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

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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Acknowledgements

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Table of Contents

Introduction

Hōʻike o Haleakalā

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

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.

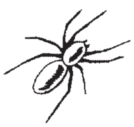
Today's young people have the future of Hawai‘i in their hands. They need to know the value of our natural and cultural environment before they can be active stewards. *Hō‘ike o Haleakalā* is a celebration of this unique heritage, an exploration of the modern landscape, and an invitation to stewardship.

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.

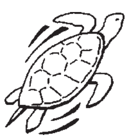
Curriculum Components

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

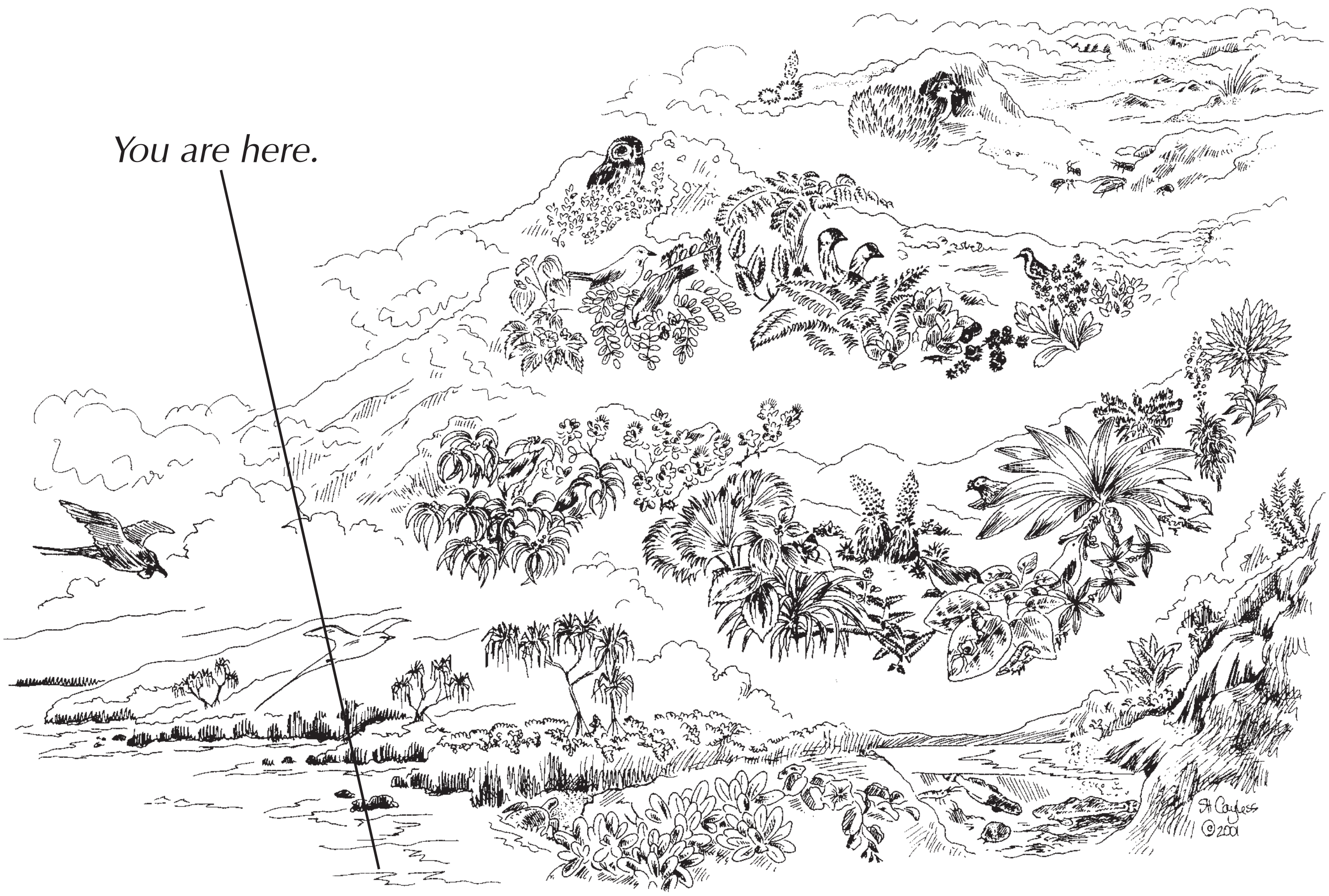
A complement of additional resources such as reports, game boards, reference books, and video tapes accompanies this curriculum. See notations within individual activities that indicate these materials. Where possible, these materials are included in a pocket that accompanies the relevant unit. Resources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

Marine Module



● ● ● What Does the Marine Zone Mean to You?

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

From the sea we have ventured and to the sea we glimpse our future. From the shallow sands that skirt Haleakalā to the depths of her foundation three miles below, the sea sustains Haleakalā, holding her high, forever reaching to the sun.

—Eric Andersen

Surfing, diving, fishing
Looking up at the mountain from the ocean
Watching fish watching me

—Kim Martz and Forest Starr

I think of the gardens of coral and how people are screwing it up. I think of people overfishing, overusing the resources. I think of people looking for immediate satisfaction and not worried about tomorrow.

