Left High and Dry?

Photo courtesy of Dr. Susan Cordell.

Attempting To Restore a Tropical Dry Forest in Hawai'i

Meet the Scientists

◀ **Dr. Susan Cordell,** Ecologist: My favorite science experience is returning to our tropical dry forest **restoration** experimental plots and seeing native species thrive. A decade ago, most people thought we were crazy to attempt restoration in Hawaiian dry forests. They believed that fountain grass, a highly **invasive** grass from Africa, would out-compete native seedlings. Fountain grass had already displaced most of Hawaiian tropical dry forests. When we first removed fountain grass in areas where goats were kept out, native species flourished while the fountain grass took a long time to recover. Science allows us to ask questions and challenge ideas and, in this case, we learned that, with a lot of effort, tropical dry forests can be restored.

▶ **Ms. Moana McClellan,** Ph.D. Student: One of my favorite things about working in the Hawaiian tropical dry forests is the chance to learn about **endemic** plant species. These are plants that are found nowhere else. Hawai'i has so many endemic species. One of my favorite experiences working at *Ka'ūpūlehu* was my first encounter with the *'ohe makai* tree; a magnificently beautiful tree that grows out of nothing substantial enough to be called soil. For me, being a scientist gives me the opportunity to ask questions that no one knows the answer to. Then, I get to go out to find the answers.

▲ **Ms. Yvonne Yarber Carter,** Outreach Education Coordinator: Only 5 percent of Hawai'i's dry tropical forest remains. A special science experience was having two different kinds of volunteer groups help with our restoration efforts in the dry forest. We had a group of intermediate students from Hawai'i from a program called *Na Kahumoku*. These students teamed up with a group from Cornell University's Environmental Earth Sciences program. They **mentored** each other. Because *Na Kahumoku* had worked with us many times before, the students had plenty to share about dry forest restoration.

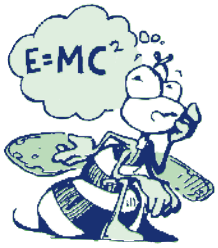
The Cornell students shared science that applied to the restoration. I could feel their excitement about seeing how the trees and shrubs they had planted as seedlings were thriving. That excitement has grown into real commitment, and each year a new Cornell group comes. They measure and record growth data on those trees planted the year before.

When two groups come together in harmony, the days are filled with *aloha,* learning, hope, knowledge, and being part of change for the better. It feels like we can, one day at a time, heal this dry forest budding up out of the lava. In this photo, I am talking to students about the dry forest of *Ka'ūpūlehu* before working on the land. Photo by Keoki Apokolani Carter.

Glossary words are in **bold** and are defined on page 99. Hawaiian words are in *italics* and their pronunciation is given on page 106.

Be sure to read "A Hawaiian View of Dry Tropical Forests" on page 102.

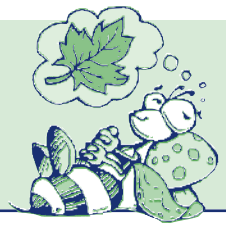
Thinking About Science



Sometimes, a research project is viewed as a case study. A case study is a detailed look at one thing as an example of similar things. Consider the experiences of a student who has transferred into a classroom in the middle of the school year. A detailed study of this student's experience may be done as a case study. The findings from such a study would be used as an example of what other students in the same situation may experience.

In the research you are about to read, the scientists studied a special kind of tropical forest in Hawai'i. This kind of forest is **endangered** in Hawai'i and in other **tropical** regions. The scientists wanted to learn how to **restore** this particular forest. They also wanted to share what they learned with other people hoping to restore this type of forest in other places. They hoped that their research would be used as a case study of how to restore this special type of tropical forest wherever it is found.

Thinking About the Environment



The tropical zone of Earth is a band near the Equator (**figure 1**).
[continues on page 93]

Figure 1. The tropical zone of Earth is an area between the Tropic of Cancer and the Tropic of Capricorn.

Islands with mountains in the tropical zone usually have two distinct sides (**figure 2**). One side is called the windward side. This side is where the winds coming off of the ocean, known as the trade winds, approach the island. In Hawai'i, the trade winds blow from the northeast to the southwest (**figure 3**). As the wind travels up the mountains, the cooler air causes clouds to form. This side of the island has a lot of rain. The forests on this side are called tropical rain forests. The other side of the island is called the leeward side. This side of the island has very little rain, because all the moisture has been lost on the windward side. The forests on the leeward side are called tropical dry forests (**figure 4**).

