more than 40 per year. At this rate of introduction, native species are under increasing pressure from aliens, with virtually no time (on the evolutionary time scale) to adapt.

Biologists removing miconia plants (Photo: The Nature Conservancy)

The Hawaiian Islands currently have more than 10,000 introduced plant species, most of which grow only in cultivation. Over 1000 of these introduced plants now have reproducing populations in the wild. At least 100 of these nonnative plant species are considered by scientists and resource managers to pose a threat to native Hawaiian ecosystems. Why are some of these introduced plants such a threat while others are not? The answer is that some nonnative plants are more "invasive" than others.

What Makes a Plant Invasive?

Plants that have been introduced into an environment in which they did not evolve may become invasive. In these environments, they usually have no natural controls to limit their reproduction and spread, so they grow quickly and reproduce rapidly. A common term for invasive plants, especially on agricultural lands where they interfere with crop production, is "weeds." In natural areas, invasive plants produce a significant change in the composition, structure, or function of ecosystems.

Invasive plant species possess characteristics that permit them to aggressively invade new areas and outcompete native plants for light, water, and nutrients. Some of these characteristics include:

- Quick growth to reproductive maturity;
- Profuse reproduction by seeds and/or vegetative structures (parts of the plant such as root runners);

- Long seed life in the soil;
- Seeds that can lie dormant through unfavorable conditions and sprout when conditions are ideal for rapid growth;
- Seeds that are adapted to be easily spread by wind, animals, water, and/or humans;
- Production of "biological toxins," natural substances that suppress the growth of other plants;
- Spines, thorns, and other structures that cause physical injury and repel animals;
- The ability to parasitize other plants, taking nutrients from the host plant rather than producing them itself;
- Roots or "rhizomes" with large food reserves. A rhizome is a rootlike stem that grows under or along the ground, sending out roots from its lower surface and leafy shoots from its upper surface;
- Survival and seed production under adverse environmental conditions; and
- Large leaves or the ability to photosynthesize rapidly and efficiently, which allow plants to tolerate low-light conditions and to grow quickly.

Invasive plants often gain a foothold in new areas by establishing in places that have been disturbed by human activity (e.g., road and trail construction, farming, and building houses), by natural events (e.g., high winds and flooding), or by introduced animals (e.g., pigs rooting in the rain forests and cattle or goats grazing native plants). While not necessary for a new establishment of an invasive plant species, disturbing the native ecosystem makes it more vulnerable to invasion.

In general the mild climate and varied habitats of the Hawaiian Islands makes them particularly vulnerable to invasion. Nonetheless, the success of invasive plants may be restricted by temperature or other conditions that limit their growth. On Maui, as in other places, some invasive plants are restricted to certain elevations because cooler temperatures or frost prevent seed germination, kill the plants outright, or inhibit their growth, making them less invasive.

In the Haleakalā rain forest, as in other Hawaiian rain forests, invasive plants are spread by a handful of common "dispersal mechanisms" or means by which they are spread to new areas. Successful plant invaders are spread by introduced and native birds, introduced rats, feral pigs, people, wind, water, and gravity. Each dispersal mechanism a plant can use provides it with a different way to become established in new areas. And each dispersal mechanism poses a different threat for spreading invasive plants to or within the Haleakalā rain forest and beyond to other ecosystems and places. Table 1: Common Dispersal Mechanisms (p. 24) gives more detail about these common dispersal mechanisms.

Invaders in the Rain Forest

Invasive plants possess a combination of characteristics that allow them to compete with and sometimes totally displace native plants. In native Hawaiian rain forests, such as those on Haleakalā, native vegetation grows in four distinct layers (see "Major Layers of a Hawaiian Rain Forest"on p. 30). Different invasive plant species threaten native vegetation in different layers by crowding out plants in a specific layer, shading layers below, outcompeting plants for soil nutrients and moisture, reducing habitat for epiphytic plants (which grow supported on another plant, often a tree), and other impacts.

When researchers and land managers are gauging the threat posed by a nonnative plant

Strawberry guava in fruit (Photo: Kim Martz and Forest Starr)

Table 1: Common Dispersal Mechanisms

Dispersal Mechanism	How It Works	Distance for New Establishments
Birds (Include native and introduced species)	• Birds eat fruit or seeds, fly elsewhere, and excrete the seeds. Excreted seeds may germinate more readily. • They transport seeds attached to their bodies.	• Generally up to two kilometers (one mile) • Birds can move seeds anywhere on Maui and even to or from another island.
Rats (All rats were introduced to the Hawaiian Islands by Polynesians or Europeans.)	• Rats eat fruit or seeds, crawl elsewhere, and excrete the seeds. Excreted seeds may germinate more readily. • They transport seeds attached to their bodies.	• Around 500 meters (1600 feet)
Feral Pigs (Descended from European pigs originally introduced as a food animal.)	• Pigs eat fruit or seeds, walk elsewhere, and excrete the seeds. Excreted seeds may germinate more readily. • Their rooting in the forest causes disturbances that facilitate the establishment of invasive plants. • They transport seeds on their bodies.	• Maximum of a couple dozen kilometers (several miles), usually much less
People	• People unintentionally transport seeds on boots and clothing or by eating fruit or seeds and excreting seeds elsewhere. • They intentionally use nonnative plants in landscaping, horticulture, and food production.	• Potentially global • Unintentional transport could occur anywhere on Maui, between islands, or elsewhere
Wind	• Lightweight seeds are transported on wind currents.	• Likely on Maui and between islands, following prevailing winds
Water	• Seeds are transported in flowing or moving water. • Water can also cause erosion, which may move seeds and cause disturbances that facilitate the establishment of invasive plants.	• Up to several miles, generally downstream • Generally localized
Gravity	• Gravity causes fruits/seeds to fall to the ground. • It contributes to erosion, directly moving seeds and causing disturbances that help invasive plants become established.	• Maximum of several miles, generally downhill • Generally very localized

species within the Haleakalā rain forest, they consider which native vegetative layers the plant would affect and how thoroughly the invader may displace native plants (i.e., whether any native plants are likely to be left in areas invaded by this plant). Other factors they consider include:

- Whether there are elevational limits to the invasive plant's growth,
- Which ecosystems it is capable of invading,
- How it is dispersed,
- How rapidly it reaches reproductive maturity,
- How long the seeds can survive in the soil and still germinate,
- The plant's current known distribution, and
- Whether the plant has established populations in or near pristine or sensitive areas or habitat for endangered species.