—Kalei Tsuha

Illustration: John Dawson

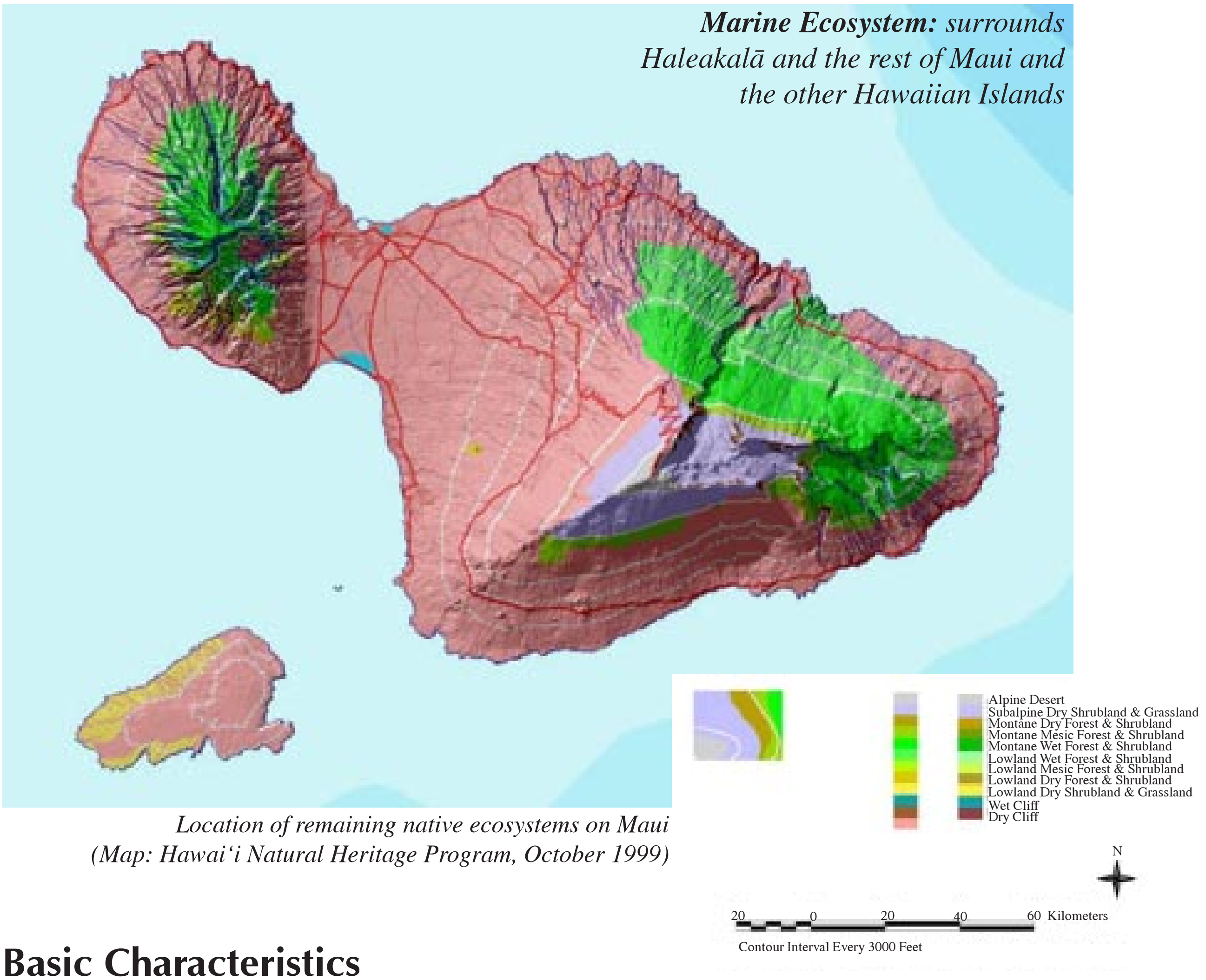
Ku mai! Ku mai!	Arise! Arise!
Ka nalu nui mai Kahiki mai.	Great surfs from Kahiki.
‘Alo po‘i pu!	Waves break together!
Ku mai i ka pohuehue	Rise with the *pohuehue*
Hu! Kaiko‘o loa!	Well up, raging surf!

Jane Gutmanis, Na Pule Kahiko: Ancient Hawaiian Prayers,
Editions Limited, Honolulu, Hawai‘i, 1983, p. 101.

● ● ● Ecosystem Summary

Where on Haleakalā?

Marine ecosystems surround Haleakalā, from the shallow waters often found near shore to deeper waters further offshore. The intertidal area between high- and low-tide lines is also considered a part of the marine environment because of its exposure to ocean water and the marine organisms that live there.



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

Basic Characteristics

The marine ecosystem is characterized by constant or regular inundation by salt water. Marine plants and animals are distributed in more or less distinct zones which are distinguished by the island's age, the amount of reef growth, exposure to wave action (determined in part by geographic orientation), light and temperature (functions of depth), and latitude.

Marine habitats include coral reefs of various types, boulder fields, sandy bottoms, areas where the reef drops steeply to great depths, and caves, caverns, and lava tubes. An incredible array of plants and animals live in these habitats, many of which are commonly encountered by snorkelers and divers. These plants and animals display a wide range of adaptations to different marine environments, from the tube feet with which sea stars move and attach themselves to stable surfaces to the hardened "beak" with which parrotfish feed on algae from the surface of dead coral, turning the coral structure into sand in the process.

Did You Know?

Compared to many other western Pacific island groups, the oceans surrounding Hawai'i are relatively species-poor. Looking at shallow-water species of corals, mollusks, echinoderms, and fish is illustrative:

Corals	Hawai'i: 17 genera and subgenera Marshall Islands: 59 Line Islands: 59
Marine Mollusks	Hawai'i: 1000 species Ryukyu Islands: 2500
Echinoderms (e.g. sea urchins, sea stars)	Hawai'i: 90 species Philippines: 345
Reef and Shore Fish	Hawai'i: 700 species Marshall Islands: 1000

This *attenuation*, or lessening, of species diversity in Hawai'i as compared to other island groups in the western Pacific can be explained in large part by geographic isolation. Hawai'i is far away from continents and other major islands and reef systems, separated by distances that do not favor species with short larval stages. The west coast of North America is 3900 kilometers (2400 miles) away, and Japan is 6100 kilometers (3800 miles) away. The Society Islands lie some 4400 kilometers (2750 miles) to the south in the South Pacific Ocean. Like other Pacific island groups that are rich in marine life, the Society Islands are separated from Hawai'i by ocean currents that do not favor the dispersal of marine life. In addition, Hawaiian waters are cooler in the winter, and nearshore habitats are exposed to destructive storm waves from both the Arctic and Antarctica. In this harsh, mostly subtropical marine environment, fewer species can exist than in the equatorial and tropical western Pacific.

Status and Threats

Hawaiian marine ecosystems are relatively healthy in comparison to many other places around the world. But human pressures still degrade these ecosystems, particularly the near-shore environment. Long-term fishing catch trends suggest a dramatic decline in the nearshore fishing stocks during the 20th century, perhaps as much as 80 percent. Three factors are probably responsible for this decline:

- Overfishing,
- Inability to enforce existing regulations and implement new fishing restrictions,
- Habitat degradation caused by coastal development and pollution.

Other threats to marine ecosystems include alien species (including fish and algae), heavy recreational use of beach and reef areas, shoreline modifications such as seawalls, land uses that contribute to sediment runoff, sewage and industrial pollution, and harassment or feeding of marine animals.

● ● ● 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.

In traditional Hawaiian society, the ocean and marine life were as familiar as landforms and terrestrial life. The ocean was a source of food and other resources needed for living, as well as a “highway” between shoreline locations and between islands. Living in such close association with the ocean, early Hawaiians were skilled in swimming, navigating, fishing, and aquaculture.

Early Hawaiians were equally at home on land and in the sea. In their cultural traditions, most of the important land creatures had ocean-dwelling counterparts. A counterpart of the humpback whale, for example, was the sandalwood tree. In some cases, Hawaiian *kāhuna* could accept the ocean counterpart for an offering to the gods if the land creature could not be offered.

Like many land animals, certain marine animals could become *‘aumākua* or personal gods that were regularly fed and recognized as individuals. Sharks and turtles were common *‘aumākua*.