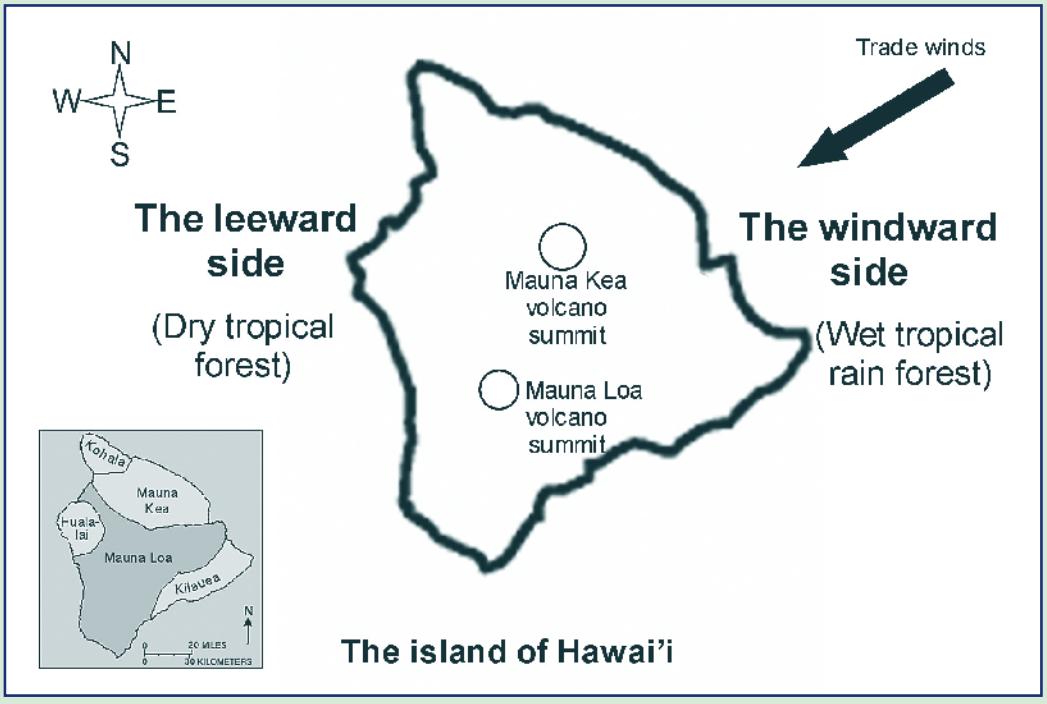
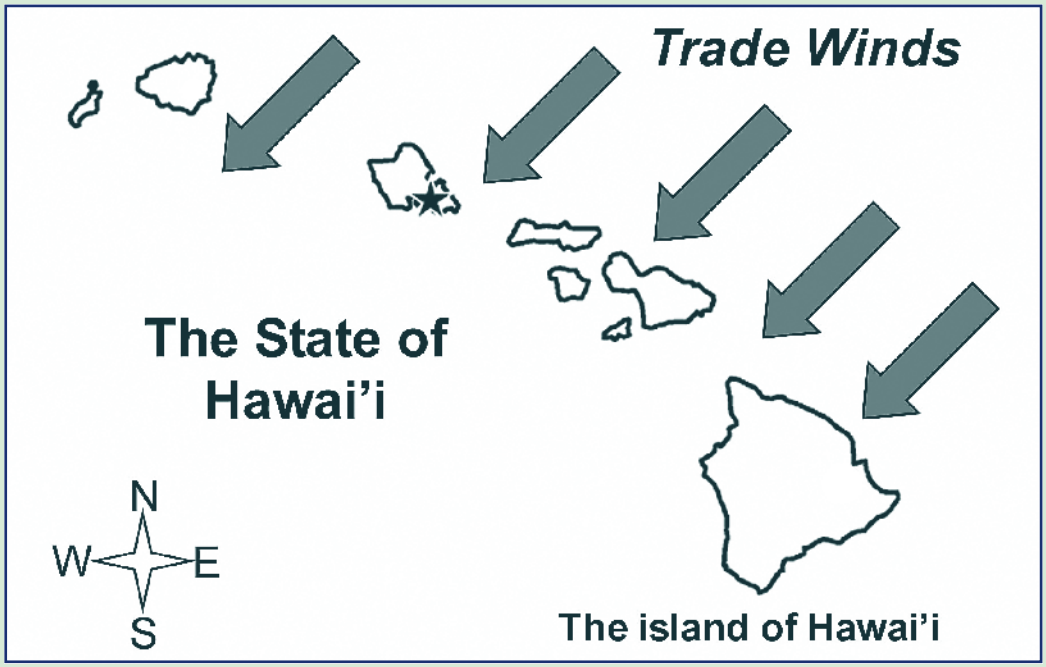