Looking at all of these factors helps researchers and land managers decide how likely it is that this plant will reach the native rain forest and how disruptive it is likely to be if it becomes established.

Six Invaders of Concern

Among the most threatening invasive plants to the Haleakalā rain forest are these six "most wanted" (or should that be "least wanted"?) invaders that you'll be learning more about later in this unit:

Clidemia or Koster's Curse
(Clidemia hirta)

This densely branching shrub is an aggressive invader that grows up to three meters (ten feet) tall. It shades out all vegetation below it. Clidemia is native to the humid tropics of Central and South America. It is found on many Pacific islands and is thought to have been introduced to the Hawaiian Islands as an ornamental plant.

Distribution on East Maui: Clidemia is established throughout East Maui, in a broad belt along the windward side of Haleakalā. Dense infestations occur in Kīpahulu Valley and the Nāhiku and Kailua areas. The complete extent and intensity is not known.

Miconia or Velvet Tree
(Miconia calvescens)

This decorative tree is an evergreen that grows to about 15 meters (50 feet) in height when mature. Its large leaves (up to one meter or three feet long) are dark green above and purple underneath. Miconia was brought to the Hawaiian Islands as an ornamental in the 1960s.

Distribution on East Maui: Miconia was first detected on Maui in 1990 at a botanical garden near Hāna. There is a large core population near Hāna in the Kawaipapa Gulch area, with smaller populations elsewhere on East Maui.

Kāhili Ginger
(Hedychium garderianum)

This showy flowering plant grows just over one meter (three feet) tall. It is commonly used in gardens and landscaping, where it is popular for its dark green foliage and showy yellow and red flowers.

Distribution on East Maui: *Kāhili* ginger is found in protected rain forest areas such as Waikamoi Preserve and Kīpahulu Valley. It is also found in Koʻolau Gap between 600-900 meters (1968-2952 feet) in elevation and has displaced thousands of acres of native rain forest in the East Maui watershed. Its distribution is not fully known.

Australian Tree Fern
(Cyathea cooperi)

This decorative fern is widely used in landscaping and gardening and is often seen in people's backyards. Nurseries sell this fern much more than the native *hāpuʻu*, probably because there is little or no commercial propagation of *hāpuʻu*. The few *hāpuʻu* ferns available for sale are probably collected as whole plants from the native rain forest.

Distribution on East Maui: Australian tree ferns are scattered across the East Maui watershed from Koʻolau Gap to Kaupō Gap, with dense pockets in certain locations. In Kīpahulu Valley, a dense infestation is thought to have originated from spores transported by wind from nurseries in the Hāna area, 12 kilometers (7.4 miles) away.

Pampas Grass *(Cortaderia jubata)*

This giant, tussock-forming perennial grass has finely saw-toothed leaves and white to pink flower plumes that grow up to three meters (ten feet) tall. Pampas grass is a popular ornamental plant.

Distribution on East Maui: Pampas grass has been found in the Kīhei area, with extensive populations in other locations, especially along roadways leading up to Haleakalā National Park and in the upper-elevation rain forests on windward Haleakalā.

Strawberry Guava *(Psidium cattleianum)*

This medium-sized tree with a smooth trunk and dark green, shiny leaves bears small, purple or yellow fruits. Strawberry guava was originally introduced to Hawaiʻi in the early nineteenth century for its edible fruit.

Distribution on East Maui: Strawberry guava is found in protected rain forest areas such as Kīpahulu Valley. Strawberry guava has displaced thousands of acres of native rain forest in the East Maui watershed. Its distribution is not fully known.

Controlling the Invaders

Especially in protected areas such as Haleakalā National Park and The Nature Conservancy's Waikamoi Preserve, resource managers are waging an ongoing battle against existing invasive plant populations as well as against the threat of future invasions. Within preserve boundaries, the main activities of paid workers and volunteers are:

- Patrolling for new or undiscovered populations of invasive plants on foot or by helicopter;
- Eliminating or controlling populations of invasive plants through manual removal or use of herbicides;
- Monitoring and retreating sites where invasive plant control has been done; and
- Controlling agents of dispersal such as rats and feral pigs through trapping, fencing, hunting, and poisoning.

Cooperating to Get the Job Done

Because so many parts of the Maui rain forest are not protected natural areas and protected areas are threatened by alien plants that come from outside their boundaries, cooperation is key in controlling these nonnative plants and preventing their arrival. On Maui, resource managers and

Kāhili *ginger (Photo: The Nature Conservancy)* researchers have joined together to form the Maui Invasive Species Committee (MISC).

MISC is a voluntary partnership of private, government, and nonprofit organizations to prevent new pest species from becoming established in Maui County and to stop newly established pests from spreading. MISC maintains prevention, containment, and eradication plans for Maui, Molokaʻi, and Lānaʻi. It also organizes specific eradication and containment projects such as Operation Miconia, and convenes ad hoc meetings to address new threats.

MISC and other groups working outside the boundaries of a specific protected area try to do more than directly control plant populations. They also attempt to control the spread and arrival of invasive plants through public education, inspections of cargo and shipments, early detection of new populations, and other activities such as working with nurseries and landscapers to prevent the sale and planting of invasive species. Looking at the big picture, it is preferable to avoid the arrival of new invasive plant species on the islands than to attempt to detect, control, or eradicate them once they are established. Prevention is a top priority for MISC and other agencies and landowners who are involved in the fight against invasive plants on Maui.

Management Strategies for Invasive Plants

Many resource managers think of management strategies for invasive plants in a sort of hierarchy, with the most preferred strategy and result at the top. Here is one such hierarchy:

1) **Prevention:** Invasive plants cause no problems for native ecosystems if they do not arrive in the first place.

2) **Eradication:** Eliminating the invasion is the next most desirable scenario.

3) **Control the Spread:** If there is a single large population, resource managers may do manual removal (cutting, pulling, or digging up the plants) and/or herbicidal control (sprayed on foliage or applied directly under the bark or to a cut stump) to limit the expansion of that population. At the same time, they must patrol surrounding areas for new, smaller populations to remove them before they are too well established. In some cases, but not always, workers may be able to gradually decrease the size of the core population and may even be able to eradicate it.

4) **Eradicate Populations in Special Areas:** When eradication of the invading species is not possible, managers may focus on identifying and eliminating populations within or near pristine or sensitive natural areas or endangered species habitat.

5) **"Biocontrol":** Managers may release insects or a disease-causing organism that selectively affects the invasive species, weakening it or limiting its reproduction. Biocontrol is used only when eradication is not possible, since a small population of the invasive species must be maintained in order to continue to support the insect or disease.