Hawaiians knew that the ocean was a great reservoir of food for them, and fishing, collecting shellfish, tending fish ponds, and gathering *limu* were constant, necessary occupations. Conserving the supply of the ocean’s important resources was also a necessary part of Hawaiian culture and society. In traditional Hawaiian society, the ocean was treated like an icebox. Hawaiians took only what was needed at a specific time, knowing that what they needed in the future would be there then. Conservation was based on the understanding that greediness or waste would displease the gods, and on a knowledge of the life cycles and behaviors of each marine species.

The *kapu* system, which regulated all aspects of society, applied to fishing as well. Certain activities were prohibited or restricted to particular locations or seasons. For example, fishing for certain species during their spawning season was prohibited. Since different fish species spawned in different seasons, there was always food available and the reproducing fish were protected. Other *kapu* applied to fishing in specific inshore areas to allow populations of fish, shellfish, and *limu* to rebound. There was also a rule that ensured that all of the fish would not be removed from any given feeding area (or *ko‘a*).

● ● ● 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?
- What comes to mind when you think of the ocean? What are your favorite areas and memories?
- Do you fish or gather sea life? Or do you know someone who does? What have you learned about the ocean from this person or this activity?

● ● ● To Get a Feel for the Marine Zone

If you are not doing Marine Unit 2, Activity #1 “Adaptation Concentration,” you may use the Waikiki Aquarium video *Far from the Cradle* (included with this curriculum) to provide an overview of the Hawaiian marine environment for any of the units. Another overview video is the Island Heritage production *The Underwater World of Hawai‘i* (available from Island Heritage, Aiea, Hawai‘i, telephone (808) 487-7299, website at <www.islandheritage.com>).

● ● ● Marine Units at a Glance

Unit 1
Riding the Currents

Subjects

Dispersal of marine life
Oceanic currents in the Pacific Ocean
Endemism

Importance

As the Hawaiian Islands formed, marine life arrived here from other parts of the Pacific Ocean to become what we know as the native marine life of the islands. The ongoing dispersal of marine life depends upon ocean currents and the life cycle of marine organisms.

Activities in this unit

- Navigating the Currents
  Students plan a trip and course for a hypothetical Polynesian canoe voyage to learn some of the primary oceanic currents and wind patterns in the Pacific Ocean.

- Dispersing on the Currents
  Students learn about marine life reproduction and dispersal, and apply that knowledge to explain the dispersal of marine animals to Hawaiʻi.

Unit 2
Marine Relationships

Subjects
Marine species
Adaptations
Trophic levels and food webs
Cultural significance of marine organisms

Importance
Marine organisms exist in specific environments or habitats to which they are well adapted. Understanding relationships among organisms, between organisms and their environment, and between people and marine life is one key to understanding the marine ecosystem.

Activities in this unit
- Adaptation Concentration
  Students watch a video and play a game to learn about native Hawaiian marine animals and how they are adapted to the marine environment.

- Marine Food Webs
  Students create food webs using native Hawaiian marine organisms and examine the effect of bioaccumulation on the flow of toxic organisms through these webs.

- Marine Life Scrapbooks
  Students assemble scrapbooks about the natural history and cultural significance of native Hawaiian marine species.

Unit 3
On the Edge: Living in the Intertidal Zone

Subjects

Intertidal habitats
Zonation
Marine species
Adaptations

Importance

The intertidal zone is a small part of the marine environment of Haleakalā, but one that many students may be familiar with because of its cultural significance. Environmental conditions vary dramatically in the intertidal zone. Studying the conditions and organisms of this zone helps students understand the concept of zonation and provides a complement to the focus on sandy beaches in Coastal Unit 1 "Beach Today, Gone Tomorrow?"

Activities in this unit

- Intertidal Zonation
  Students work in groups to understand environmental conditions within the five subzones represented in intertidal areas, and how Hawaiian marine organisms are adapted to survive in these conditions.

- A Day in the Neighborhood: Skits About the Intertidal Zone
  Student groups develop and perform skits to teach the class about environmental conditions, organisms, and adaptations within an intertidal subzone.

Unit 4
Keeping an Eye on Coral Reefs

Subjects
Coral reef ecology
Coral reef study and monitoring techniques

Importance
Hawaiian coral reefs may generally be in better shape than reefs in many other parts of the world. Still, people are putting pressure on Hawaiian coral reefs, and the extent of our impact is not always known. That is why studying and monitoring coral reefs is so important.

Activities in this unit
- Coral Reef Monitoring Simulations
  Through simulated exercises, students learn some fundamental skills and techniques used in monitoring coral reefs.

- Protecting Coral Reefs
  Students perform Internet research on one of the main threats to coral reefs in Hawai‘i and around the world.

Unit 5

Marine Management

Subjects

Science-based management
Conservation
Current issues in marine management

Importance

Since the time of the early Hawaiians, people have been making rules governing the use of the ocean and marine life. This unit helps students explore the types of rules used for conserving marine species and habitats as well as how science can contribute to making these rules.

Activities in this unit

- "Weren't There More of Us?" Game
  Students play a game to learn about Hawaiian reef animals and regulations intended to protect them.

- Impact of Aquarium Fish Collecting on Coral Reefs
  Students read a study of the impact of aquarium fish collecting and interpret data from that study.

- Design a Monitoring Study
  Using research design principles learned from the aquarium fish-collecting study, students design their own marine-monitoring study.

- Marine-Management Research Projects
  Students undertake research projects on marine-management topics of their choosing.

● ● ● 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 marine 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

Maui Ocean Center

Description

Self-guided tour with naturalist presentations

A naturalist greets every student group and makes an initial presentation at one of three main stations in the center. Students then tour the facility in small groups, seeing all of the exhibit areas including the Discovery Pool, Open Ocean, and Stingray Cove. Naturalists make formal presentations on a regular basis throughout the morning.

You will receive a curriculum packet in advance of your field trip that will help you link your classroom activities to the field trip.

Field Trip Time

Two hours for the self-guided tour, plus 1/2 hour for lunch

School groups may visit the Maui Ocean Center Tuesdays and Fridays from 9 a.m. to 12 p.m.

What to Bring

- Have students bring their own lunch or add lunch from the Maui Ocean Center for an additional per-student fee.

Group Size Limits

None

Contact

Call the Education Department at 270-7000 Ext. 119 at least two weeks in advance to make arrangements.

Fees

Per-student fee of $5, one chaparone per 8 students is admitted free.

Getting There

The Maui Ocean Center is located at 192 Māʻalaea Road, about seven miles from Wailuku.

Pacific Whale Foundation

Description

Several standard programs are available, as well as custom-tailored programs for your class.

- *Ocean Van* brings the foundation's educators to your school. Presentations include a multi-media presentation, lecture, and time for student questions. Specific objectives are prearranged with teachers.