Figure 2. The windward and leeward sides of the island of Hawai'i. The inset shows that Hawai'i is a collection of five volcanoes. Most of Hawai'i, therefore, is mountainous. Inset courtesy of the U.S. Geological Survey (USGS), http://hvo.wr.usgs.gov/maunaloa/.

Figure 3. Hawaiian trade winds blow from the northeast to the southwest.



What is the tropical zone?

The tropical zone is an area north and south of the Equator that is warm all year. In the tropical zone, the sun is directly overhead at least 1 day during the year. Because the climate is warm, land in the tropical zone is home to more than one-third of Earth's human population. The tropical zone is sometimes called the tropics.

Tropical dry forests are one of the most endangered tropical forests. In the past, people allowed cattle and horses to graze in these forests. Wildfires have destroyed many of the dry forests, and people have cleared them to build homes and for agriculture. Invasive **species** have also come into the dry forests, taking over areas that once had **native** species. The scientists in this study wanted to learn how to restore a dry tropical forest in Hawai'i that was in danger of being lost.

Figure 4. Tropical dry forests have little rainfall.

Introduction

The *Ka'ūpūlehu* dry forest is located on the leeward size of the island of Hawai'i (**figures 5 and 6**). The forest land is owned by *Kamehameha* Schools, which is dedicated to preserving traditional Hawaiian culture through education. This forest, like most tropical dry forests, was in danger of being lost as a native ecosystem. In the past, people had cleared the land for agriculture and had allowed cattle and horses to graze on it.

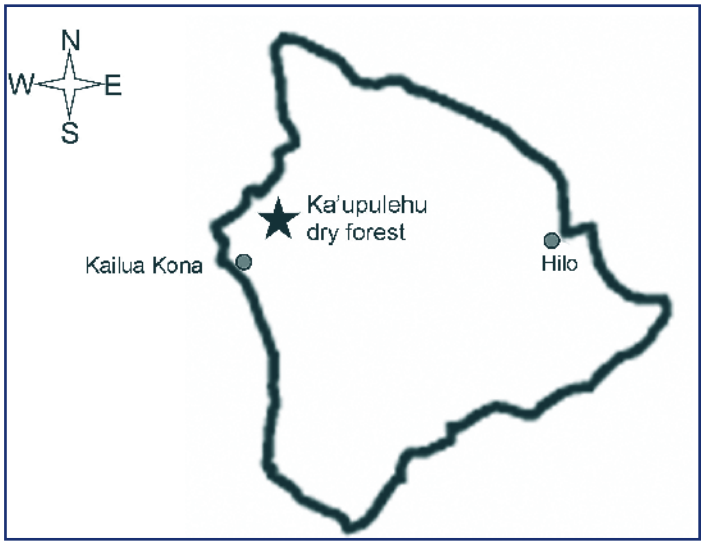


Figure 5. The *Ka'ūpūlehu* dry forest is located at 600 meters **elevation**. It is 25 hectares in size. Average rainfall in the dry forest is less than 750 millimeters per year. Contrast these measurements with rainfall on the windward side of Hawai'i, which is about 3,000 millimeters per year.

Figure 6. The *Ka'ūpūlehu* dry forest on the island of Hawai'i.

With the help of scientists, a group of people began trying to restore the dry forest. When they began, they were not sure of the best way to restore a tropical dry forest. The scientists in this study wanted to understand whether the things the group did to restore the forest were successful. Based on this understanding, the scientists then wanted to develop suggestions to help others to restore dry tropical forests in other areas.