6) **Do Nothing:** Some invasive species have become so widespread, or removing them would cause such great damage to surrounding native vegetation, that managers decide to take no action to control them.

Matrix of Factors that Influence Invasiveness

Species	Potential Elevation	Habitats Subject to Invasion	Dispersal Mechanisms	Time to Reproductive Maturity	Seed Size and Production	Vegetation Layers Affected	Potential Displacement of Natives in Layers
Clidemia Each fruit contains over 100 seeds, and mature plants produce over 500 fruits per year	0-1300 m (396 ft)	Mesic to wet forest, shrubland, and bogs	Birds Rats People Water Gravity	6 months	.5 mm	Ground to shrub layer (or under-story)*	Partial
Miconia Dark purple fruit each contain huge numbers of seeds and are very attractive to birds	0-1800 m (549 ft)	Mesic to wet forest, shrubland, and bogs	Birds Rats People Water Gravity	4 years	< .5 mm Massive quantities of small seeds, easily bird-dispersed	All: ground to tree canopy	Complete
***Kāhili* Ginger** Grows rapidly by stolons (runners that extend from the base of the plant) and produces red, fleshy seeds attractive to birds	0-2400 m (732 ft) (frost tolerant)	Mesic to wet forest, shrubland, and bogs	Birds Rats People Water Gravity	3+ years	4 mm	Ground to shrub layer (or under-story)	Complete
Australian Tree Fern Produces huge quantities of spores that are carried on the wind	0-1800 m (549 ft) (frost tolerant)	Mesic to wet forest, shrubland, and bogs	Wind People Water	2 years	< .5 mm Massive quantities of small spores, easily wind-dispersed	Ground to subcanopy layer	Partial to complete

* Displacing the ground or shrub layer over time impairs or completely inhibits the regrowth of other vegetative layers.

Matrix of Factors that Influence Invasiveness (cont'd)

Species	Potential Elevation	Habitats Subject to Invasion	Dispersal Mechnanisms	Time to Reproductive Maturity	Seed Size and Production	Vegetation Layers Affected	Potential Displacement of Natives in Layers
Pampas Grass Seeds itself freely, dispersing windborne seeds long distances from tall flower-ing stalks	0-2300 m (710 ft)	Grassland, mesic to wet forest, shrubland, and bogs	Wind People	2 years	2 mm	Ground to shrub layer (or under-story)	Partial to complete
Strawberry Guava Produces golf-ball sized fruits prolifically	0-1800 m (549 ft) (frost tolerant)	Mesic to wet forest, shrubland, and bogs	Birds Rats Pigs People Water Gravity	2+ years	5 mm	All: ground to tree canopy	Complete

Layers of a Hawaiian Rain Forest

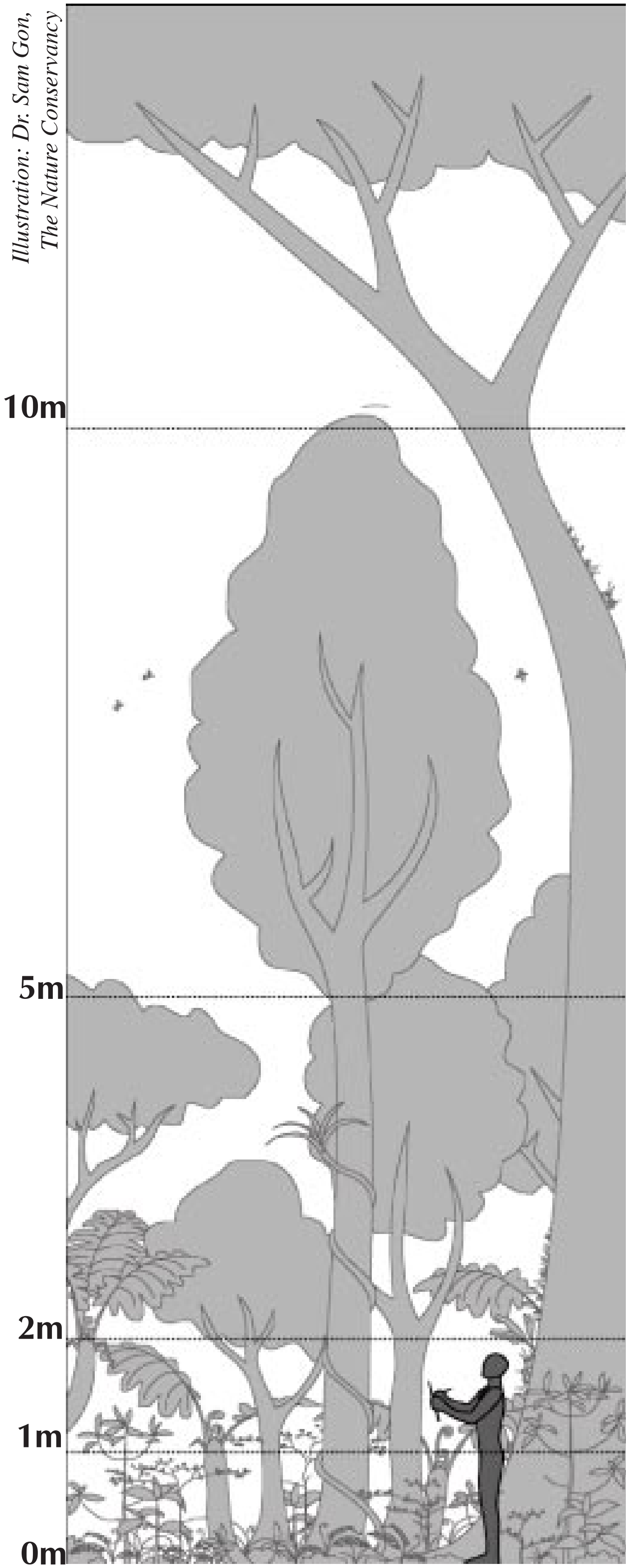


Illustration: Dr. Sam Gon, The Nature Conservancy

Canopy

Height above five meters (16 feet) This layer includes the majority of trees, primarily consisting of *Acacia koa* and *Metrosideros polymorpha*. The height of the main canopy layer is usually under ten meters (33 feet). In some places, taller trees emerge above the prevailing canopy height.

Epiphytes and Climbing Plants

Epiphytes are present in all layers, increasing in cover and diversity closer to the ground. Epiphytes include mosses and liverworts, lichens, a variety of ferns, and flowering plants. Vines and climbing plants are most abundant in lower layers, but may extend to the canopy.