- *Whalewatch* excursions involve high school students in basic whale research techniques, available January through April.

- *Marine Debris Beach Survey* involves students in surveying a local beach to analyze the marine debris problem.

- *Tide Pool Exploration* involves students in identifying and observing common Hawaiian reef species, practicing sound field techniques, collecting data on marine debris, and learning about factors determining beach formation.

Pacific Whale Foundation programs can also be combined with a visit to Maui Ocean Center.

Field Trip Time

- *Ocean Van* visits involve up to two presentations that last one class period each.

- *Whalewatch* excursions are 1 1/2 hours long, not including travel time.

- *Marine Debris Beach Survey* takes two hours spent at each of one or more survey locations.

- *Tide Pool Exploration* takes one or more hours, dependent on tides and additional activities selected.

What to Bring

- Requirements depend upon the program selected. Check with the Education Department for details.

Group Size Limits

- Two presentations per *Ocean Van* visit, with each accommodating up to 40 students

- *Whalewatch* excursions, 100-125 (includes students and adults)

- *Marine Debris Beach Survey*, 15-30 students per survey site

- *Tide Pool Exploration*, maximum 60 students

Contact
Call the Education Department at 879-8860 to request an Ocean Outreach Programs brochure, which covers all of the foundation's class presentations and field excursions, or to develop a custom-tailored program for your class.

Fees
Ocean Van visits cost $30.00 per visit (for up to two presentations). Some field trips (e.g., the whalewatch excursion) involve per-student fees, while most are free of charge.

Getting There
Location depends upon the field excursion chosen

Hawaiian Islands Humpback Whale National Marine Sanctuary

Description
Sanctuary staff generally offer field trips for grade school groups but will work with high school teachers to design an educational experience appropriate to the class and learning objectives. Educational resources include humpback whale exhibits and specialists, a traditional Hawaiian fishing pond and an on-staff Hawaiian culture expert, a *lānai* that offers excellent whale viewing from December through April, and populations of many native coastal plants. Adjacent beach parks offer opportunities to explore sand dune ecology or sea turtle nesting, or collect *limu* as a focal point for learning about its uses.

Field Trip Time
Flexible, depending upon the schedule you arrange with Sanctuary staff

What to Bring
Depends upon specific field trip plans

Group Size Limits
None
Larger classes may be divided into smaller groups to rotate through several learning stations.

Contact
Call the education coordinator at 879-2818.

Fees
None

Getting There
The Hawaiian Islands Humpback Whale National Marine Sanctuary office is located at 726 S. Kihei Road, approximately 13 miles from Wailuku.

Connecting Your Field Trip to the Marine Module

Here are some ideas for student assignments that link the field trip to the classroom activities of the marine module:

- During the field trip, have students identify and make a list of species they see that they learned about in Marine Unit 2 (all activities); Unit 3, Activity #1 “Intertidal Zonation”; and Unit 4, Activity #1 “Coral Reef Monitoring Simulations.”

- Have students take notes about or make a visual representation of marine relationships they learned about on the field trip.

- Have students make journal entries about reproductive strategies used by different marine organisms, how marine species are adapted to live in different environments, or major threats to the marine environment.

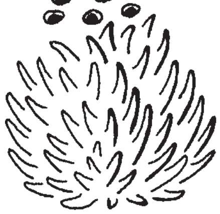
Extensions

- Maui Ocean Center offers volunteer opportunities. Beach clean-up and other service projects may be arranged by calling the Education Director at 270-7000 Ext. 128.

- The Pacific Whale Foundation makes available two programs for individual students or pairs of high school students. Contact the Education Department at 879-8860 for details.
  - *Student Naturalists* involves students in independent research on a marine science topic of their choosing. A marine biologist reviews this research before students present it to the public on board the foundation’s regular public educational cruises.
  - *Career Shadowing* involves students in half-day “shadowing” interactions with a charter boat captain, field research marine science naturalist, public information liaison, or retail associate. Students learn about the training required and daily responsibilities of individuals in these occupations.

- Project S.E.A.-Link offers a *High School Naturalists* program in which students are trained to share information about the marine environment with customers on snorkel boats. Call Project S.E.A.-Link at 669-9062 for details or e-mail info@projectsealink.org.

- Reef Environmental Education Foundation (REEF) carries out its mission to educate and enlist divers in the conservation of marine habitats primarily through its *Fish Survey Project*. REEF surveys are conducted as part of a diver’s regular diving activities, anytime they are in the water. For more information, see REEF’s website at <www.reef.org>.

Marine Unit 1

Riding the Currents

Overview

For millions of years, plants and animals have been making their way to the Hawaiian Islands with the help of air and ocean currents. Beginning with the Polynesians who voyaged here, humans have been similarly assisted in reaching Hawai‘i. This unit engages students in exploring how marine life reached the Hawaiian Islands. Planning a course for a hypothetical Polynesian canoe voyage from the South Pacific to Hawai‘i provides a context in which students begin to understand the oceanic currents that helped determine the geographic origin of Hawaiian marine species.

Length of Entire Unit

Two class periods

Unit Focus Questions

1) What major oceanic currents influence the origins of Hawaiian marine species?

2) How did marine life disperse throughout the Pacific Ocean?

3) How do origin, means of dispersal, and island location influence the species variety and rate of endemism among Hawaiian invertebrates?

Unit at a Glance

Activity #1

Navigating the Currents

Students plan a trip and course for a hypothetical Polynesian canoe voyage to learn some of the primary oceanic currents and wind patterns in the Pacific Ocean.

Length
One class period

Prerequisite Activity
None

Objectives

- Apply knowledge of major Pacific Ocean currents to create a sailing plan and course heading for a Polynesian canoe voyage between the South Pacific and Hawai‘i.

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.

Activity #2

Dispersing on the Currents

Students learn about marine life reproduction and dispersal, and apply that knowledge to explain the dispersal of marine animals to Hawai‘i.

Length
One class period

Prerequisite Activity
Activity #1 “Navigating the Currents”

Objectives

- Describe the life cycle of marine animals that have planktonic larval phases.
- Explain how marine life is dispersed throughout the Pacific Ocean, using knowledge of marine animal life cycles, ocean currents, and other factors that influence the composition of Hawaiian native marine life.
- Hypothesize about why the rate of endemism among Hawaiian marine invertebrates is lower than the rate of endemism among Hawaiian terrestrial insects.

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.

Enrichment Ideas

- Do Internet and library research to compile a collection of images of adult marine animals and the larval phases of the same species to provide a visual context for Activity #2 “Dispersing on the Currents.”

- Research the problem of marine debris in the Hawaiian Islands, analyzing the influence of oceanic currents on the origin of marine debris found here and the location of problem areas for marine debris on the islands.