Number Crunches

- What is the elevation of *Kaʻūpūlehu* dry forest in feet? Multiply 600 by 3.28 to find out.
- What is the size of *Kaʻūpūlehu* dry forest in acres? Multiply 25 by 2.47 to find out.
- How much rain falls in Hawai'i in inches? Multiply the amount in millimeters by 0.039 to find out.

Reflection Section

- Why do you think it is important to save native ecosystems?
- What is one way to restore a native forest?
- What question did the scientists want to answer? What did the scientists want to do after they answered their question?

Methods

The scientists first placed a wire fence around the *Kaʻūpūlehu* dry forest (**figure 7**). The fence was built to keep cattle and other grazing animals out of the forest. Hawai'i has no native ungulates (**un** gə lāts: mammals with hooves) so the native plants are not adapted to them. Then, the scientists removed as many invasive plant species as they could. When these efforts did not cause the native forest to return, the scientists decided to try something else.

The scientists removed an invasive grass from the forest. This grass was growing thickly along the ground. They removed the invasive grass by first cutting the grass, then applying a chemical to kill it. The scientists collected native seeds from trees and plants in *Kaʻūpūlehu* dry forest and other nearby dry forests. They

Figure 7. A fence kept cattle and other grazing animals out of the dry forest.

planted the seeds in a greenhouse. As each plant grew large enough, the scientists planted it in the forest ground. From 1999 to 2006, the scientists and others planted almost 5,000 plants (**figure 8**).

Type of plant	Number planted
Trees	2,996
Shrubs	997
Vines	237
Herbs	33
Sedges	4

Figure 8. The types and numbers of native plants planted in the dry forest between 1999 and 2006.

When the scientists planted a plant, they attached a tag to it (**figures 9a and 9b**). This tag contained information about the species of plant and when it was planted. The scientists recorded information from each plant on paper and then entered it into a computer. Unfortunately, 625 plants died before their information was recorded. For these 625 plants, the information was lost. All plants were watered for 6 months after planting to encourage their growth.

The scientists counted the number of living and dead plants and trees according to species in every year except 2004.

Number Crunches

- What was the total number of native plants planted between 1999 and 2006?
- What was the average number of plants planted per year?

Figure 9a and 9b. A tag with information on it was attached to each plant that was planted (9a, top). As the plant grew, the tag remained so that the scientists could track its growth (9b, above).

Reflection Section

- Why do you think the scientists wanted to keep track of each plant species and the date of planting?

- From this method, could the scientists determine whether it was necessary to kill the grass with a chemical after they had cut it? Why or why not?

Findings

From 1999 to 2003, rainfall was below normal. In 2004, *Kaʻūpūlehu* dry forest had the highest rainfall ever recorded there (1,249 millimeters). In 2005 and 2006, rainfall was considered normal. Of the 4,892 plants and trees planted, 1,487 were still alive in 2007. The scientists found 3,357 dead plants and trees and could not find 48 plants (**figure 10**).

Vines were the most successful type of plant, with a 63-percent survival rate. Only 34 percent of the trees were still living in 2007. The Federal Government listed five of the species planted as **endangered species**. These species represented almost 60 percent of the total surviving plants (**figure 11**).