Subcanopy Trees and Shrubs

Height, two to five meters (6.5-16 feet)
In this layer, large tree ferns, shrubs, and saplings of canopy trees are present.

Understory

Height, one to two meters (three to 6.5 feet)
Typically, present here are tree ferns, shrubs, and saplings of subcanopy and canopy trees.

Groundcover or Forest Floor

Height, to one meter (to three feet)
Here are found small ferns, small shrubs, herbs, sedges and grasses, mosses and liverworts, and seedlings from all layers.

Invasive Plants in Hawai'i: Questions on the Reading

1) From the reading, select three of the characteristics that invasive plants may possess, and explain why each one could give these plants an advantage over native plants.

    •

    •

    •

2) If the goal is to control or eliminate invasive plants, why would it be important to identify and remove new populations before they reach reproductive maturity?

3) One job of field crews in protected areas is to look for previously undiscovered populations of invasive plants. If you were in charge of field crews at Waikamoi Preserve or Kīpahulu Valley, which of the plant species covered in the “Matrix of Factors That Influence Invasiveness” (p. 29) would you have field crews look for most frequently? Use the information in the matrix to explain your answer.

4) Give two reasons why it would be important for field crews to reinspect areas where they have already manually removed a population of invasive plants and/or treated it with herbicides.

5) How long would you have crews return to a treated site to monitor it? Use the information in the matrix to explain your answer.

6) Imagine that you are in charge of controlling invasive plants in Waikamoi Preserve or Kīpahulu Valley. Use the information provided in the last two columns of the invasiveness matrix ("Vegetative Layers Impacted" and "Potential Displacement of Natives in Layers") to determine the potential threat each plant poses to native rain forest plants. Rank the six plant species in order of the threat they pose to the native rain forest, with "1" indicating the greatest threat and "6" indicating the least threat. (If there is a tie between two species for a given ranking, use other information in the matrix to determine your ranking.) Explain why you ranked the plants the way you did.

1.

2.

3.

4.

5.

6.

7) Use the other columns of the invasive matrix to double-check your ranking. Would you change anything based on this additional information? If so, what would you change and why? If not, why not?

8) How can knowing the potential elevation range help a resource manager plan a control strategy for a particular plant species?

Invasive Plant Identification Quiz

Select one answer from each category on the following page and note it next to the appropriate image. Use each answer only once.

Photo: The Nature Conservancy

Species Name:

Human Use and Introduction:

Invasiveness and Distribution:

Photo: The Nature Conservancy

Species Name:

Human Use and Introduction:

Invasiveness and Distribution:

Photo: Steve Anderson

Species Name:

Human Use and Introduction:

Invasiveness and Distribution:

Photo: Steve Anderson

Species Name:

Human Use and Introduction:

Invasiveness and Distribution:

Photo: Kim Martz and Forest Starr

Species Name:

Human Use and Introduction:

Invasiveness and Distribution:

Photo: Kim Martz and Forest Starr

Species Name:

Human Use and Introduction:

Invasiveness and Distribution:

Species Name

Miconia
Australian Tree Fern
Pampas Grass
Kāhili Ginger
Clidemia
Strawberry Guava

Human Use and Introduction

A. A densely branching shrub that is thought to have been introduced to the Hawaiian Islands unintentionally
B. A popular flowering plant in gardens and landscaping
C. Originally introduced to the Hawaiian Islands as a food source because it bears edible purple or yellow fruit
D. Nurseries sell more of these plants than the native *hāpu'u,* which could serve the same function in landscaping.
E. Originally brought to the Hawaiian Islands as an ornamental tree because of its dark green and purple leaves
F. A popular ornamental plant with saw-toothed leaves and white to pink flower plumes

Invasiveness and Distribution

1. Birds are one of the main dispersal mechanisms for this plant, which produces bright red seeds.
2. Is capable of completely displacing native plants in all vegetative layers of the rain forest
3. Restricted to elevations below 1300 meters (4264 feet) because it cannot tolerate cooler temperatures or frost
4. A dense infestation of this plant in Kīpahulu Valley is thought to have originated from nurseries in the Hāna area, 12 kilometers (7.4 miles) away.
5. Is spread by pigs and can completely displace native plants in all vegetative layers of the rain forest
6. Is capable of invading many habitats including grasslands, mesic forests, wet forests, shrublands, and bogs

Activity #3

Managing Invasives on Survivor Island

● ● ● **Class Period One** *Managing Invasives on Survivor Island*

Materials & Setup

For each group of four to five students

- Student Page "Invasive Plants of Hawai'i" (Students should have these from Activity #2.)
- Student Page "Survivor Island Background" (pp. 38-45)
- Student Page "Invasive Plant Action Sheet" (pp. 46-49)

Instructions

1) Divide the class into groups of four to five students. Explain that each student group is a management team in charge of controlling invasive plants within a rain forest preserve on an imaginary island called Survivor Island.

2) Hand out the Student Pages "Survivor Island Background" and "Invasive Plant Action Sheet" to each group. Have each group select a) a **leader**, who will facilitate the group's discussion and make sure it completes its assignment, b) a **recorder**, who will fill out the "Invasive Plant Action Sheet," and c) a **spokesperson**, who will present the group's plan and rationale to the class. Allow students to work together for the remainder of the class. (Groups will have a brief time to work together during the next class period before making presentations.)

● ● ● **Class Period Two** *Survivor Island Management Reports*

Instructions

1) Reconvene student management teams to work on their plans. When approximately 40 minutes of the class remains, have each group's spokesperson give a five-minute overview of the group's plans and rationale for their priorities.

2) At the end of class, ask students to discuss what they learned by doing this activity.

Journal Ideas

- All resource managers need to set priorities for their work. Was this an easy or difficult task for your group? Why?
- Who should decide management priorities for invasive plants? Why?
- What are the pros and cons of focusing management efforts on one species, such as miconia, that poses a huge threat and paying less attention to others?