Resources for Further Reading and Research

Polynesian Voyaging Society, “Hawaiian Star Compass” at <leahi.kcc.hawaii.edu/org/pvs/navigate/stars.html>.
    Explanation of the Star Compass and how it is used for navigation

Kawaharada, Dennis, Polynesian Voyaging Society, “Wayfinding, or Non-Instrument Navigation” at <leahi.kcc.hawaii.edu/org/pvs/navigate/navigate.html>.

Kay, E. Alison and Stephen R. Palumbi, “Endemism and Evolution in Hawaiian Marine Invertebrates,” in Kay, E. Alison, (ed.), *A Natural History of the Hawaiian Islands: Selected Readings II,* University of Hawai‘i Press, Honolulu, 1987, pp. 346-353.

Scheltema, Rudolf S., “Long-Distance Dispersal by Planktonic Larvae of Shoal-Water Benthic Invertebrates among Central Pacific Islands,” in Kay, E. Alison, (ed.), *A Natural History of the Hawaiian Islands: Selected Readings II*, University of Hawai‘i Press, Honolulu, 1986, pp. 171-186.

Moanalua Gardens Foundation and Computer Visualizations, Inc., *Sea Search: Exploring Tropical Marine Life* CD-ROM, Moanalua Gardens Foundation, Honolulu, 1996.

Activity #1

Navigating the Currents

● ● ● In Advance *Student Reading*

Assign the Student Page “Navigating the Currents” (pp. 15-19) as homework. (Students should bring this reading to class with them.)

● ● ● Class Period One *Charting a Course*

Materials & Setup

- “Map of Pacific Ocean Currents” acetate (master, p. 12)
- “Reference Course and Course Heading Map” acetate (master, p. 13)
- “Map of Currents Between Hawai‘i and Nuku Hiva” acetate (master, p. 14)
- Overhead projector and screen

For each group of three to six students
- Student Page “From Nuku Hiva to Hawai‘i: Charting a Course” (pp. 20-27)

For each student
- Student Page “Navigating the Currents” (pp. 15-19)

Instructions

1) Show the “Map of Pacific Ocean Currents” acetate to put Hawai‘i and Nuku Hiva (in the Marquesas Islands) in context. Ask students if they know which main South Pacific island group the islands of Hiva belong to. (They are in the Marquesas, a part of the “French Polynesia” group of islands.)

2) Divide the class into groups of three to six students. Explain that each group is a team in a voyaging canoe race from Nuku Hiva to Hawai‘i. There are just a few more details to complete in planning their journey before they can set sail.

3) Give each group a copy of the Student Page “From Nuku Hiva to Hawai‘i: Charting a Course.” Groups should work cooperatively to complete the assignment quickly and accurately. The rest of the crew of *Hōkūle‘a* is waiting for them—the wayfinders—to complete their work.

4) Allow groups about 20 minutes to complete the student page. If no groups are finished at the end of 20 minutes, you may allow more time. If a few groups finish before 20 minutes are up, quickly check their work to see if there are any obvious flaws they need to correct.

5) When all groups have finished, review the assignment asking groups for their responses to each of the tasks on the student page. Use the teacher version of the Student Page “From Nuku Hiva to Hawai‘i: Charting a Course” (pp. 9-11) and the “Reference Course and Course Heading Map”

acetate (which charts the correct course headings). As additional background, you may use the "Map of Currents Between Hawai'i and Nuku Hiva" and the notes in the Teacher Background "Wind and Current Zones in the Pacific" (pp. 7-8).

Journal Ideas

- If you were an ancient Polynesian setting off to settle a distant island, what would you take with you for the trip? What would you take with you to survive in your new home?
- After a month or more at sea, what do you think it feels like for voyagers to sight land?
- What do you think you would feel if you were a voyager stepping ashore? Write a chant or poem that reflects those feelings.
- How do you think Polynesian navigation compares to the way in which fish, corals, and other marine animals originally reached the Hawaiian Islands? Explain your reasoning.

Assessment Tools

- Student Page "From Nuku Hiva to Hawai'i: Charting a Course" (teacher version, pp. 9-11; correct course headings charted on "Reference Course and Course Heading Map" acetate, master, p. 14)
- Participation in group work and class discussions
- Journal entries

Teacher Background

Wind and Current Zones in the Pacific

Based on "Winds, Weather, and Currents of the Pacific" from the Polynesian Voyaging Society website at <leahi.kcc.hawaii.edu/org/pvs>, June 2000. Quotations are from William G. Van Dorn, Oceanography and Seamanship*, 2nd ed., Cornell Maritime Press, Centerville, Maryland, 1993.*

Voyagers among the islands of Polynesia travel through several different zones marked by distinct wind and current patterns. This summary will help you understand these zones and explain them to students.

Northeast Trade Wind Belt (25° N to 9° N)

Winds

- Northeast trade winds, generally from the east, north east (ENE or *ʻAina Koʻolau*)
- Ten to twenty knots
- Produced by air circulating clockwise around an area of high pressure centered northeast of Hawaiʻi
- Summer: trade winds prevail about 90 percent of the time
- Winter: trade winds blow 40-60 percent of the time and are more easterly and generally lighter. Episodes of strong, gusty trade winds are a bit more frequent than during the summer months. Occasional Kona storms bring southerly winds and rain. Winter and spring cold fronts from storms in the North Pacific bring southwesterly winds and rain, followed by cool, dry northerly winds.
- Squalls in the trade wind flow may carry brief bursts of wind up to 40 knots.

Currents

- North equatorial current driven by northeast trade winds
- West-flowing at about .5 knots (12 nautical miles per day)

Intertropical Convergence Zone—ITCZ (varies between 10° N to 0°)

The ITCZ shifts around but, on average lies between 9° N and 3° N between Hawaiʻi and South Pacific island groups such as the Marquesas and Tahiti Nui.

Winds

- Variable, generally out of the east (*Hikina*)
- Zero to ten knots
- Conditions caused by converging winds from the northeast and southeast trade wind belts and warm air rising from equatorial waters
- Doldrum conditions: variable winds, calms, thunderstorm activity, and dense cloud cover
- The zone is characterized by an "impressive wall of clouds," and a "confused state of the swell, flukey winds that blow intensely and then subside, and intermittent showers of rain that come from nowhere in a solid, opaque overcast" (Van Dorn).

- The light, shifting winds and the confused swells and cloud cover make sailing slow and navigation difficult.
- Sometimes, however, cloudless skies and easterly winds prevail across the zone.

Currents

- Equatorial countercurrent
- East-flowing, but unpredictable
- Sporadic and shifting
- Generally weakest in May/June and strongest in September through November, when its speed can reach about one knot
- Occasionally becomes stronger (This happened in 1992, for example, when the El Niño weather condition brought westerly winds and dangerous winds to the southern Pacific.)