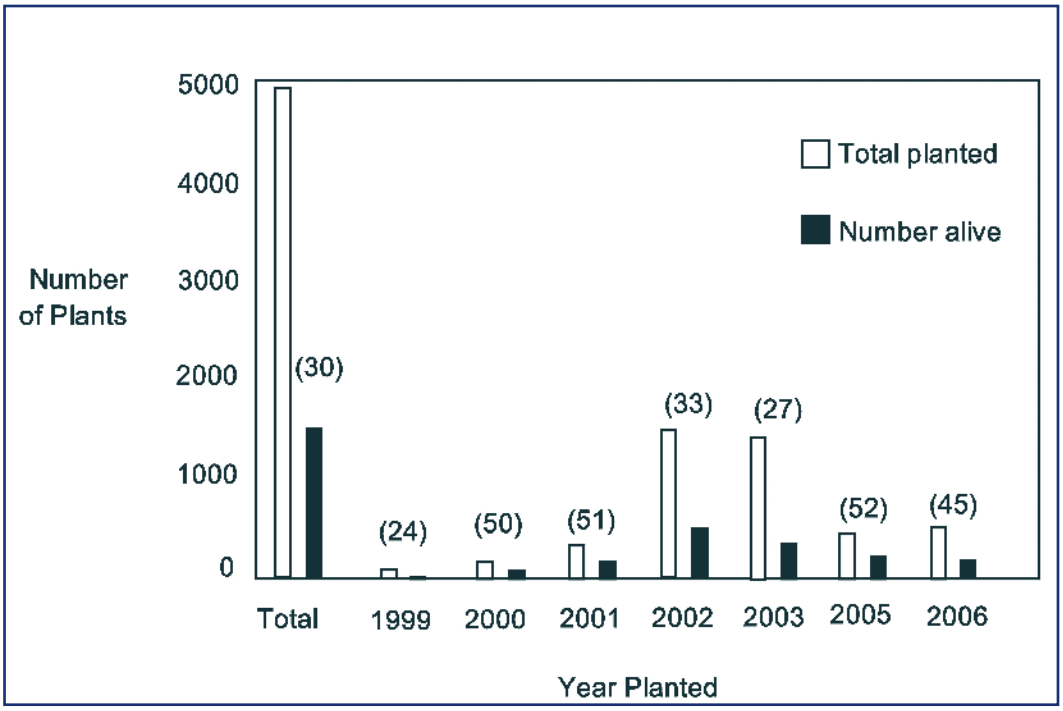


Figure 10. Survival of plants and trees by the year they were planted. The numbers in parentheses represent the percentage of surviving plants.

Scientific name of the endangered plant	Hawaiian name of the plant	Number of plants in the State of Hawai'i before the planting program	Percent increase in the plant population after the planting program
Abutilon menziesii	*Koʻoloaʻula*	450	22
Bonamia menziesii	*No known name*	200	75
Caesalpinia kavaiensis	*Uhiuhi*	42	20
Colubrina oppositifolia	*Kauila*	800	21
Hibiscus brackenridgei	*Maʻo hau hele*	70	146
Kokia drynarioides	*Kokiʻo*	3	9,733
Nothocestrum breviflorum	*ʻAiea*	100	54
Pleomele hawaiiensis	*Halapepe*	300	99
Sesbania tomentosa	*ʻOhai*	100	3

Figure 11. Increase in Federal endangered plant species as a result of the planting effort. When scientists were planting the plants, three *kokiʻo* plants were living in the wild. Scientists now believe that no living *kokiʻo* plants live in the wild in Hawaiʻi.

Reflection Section

- How is the effect of the drought from 1999 to 2003 reflected in figure 10? How is the year of high rainfall reflected in figure 10?
- Examine figures 10 and 11. Would you say the planting effort was a success? Why or why not?

Discussion

Vines had the highest rate of survival. The scientists believe the vines had a high rate of survival because vines grow quickly and can climb over shrubs and trees. Vines, therefore, receive more sunlight and are able to shade out grasses and weeds. The scientists recommend that future efforts to restore native dry forests begin with planting vines. The vines will shade out invasive grasses and weeds. They will also provide shade for future shrub and tree plantings. The shade should increase the rate of survival for shrubs and trees.

The most important finding from this study is what should be done in the future to help restore native dry tropical forests. Although fewer plants and trees survived than the scientists had hoped, they learned many things from this project. In the future, they will do a better job of planning how to restore the dry forest. They will do a better job of keeping track of each plant and tree. They will count the surviving plants and trees more frequently, and they will use technology to help them be more accurate and complete in their research. The scientists concluded that this research was a success. It will help them and other scientists do a better job of restoring native dry tropical forests in the future.

Reflection Section

- State in your own words what the most important finding is from this study. How did the scientists determine this finding?
- How can you apply this finding to your own life?

Adapted from Cordell, S.; McClellan, M.; Yarber Carter, Y.; Hadway, L. 2008. Towards restoration of Hawaiian tropical dry forests: the *Ka'ūpūlehu* outplanting programme. *Pacific Conservation Biology.* 14: 279–284. http://www.fs.fed.us/psw/publications/cordell/psw_2008_cordell001.pdf.

Glossary

Aloha (a **lō** ha): Hawaiian word meaning love, compassion, peace, mercy, or connection. Also used today for both hello and goodbye.

Degraded (dē **grā** dəd): Being in a worse condition than before.

Dense (den(t)s): Marked by compactness or crowding together of parts.