Assessment Tools

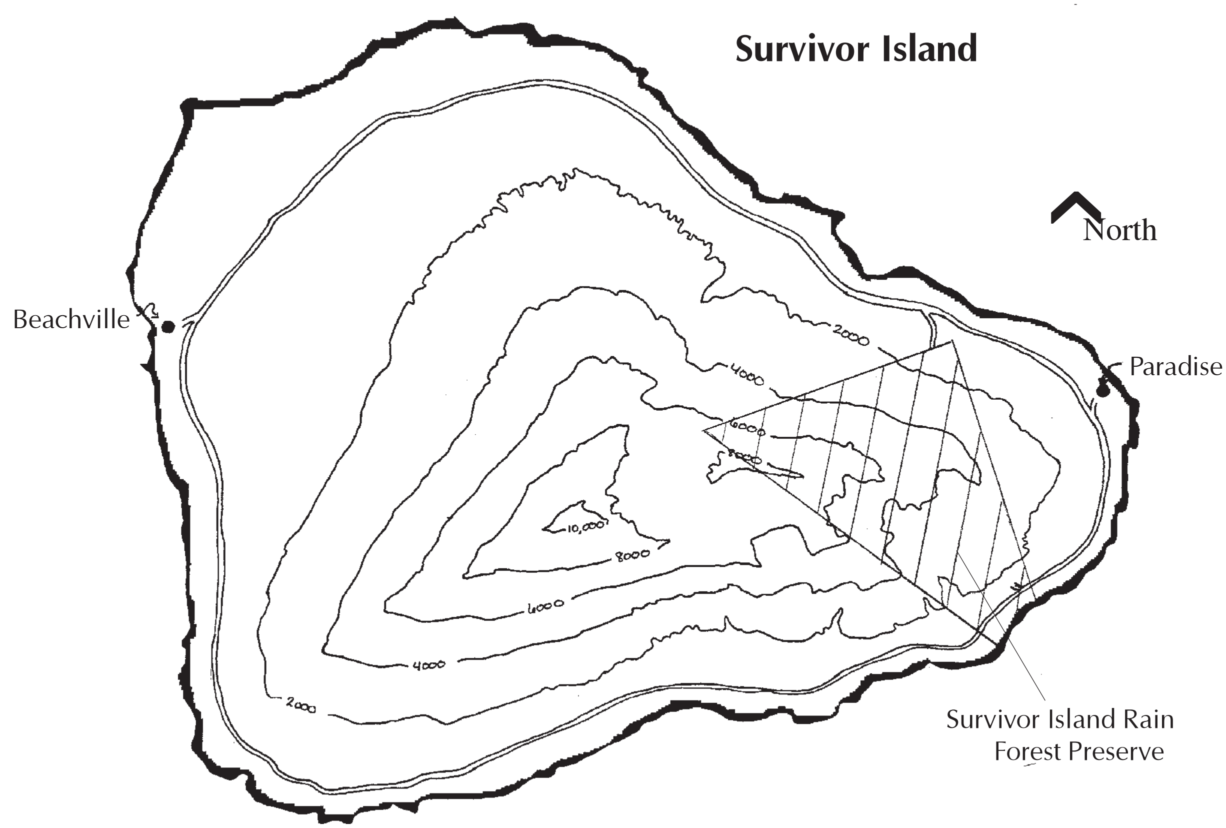
- Group participation and class presentations
- Student Page "Invasive Plant Action Sheet"
- Journal entries

Survivor Island Background

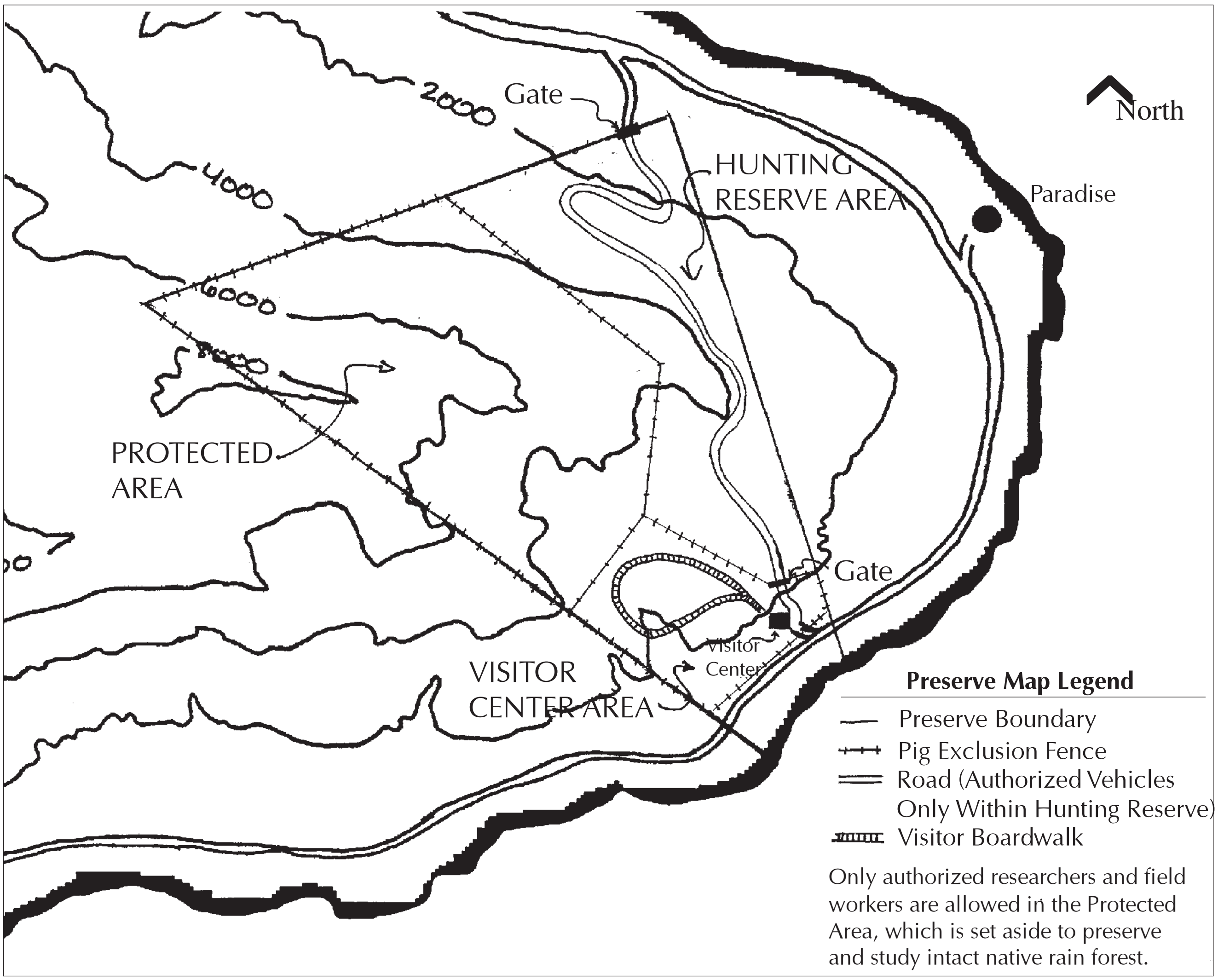
Survivor Island is a small island in the tropical north Pacific, where the trade winds blow from the northeast, just as they do on Maui. There are two small cities on the island, Beachville and Paradise. There are other small communities along the main road that rings the island, although few people live along the rugged, dry southern coast.