Southeast Trade Wind Belt (0° to 25° S)

Winds

- Southeast trade winds, generally from the east (*Hikina*), east by south (E by S or *La Malanai*), or east by south east (ESE or *‘Aina Malanai*)
- Ten to twenty knots
- “Generally stronger, steadier, and cover a much wider zone of latitudes” (Van Dorn) than the northeast trade winds
- Produced by air circulating counterclockwise around an area of high pressure centered around 30° S and stretching westward off the coast of South America
- During the southern hemisphere summer and fall (December-April), infrequent hurricanes form around Tahiti.

Currents

- South equatorial current, driven by southeast trade winds
- West-flowing at .5 knots

For More Information

- On the global air circulation patterns that cause the trade winds and westerlies, see Alpine/Aeolian Unit 2 “Summer Every Day and Winter Every Night,” for background.
- On ocean currents and what causes them see Pierre Flament, et al., “The Ocean,” *Atlas of Hawai‘i*, 3rd ed., University of Hawai‘i Press, 1998, pp. 82-86.

Teacher Version

From Nuku Hiva to Hawai'i: Charting a Course

Task #1: Check the Weather

Safest month or months for *Hōkūle'a* to sail:

April or May (or both)

Rationale:

To avoid the likelihood of either winter storms or hurricanes in either hemisphere

Task #2: Confirm Your Target Screen

Sighting distances and calculations:

Mauna Kea Square root 9 + square root 13,796 = Distance
3 + 117.5 = Distance
120.5 nautical miles

Haleakalā Square root 9 + square root 10,023 = Distance
3 + 100.1 = Distance
103.1 nautical miles

Kawaikini Square root 9 + square root 5,243 = Distance
3 + 72.4 = Distance
75.4 nautical miles

[Using the formula: Square root of h + square root of H = distance in nautical miles from which an object can be seen (h = height of the observer above sea level in feet, H = height of the object in feet)]

Given the average range of seabirds such as the *noio* and *manu o Kū*, would you be likely to see these landmarks first, or would seabirds likely give away the presence of islands nearby first?

You'd probably see the islands first, since the average range of these seabirds is 60 miles from the island. (Information provided in the Student Page "Navigating the Currents.")

Task #3: Finalize Your Sailing Plan

Segment 1: In the Southeast Tradewinds

Latitudes: ____9°S_____ to _____3° N______

Average canoe speed: 15 knots average wind speed x 1/3 wind speed = 5 knots

Average distance traveled per day: 5 knots x 24 hours = 120 miles/day

Total distance to be traveled: 710.6 miles

Total number of days for this segment: 5.9 days

Expected total distance and direction of drift due to the current: .5 knots W x 24 hours = 12 miles west per day x 5.9 days = 70.8 miles west

Heading: NNW

Determine the actual heading with current factored in and draw it on the reference course map. See "Reference Course and Course Heading Map" (p. 13) acetate for answer.

Segment 2: In the Intertropical Convergence Zone

Latitudes: ____3°N_____ to ____9°N______

Average canoe speed: 7.5 knots average wind speed x 1/3 wind speed = 2.5 knots

Average distance traveled per day: 2.5 knots x 24 hours = 60 miles/day

Total distance to be traveled: 368.1 miles

Total number of days for this segment: 6.1 days

Expected total distance and direction of drift due to the current: Not factored in because it's so variable

Heading: NNW

Determine the actual heading with current factored in and draw it on the reference course map. See "Reference Course and Course Heading Map" (p. 13) acetate for answer.

Segment 3: In the Northeast Tradewinds

Latitudes: 9°N to 20° 30' N

Average canoe speed: 15 knots average wind speed x 1/3 wind speed = 5 knots

Average distance traveled per day: 5 knots x 24 hours = 120 miles/day

Total distance to be traveled: 785.3 miles

Total number of days for this segment: 6.5 days

Expected total distance and direction of drift due to the current: .5 knots W x 24 hours = 12 miles west per day x 6.5 days = 78 miles west

Heading: Between N by W and NNW

Determine the actual heading with current factored in and draw it on the reference course map. See "Reference Course and Course Heading Map" (p. 13) acetate for answer.

Segment 4: Westward to Hāna

Latitudes: 20° 30' N to 20° 45'N

Average canoe speed based on wind speed: 15 knots average wind speed x 1/3 wind speed = 5 knots

Expected HOURLY distance and direction of drift due to the current: .5 knots west

Expected actual performance of the canoe (add speed based on wind and current together): 5.5 knots

Average distance traveled per day: 5.5 knots x 24 hours = 132 miles

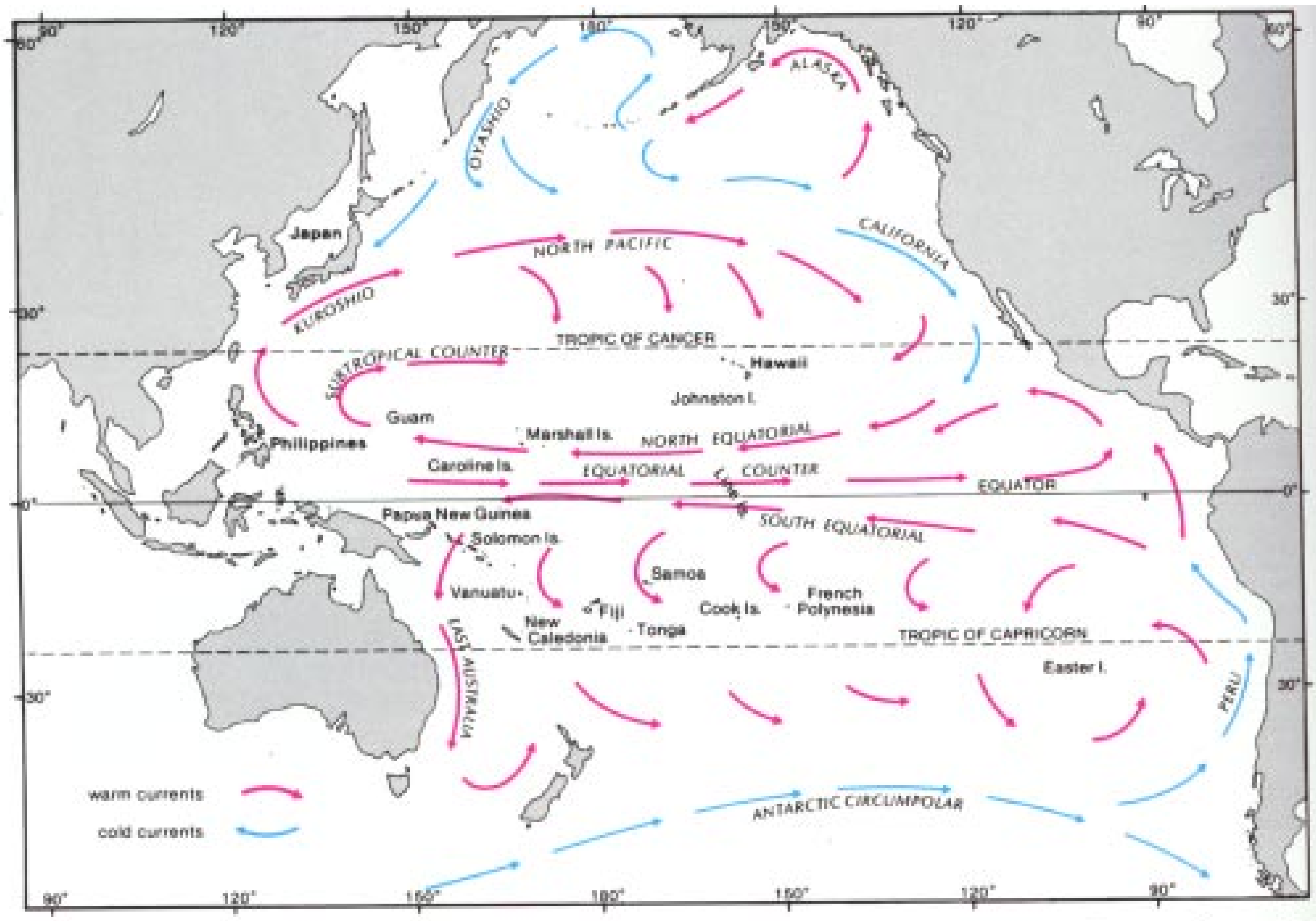
Total distance to be traveled: 405.3 miles