Ecosystem (**ē** kō **sis** təm): A system made up of an ecological community of living things interacting with their environment especially under natural conditions.

Elevation (el ə **vā** shən): Height above sea level.

Endangered (en **dān** jərd): Being in danger or peril.

Endangered species (en **dān** jərd **spē** sēs): A species of animal or plant in danger of becoming extinct or dying off.

Hardwood (**härd** wud): The wood of a tree without cones.

Invasive species (in **vā** siv **spē** sēs): A plant or animal species not native to an area and with the potential to harm the native environment.

Mentor (**men** tör): To tutor or to teach.

Native (**nā** tiv): Plant or animals species living or growing naturally in an environment.

Restoration (**res** tə **rā** shən): The act of bringing back to an earlier condition.

Restore (rē **stör**): To bring back to an earlier or normal condition.

Tropical (**träp** ə kəl): Of, in, or like the tropics, a region of Earth close to the Equator.

Accented syllables are in **bold.** Definitions and marks are from http://www.merriam-webster.com.

FACTivity

Time Needed

1 class period.

Materials

- "Left High and Dry" article, one for each pair of students (or one per student).

The question you will answer in this FACTivity is: If people are able to restore **degraded** ecosystems, is it acceptable to destroy them for our temporary use?

You will answer this question by doing a case study. See "Thinking About Science" for information about case studies. First, read the background information below for this case study. Then, follow the procedure for small group debate and class discussion.

Background

There is a small island off of the coast of the Southeastern United States that is protected by a shore protection law. This law protects the beach and sand dunes of the island. Signs warn visitors not to walk on the dunes, and visitors can be fined if they do so.

The sand dunes are home to millions of species of plant and animal life. They form a natural buffer and protect upland homes, hotels, and other buildings from the tides, winds, waves, and storms. Morning glory vines, ghost crabs, sea gulls, Spanish bayonets, and sea oats all make their home in and around the sand dunes. Many shorebirds lay eggs directly on the sand in the dune area. Even the threatened loggerhead turtles come ashore during the summer months to lay their eggs in the warm sands. The dunes are extremely fragile, and the plants that hold the sand in place are easily killed by foot traffic. All of these communities are protected by the law. It is the goal of the people that own the island to promote the preservation of these natural habitats.

Recently, however, the people responsible for the island allowed a large film company to use almost 5 acres of the island's sand dunes to film an action movie. The movie set had to look like it was in a tropical location. The island is located just north of the tropical zone. To make the dune area look tropical, the existing dunes had to be changed. The film company covered the existing dunes with 4 feet of new sand, covering all the plants and animals living there. They used trucks and machines to create a brand-new dune area. They brought in palm trees from a tropical area and planted them in the new sand.

The people responsible for the area said that it was okay to allow the film company to destroy the existing sand dunes. They made this decision because the film company said they would restore the sand dunes to their original condition when they finished filming. The people responsible for the area said the film company might even make the area better than it was before because some invasive plant species had been growing on the dunes.

Members of a citizens' organization that opposed the change to the existing dunes said that no one had documented what the existing area was like before the film company changed it. Because of lack of evidence, no one knew exactly what they had changed. The citizens' organization did not like the fact that plants and animals had been covered with new sand in a protected area, and that the people responsible for the area did not respect a law intended to protect the dunes.

Method

For this case study, your teacher will divide the class into groups of four students. Two students in each group will take the managers' position that the destruction of the dunes was acceptable, as long as the film company agreed to restore the area. The other two students will take the citizens' position that just because a fragile natural area that is protected by law can be restored, that does not mean it should be destroyed in the first place. With your partner, you should spend 10 minutes thinking about your position and writing out your argument. Then, debate and discuss your position with the other group.

Thinking about this case study and about the restoration of the tropical dry forest, answer the question posed at the beginning of this FACTivity. In a class discussion, consider the restoration of degraded ecosystems. What is similar and different about the restoration of the dry tropical forest and the sand dunes? From these two case studies, what can your class conclude about ecosystem restoration?

Another FACTivity

Using the figure below, calculate the number of endangered plants that survived the *Ka'ūpūlehu* planting program and then calculate the total number of endangered plants of each species growing in Hawai'i. Pretend that you are in charge of taking care of endangered species across Hawai'i following this planting program. Which species would be the most important and why? Discuss your decision in a classroom discussion.