In the rain forest on the eastern end of Survivor Island, near the town of Paradise, island residents have established the Survivor Island Rain Forest Preserve. The preserve is divided into three main areas:

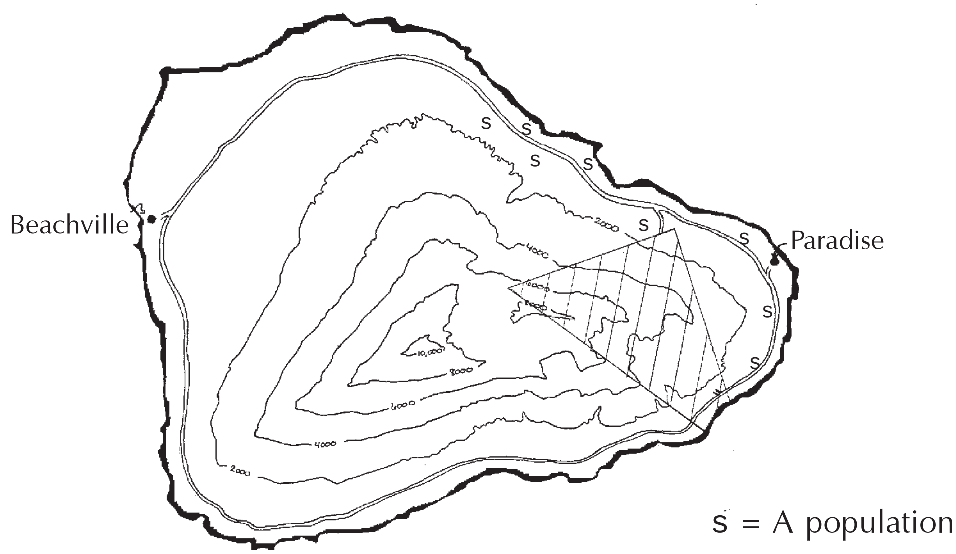
- The Visitor Center Area, where preserve visitors can learn about the native rain forest and the preserve and take a walk through native rain forest along a boardwalk that volunteers built.
- The Hunting Reserve Area, where pig hunting on foot is allowed. Only work vehicles authorized by the preserve are allowed in this area.
- The Protected Area, which is set aside to preserve and study the intact native rain forest. Researchers must obtain permission from preserve managers to work in this area, and in general, the only other people allowed into the area are crews working to eradicate or control invasive plants, inspect the fences surrounding this area, monitor for signs of pigs that sometimes get through the fences, and remove intruding pigs.



Survivor Island Rain Forest Preserve



Invasive Species Information Sheet
Clidemia



Distribution Notes

- Scattered plants have been found and removed from the Visitor Center Area of the preserve.
- Clidemia is common roadside plant along the windward highway.

Control Strategies

New populations

- Small seedlings: Pull by hand
- Larger plants: Remove and bag seed heads and inject herbicide under the bark or cut the plant and treat the cut stump with herbicide

Larger, established populations

- More research is needed on effective herbicides to be sprayed on the foliage of larger populations. These herbicides could also be sprayed on dense mats of seedlings.

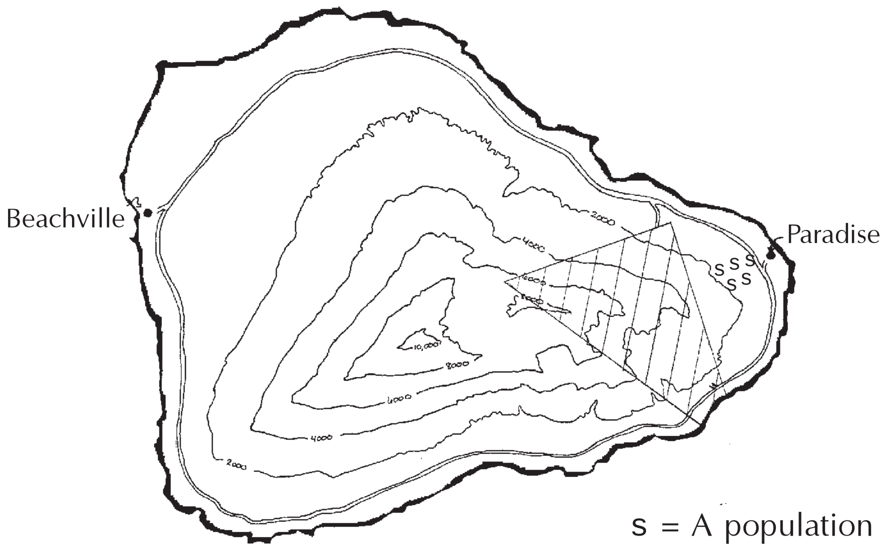
Biological control

- Two partially successful biological control agents have been released, and the results are being monitored. Other insects are being screened.

Inspection and retreatment

- New populations need to be reinspected yearly, with retreatment as necessary.

Invasive Species Information Sheet
Miconia



Distribution Notes

- There is a large infestation outside preserve boundaries up to about 600 meters (1968 feet) elevation. This infestation is believed to have originated at a botanical garden near the town on the eastern tip of the island.
- No plants have been discovered within the preserve yet.

Control Strategies

New populations

- Seedlings and saplings under about three meters (ten feet) tall: Uproot manually, dry completely, and allow to decompose in the contaminated area

Larger, established populations

- Fruiting trees: Limit seed production with helicopter spraying of herbicides (Dye is added so the pilot can see where the herbicide is going and identify treated plants. This treatment is expensive and requires careful planning to avoid spraying native vegetation.)
- Larger trees: Cut down and immediately apply herbicide to the cut stump
- To prevent the dispersal of tiny seeds that look like soil particles, change clothes and shoes and wash all machinery and other equipment before departing infested areas.