Total number of days for this segment: 3.1 days

Heading: W

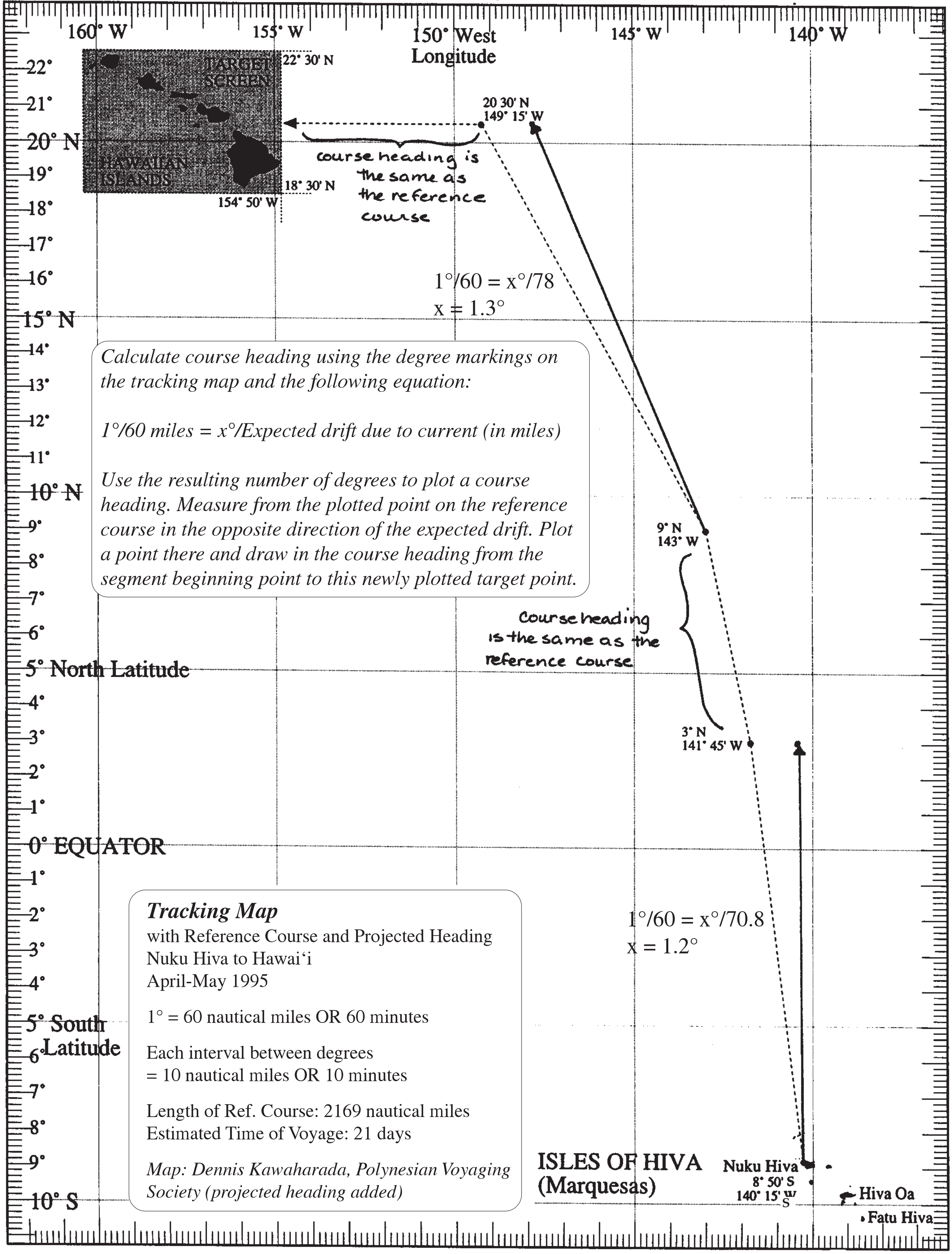
Determine the actual heading with current factored in and draw it on the reference course map. See "Reference Course and Course Heading Map" (p. 13) acetate for answer.