Scientific name of the endangered plant	Hawaiian name of the plant	Number of plants in the State of Hawaii before the research	Percent increase in the plant population after the planting program	Number of plants that survived the planting (Number of plants before times the percent increase; remember the decimal)	Number of plants in the State after the planting program
Abutilon menziesii	*Ko'oloa'ula*	450	22		
Bonamia menziesii	*No known name*	200	75		
Caesalpinia kavaiensis	*Uhiuhi*	42	20		
Colubrina oppositifolia	*Kauila*	800	21		
Hibiscus brackenridgei	*Ma'o hau hele*	70	146		
Kokia drynarioides	*Koki'o*	3	9,733		
Nothocestrum breviflorum	*'Aiea*	100	54		
Pleomele hawaiiensis	*Halapepe*	300	99		
Sesbania tomentosa	*'Ohai*	100	3		

To read about a tropical dry forest in Puerto Rico, see "Some Things Will Always Change" in the Tropical Forest edition of the *Natural Inquirer* (http://www.naturalinquirer.org). What are some of the similarities and differences between these two tropical dry forests?

A Hawaiian View of Tropical Dry Forests

The Hawaiian dry forest was valued in the past for its essential natural resources. The forest was especially prized for its **hardwood** trees. The area where these forests grew had intense heat and a dry atmosphere and landscape. Native plants, therefore, grew slowly. Because of this slow growth, the rings of the tree were close together, creating a strong and durable wood product. The wood of some of these trees was so **dense** it would sink.

Traditional Hawaiian ceremonies make use of the vines and trees growing in tropical dry forests of Hawai'i, such as for *leis* and for *hula*. A *lei* is a necklace that is made from bone, seeds, leaves, flowers, or vines. The best known *leis* today are made from flowers. *Leis* are a symbol of love, connection, or respect. *Hula* is the traditional dance of Hawaiians. It includes chants and traditional musical instruments. **Figure 12** shows the uses of just four of the important trees of Hawaiian dry forests.

Before so many people moved to Hawai'i over the past few hundred years, dry forests

Latin name and status	Hawaiian name, common name, and meaning	Traditional use
Diospyros sandwicensis Endemic: Found only in Hawai'i	*Lama, Elama* Hawaiian ebony, Hawaiian persimmon, enlightenment	*Lele* (platform above a wooden alter), *ho'okupu* to *Lono* (offering to one of the four main *akua*, or gods), placed at *kuahu* (*hula* alters), *pī'oi* (edible fruit), *pupupu hale* (huts constructed from lama) were used as a healing place.
Psydrax odorata Native	*Alahe'e, Ohe'e, Walah'e*	*'ō'ō* (digging stick for gardening), fragrant flowers or seeds used in *lei,* leaves used for black dye for *kapa* (clothes or bed clothes made from bark of native plants), *'au ko'i* (adze handles; handles for a tool used to cut wood), *kao* (fishing spears), *makau* (fish hooks) and *ko'i* (adzes), *ama* (outrigger float)
Dodonaea viscosa Native	*'a'ali'i,* Hawaiian hopseed bush A reference to the people of *Ka'ū, 'a'ali'i,* standing in the wind	Seeds boiled to make red *kapa* dye, fruit and leaves used in *lei,* crushed leaves provided relief from rashes and contagious diseases, spears for *he'e* (octopus), bait stick.
Erythrina sandwicensis Endemic	*Wiliwili* *Hawaiian coral tree, tiger's claw*	*Olo* (large surfboard for nobility), fishing gear containers, seeds produced permanent *lei,* flowers for *lei.*

Figure 12. Some trees of Hawaiian dry forests.

could be found in all the leeward coastal areas of the islands. Today, only a small percentage of tropical dry forest land is left in Hawai'i.

Throughout time, Hawaiians have viewed the island's natural resources as a source of wealth. Native Hawaiians express their kinship with all life through their respect for natural resources. The *lama* tree, for example, is recognized as a *kinolau*, the physical form of *Lono*, one of the four main Hawaiian gods (**figure 13**). The *lama* tree, therefore, is sacred to Native Hawaiians. Notice the uses of the *lama* tree in the figure on page 102.