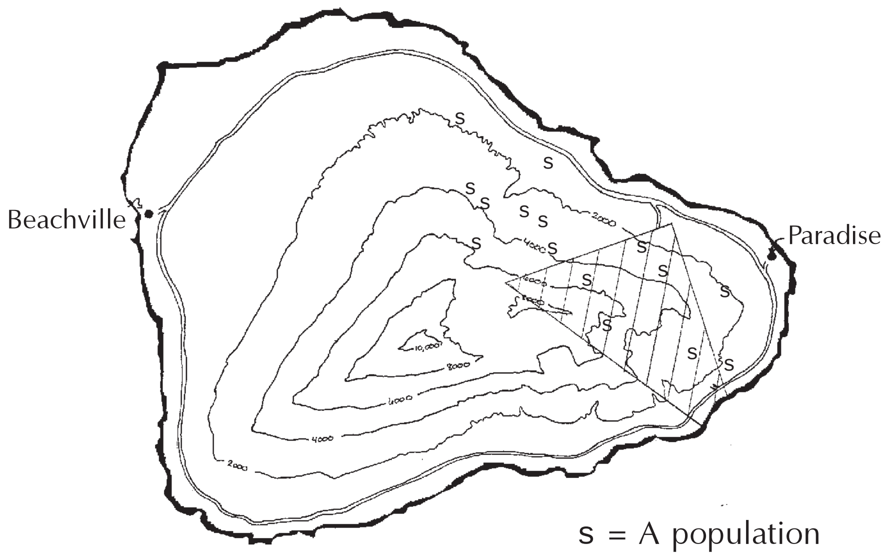
Biological control

- Methods of biological control being investigated include several insects and plant diseases

Inspection and retreatment

- Repeated surveys and treatment are necessary because trees are easily missed by ground crews and aerial surveys during the initial attempt.

Invasive Species Information Sheet
Kāhili Ginger



Distribution Notes

- Large populations have become established in the rain forest both within and outside the preserve.
- A few small populations that have not yet reached reproductive maturity have been found inside the fenced Protected Area.

Control Strategies

New populations

- Seedlings: Pull by hand
- Larger plants: Cut vegetation from the rhizome and apply herbicide to the cut surface of the rhizome

Larger, established populations

- Contain the periphery of large populations, using the techniques above to gradually reduce its size
- Search out new, small satellite populations and destroy

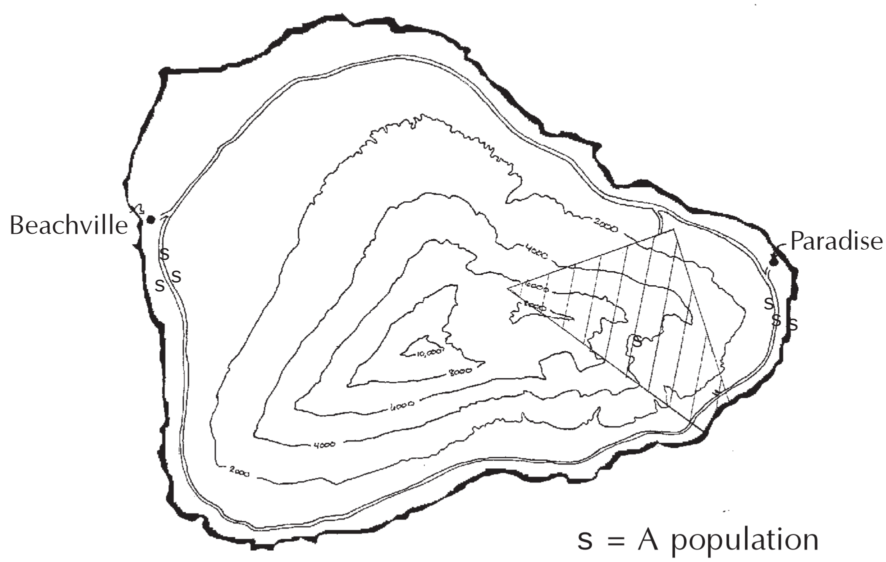
Biological control

- A bacterium has been used for about five years to control large infestations in a protected area of a neighboring island. This bacterium was an agricultural pest that was attacking ginger crops and has been modified to attack only *kāhili* ginger.

Inspection and retreatment

- Infested areas need to be reinspected yearly and retreated if necessary.

Invasive Species Information Sheet
Australian Tree Fern



Distribution Notes

- One small population has been found at around 1400 meters (4592 feet) within the fenced Protected Area.
- Australian tree fern is used extensively for landscaping in and near both of the main towns on the island.

Control Strategies

New populations

- Cut the main growth stem of all plants into small pieces

Larger, established populations

- Contain the periphery of large populations, using the technique above to gradually reduce its size
- Search out new, small satellite populations and destroy them

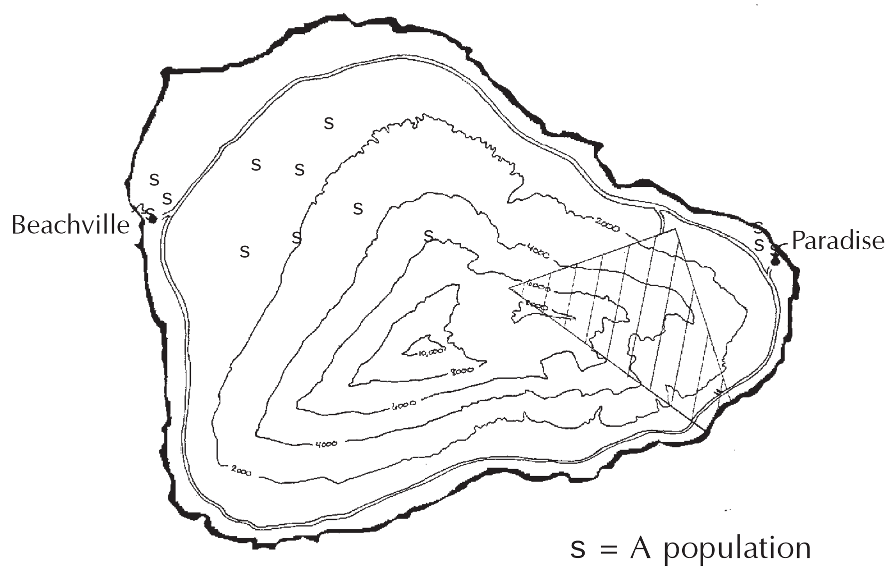
Biological control

- No known effective biological control agent

Inspection and retreatment

- Infested areas need to be inspected yearly and retreated if necessary.
- Retreatment intervals need to be refined to prevent plants from reaching reproductive maturity.

Invasive Species Information Sheet
Pampas Grass



Distribution Notes

- No populations have been discovered in the preserve.
- Scattered populations have been found on the leeward slopes of the island.
- Pampas grass is used extensively for landscaping in and near both of the major towns on the island.