Hawaiians today recognize the importance of dry tropical forests. As you read in this article, Hawaiians are taking steps to restore these valuable forests. In some communities, this restoration has become a community celebration. Take a look at the flower mural that serves as the background of the journal cover and is found at the beginning of this article. This mural was painted by Hawaiians age 7 to 60 who care about the dry tropical forests of Hawai'i. They have used their *aloha* to create a mural to celebrate and learn about dryland forests.

"Left high and dry" was first used to refer to a ship that was beached. It is now used to indicate that someone or something has been left stranded or abandoned.

Figure 13. Lama *tree. Photo by Dr. J.B. Friday.*

Additional Web Resources

Hawaiian dryland forests–Can they be restored?
http://www.hawaiiforest.org/reports/dryland.html

Tropical dry forests of the Pacific–Hawaiian Islands:
http://www.geog.ucla.edu/tdfpacific/hawaii.html#bigisland

Slideshow of Hawaiian dryland native plants:
http://www.drylandforest.org/home-slideshow-dryland-natives

Native dryland trees and their flowers:
http://www.drylandforest.org/native-dryland-trees-their-flowers

National Geographic Kids—Hawai'i Tropical Dry Forests:
http://www.nationalgeographic.com/wildworld/profiles/terrestrial/oc/oc0202.html

References:

http://www2.hawaii.edu/~eherring/hawnprop/dio-sand.htm
http://nativeplants.hawaii.edu/plant/view/Diospyros_sandwicensis

National Education Standards

National Science Education Standard	Where and How the Standard Is Addressed
Abilities Necessary To Do Scientific Inquiry	Introduction: A research question asked to address a problem. Introduction Reflection Section: Articulating a research question. Methods: What the scientists did before collecting data, the use of tags to keep track of plants (also figures 9a and 9b), data collection (counting). Methods Reflection Section: Importance of recordkeeping, are data sufficient to draw a conclusion? Figure 10: Drawing conclusions from data. Findings Reflection Section: Interpreting data and drawing conclusions. Discussion: The importance of planning future studies. Discussion Reflection Section: Communicating findings.
Understandings About Scientific Inquiry	Meet the Scientists: Scientists get to answer new questions. Thinking About Science: Case studies. Introduction: Research is done to solve problems. Introduction Reflection Section: The importance of keeping track through tagging plants. Methods: The loss of information because of poor recordkeeping. Figures 9a and 9b: Record keeping. Methods Reflection Section: Importance of recordkeeping. Discussion Reflection Section: Application of science to one's own life.
Populations and Ecosystems	Thinking About the Environment: Dry tropical forests and invasive species. Introduction Reflection Section: The importance of protecting ecosystems.
Structure of Earth System	Thinking About the Environment: The tropical zone, trade winds, and tropical forest types. Figures 1–5: Geographic features of Hawai'i. What is the tropical zone?: The tropical zone.
Populations, Resources, and Environments	Thinking About the Environment: Human destruction of native dry forests. What is the tropical zone?: Human population in the tropical zone.
Natural Hazards	Thinking About the Environment: Wildfires and dry forest destruction.
Risks and Benefits	Thinking About the Environment: People benefitted from grazing but risked the destruction of the dry forest.

Science and Technology In Society	Entire article: Student scientists gaining enthusiasm and commitment as a result of scientific work. Discussion Reflection Section: Applying results to own life.
Science as a Human Endeavor	Meet the Scientists: Science as a favorite experience. Discussion Reflection Section: Applying scientific findings to one's own life.
Nature of Science	Meet the Scientists: Proceeded even though some thought their ideas would not work. Discussion: Scientists make mistakes and learn from them for the future.

National Curriculum Standards for Social Studies	Where and How the Standard Is Addressed
Culture	A Hawaiian View of Tropical Dry Forests: Past cultural uses.
People, Places, and Environments	Meet the Scientists: People helping the environment. A Hawaiian View of Dry Tropical Forests: Historic and contemporary value of dryland forests.
Global Connections	Meet the Scientists: Outreach with college students. Thinking About Science: Research may be used in other areas of the tropics. FACTivity: Case study in Georgia.
Production, Distribution, and Consumption	A Hawaiian View of Tropical Dry Forests: Using dryland forest products for ceremonies and other uses.
Civic Ideals and Practices	FACTivity: How should we treat our commonly held natural resources?