Control Strategies

New populations

- Small plants, low-density populations, or where planted ornamenatally: Dig plants out by hand

Larger, established populations

- Large, well-established plants or high-density populations: Treat with herbicides
- Avoid seed dispersal by bagging and cutting off flowering plumes and seed heads and wear dedicated footwear and other gear
- Experiment with using heavy plastic tarps to kill previously cut plants and prevent the subsequent establishment of seedlings (This method would be useful only on a small-scale basis.)
- Use helicopter spraying of herbicides in sensitive high-elevation areas (Dye is added so the pilot can see where the herbicide is going and identify treated plants. This approach is expensive, but with careful planning, minimizes the disturbance to surrounding native vegetation.)

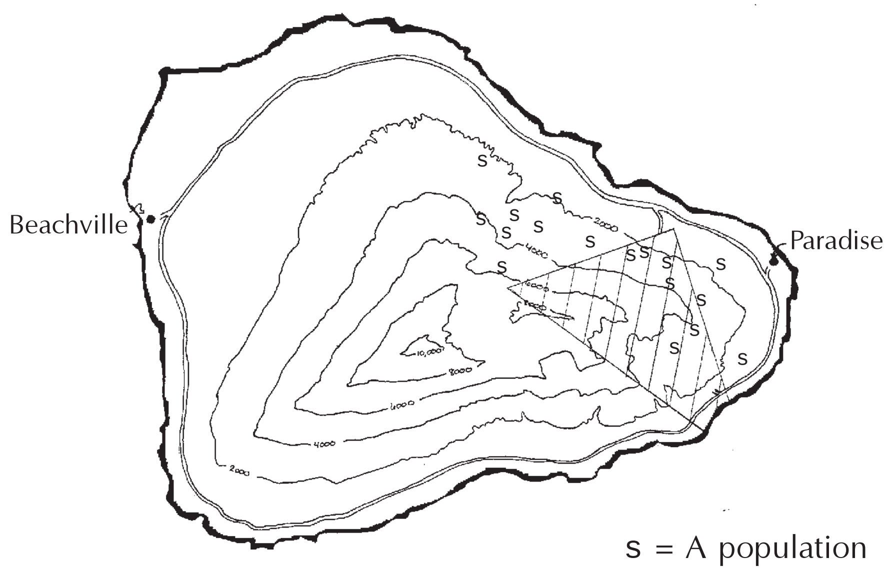
Biological control

- Has never been used successfully for any grass species worldwide

Inspection and retreatment

- Aerial reconnaissance is used to find pampas grass in high-elevation roadless areas.

Invasive Species Information Sheet
Strawberry Guava



s = A population

Distribution Notes

- Extensive populations are found in the Hunting Reserve Area of the preserve and in the rain forest outside the preserve.
- After the Protected Area was fenced, the handful of small populations known to exist within the protected area were removed using manual removal and chemical control.

Control Strategies

New populations

- Pull very small plants and apply herbicide to larger plants

Larger, established populations

- Feral pig management is a necessary first step because huge quantities of seed are dispersed by feral pigs during the fall fruiting season.
- Pig control must be followed by manual removal of plants or control with herbicide.

Biological control

- Because of the extent of the infestation, biological control is probably the only method that will work on a large scale. Two insects currently being studied have considerable potential. However, because the common guava is grown commercially here, biological control agents must be species-specific to the strawberry guava, which makes the prospects slim.

Inspection and retreatment

- Reinfestation is low in pig-free, intact forests, but areas still need to be occasionally inspected.

Invasive Plant Action Sheet

Your group is in charge of controlling invasive plants within the Survivor Island Rain Forest Preserve. Each year, you develop an Invasive Plant Action Plan based on current information about invasive plants in the preserve, as well as the existing budget. Over the course of the year, you may modify your plan if new information comes in or if the budget changes.

In this activity, your group will work together to identify key elements of your Invasive Plant Action Plan, following instructions given. Use information from:

- Student Page “Invasive Plants in Hawai‘i” (Activity #2)
- Student Page “Survivor Island Background”

Action you may take in your plan may include, but is not limited to:

- Sending out field crews to search for new populations, either in specific areas or throughout the whole preserve;
- Trapping, killing, or excluding animals that disperse invasive plants;
- Manually removing invasive plants (e.g., by cutting or uprooting);
- Using herbicides to kill or control populations of invasive plants;
- Using biological controls;
- Inspecting previously treated areas and retreating with herbicides or manual removal if necessary;
- Researching specific aspects of invasive plant biology or control methods; and
- Educating the public to help prevent the spread of invasive plants.

Your plan may include action that takes place within or outside the boundaries of the preserve.

Phase 1: Initial Planning

In past years, your group has developed a list of the six invasive plant species that pose the greatest threat to the native rain forest within your preserve. This year's budget allows you to carry out a **total of ten control or prevention actions**. You must take **at least one action on each listed species**. Indicate your priority actions in the following table, being as specific as you can.

Species	Action #1	Action #2	Action #3	Action #4	Rationale
Clidemia					
Miconia					
Kāhili Ginger					
Australian Tree Fern					
Pampas Grass					
Strawberry Guava					

Questions

1) Are any of your proposals likely to be objectionable to Survivor Island residents or preserve visitors? If so, list them here and describe the likely objections.

2) If you got a grant that allowed you to add two more actions to your plan, what would they be and why?

Phase 2: Miconia Discovered

A month after your group makes its original plan, visiting researchers discover a large population of miconia in a little-visited part of the preserve's Protected Area. They estimate that the plants are about two years old.

You learn that, in Tahiti, miconia was introduced in 1937 as an ornamental plant and now covers over two-thirds of the island, having taken over the native forest. Between 40 and 50 of the 107 plant species endemic to Tahiti are on the verge of extinction solely due to the miconia invasion. Once miconia becomes established in an area, it is exceedingly difficult to eradicate, especially after the plants reach reproductive maturity. A single miconia tree can produce eight million seeds each year, and the fruits they're contained in are highly attractive to birds, which can rapidly spread them to other areas. Some of the researchers suggest that the miconia threat is so great that your group should divert almost all of its invasive species management efforts to try to control this newly discovered population.

You haven't spent much of the money in your budget yet, so your group convenes another time to rearrange priorities based on this new information. For each new action that you want to take to address the newly discovered miconia problem, you remove one action from your Phase One plan.

Fill in the table on the following page to show how you would change your plan and why.

Revised Action Plan

Species	Actions Added or Removed	Rationale
Miconia		
Clidemia		
Kāhili Ginger		
Australian Tree Fern		
Pampas Grass		
Strawberry Guava		