Map of Pacific Ocean Currents

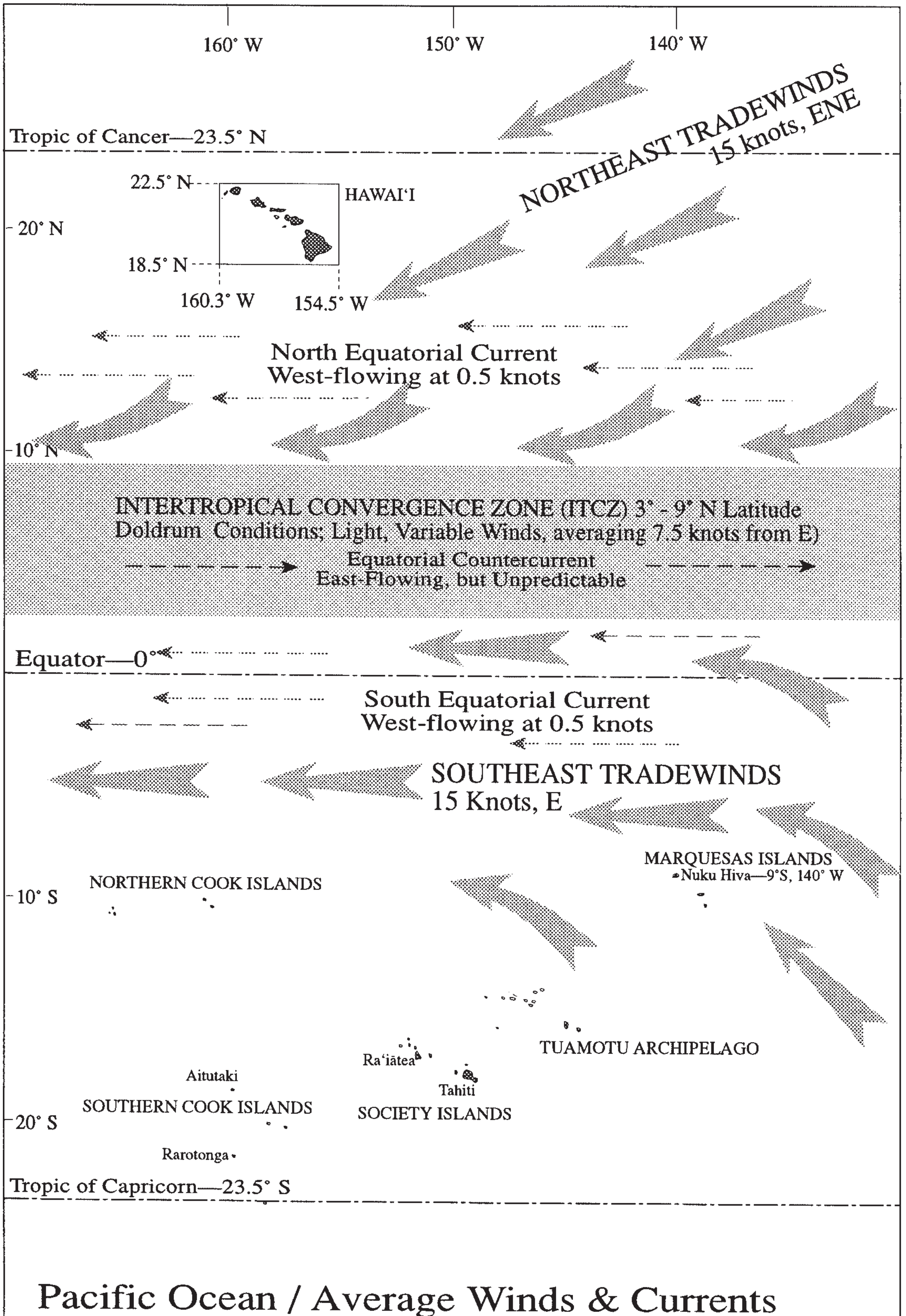


Map: Ann Fielding and Ed Robinson, An Underwater Guide to Hawai'i, *University of Hawai'i Press, Honolulu, 1987.*

Reference Course and Course Heading Map



Map of Currents Between Nuku Hiva and Hawai'i



Map: Dennis Kawaharada, Polynesian Voyaging Society

Navigating the Currents

Adapted from "Virtual Voyage: Course Strategy and Departure Time" and other sections of the Polynesian Voyaging Society website at <leahi.kcc.hawaii.edu/org/pvs>, June 2000.

Imagine that you are a wayfinder. Through long years of study and practice, you have learned the traditional art of guiding a Hawaiian voyaging canoe to its destination without using instruments. You have learned to listen to subtle differences in the sound or thrust of the ocean swell on the wooden hulls of the canoe, use the stars and the sun to determine your position and time of day, and estimate the wind speed and direction. You know how to put all of the signs together to interpret where you are in the vast expanses of the Pacific Ocean, and whether you're on course for your destination. While you're underway, you do all of this on as little as two hours of sleep each night, because the success of your journey and the lives of the entire crew depend upon your constant attention to navigating.

You have guided the crew of the *Hōkūle'a*, the first Hawaiian voyaging canoe built in modern times, from Maui to the South Pacific island of Nuku Hiva. Now, after sharing food, fellowship, and traditional dance and song with your Polynesian *'ohana*, you are ready to plan your journey home.

Charting a Course

As wayfinder, your job starts well before the canoe leaves shore. You must design an ideal course for sailing from Nuku Hiva back home to Maui. To do that, you will consider the capabilities of the canoe along with the winds, currents, and weather conditions anticipated along the way. As a modern-day wayfinder, you have a couple of advantages over your ancient counterparts: accurate ocean and current maps, and measured average current and wind conditions for different parts of the ocean and different seasons of the year.

Still the ideal course you chart is only a model of what your course will really look like once the *Hōkūle'a* is under sail. It is called a "reference course" because you will use it as a point of reference during the voyage. This course is based on average wind and current conditions, and on the ocean these conditions are never average. The canoe deviates from its reference course, sailing in whatever direction the winds allow it to sail. During the voyage, as the wind or ocean currents push *Hōkūle'a* off its reference course, you will eventually try to get the canoe back on it or close to it when conditions allow.

Under Sail

Once *Hōkūle'a* leaves the shores of Nuku Hiva, your job as wayfinder is to plot the canoe's position relative to the reference course. Charting the canoe's position is a matter of educated estimation. You plot the position of the vessel by estimating:

1) The speed and direction in which the canoe is traveling,
2) The speed and direction of ocean currents, and

Sightings of seabirds such as this albatross tell Polynesian navigators there is land within about 60 miles. (Photo: Kim Martz and Forest Starr)

3) Latitude (based on measurements of the altitudes of stars crossing the meridian).

In keeping with Polynesian tradition and techniques, you make these estimates without instruments. They can be hampered by poor weather conditions that obscure the sky and make patterns in ocean "swells" (long, crestless waves or successions of waves generated by weather events such as storms) difficult to interpret. Since the speed and direction of ocean currents cannot be estimated without instruments, you, a modern-day wayfinder, use seasonal averages to calculate your position.

Finding Land

Your goal is not to stay on the reference course, but to guide *Hōkūle'a* back home to Maui. The art of wayfinding involves adapting to variable and unexpected conditions of wind and weather while maintaining progress toward the windward side of the Hawaiian Islands.

As repeated landfalls by *Hōkūle'a* in its many journeys since 1976 show, wayfinding does not require exact positions to be successful. The wayfinder will successfully guide the canoe to its destination by keeping track of where the canoe is in relation to the reference course and destina-

A Revival of Polynesian Voyaging

Over a period of some one thousand years, Polynesian navigators explored and settled islands in an area covering over ten million square miles. How they accomplished this has been the subject of much speculation for centuries. Since 1976, the Polynesian Voyaging Society has helped scientists, anthropologists, archaeologists, and others interested in the survival of Polynesian culture understand how that achievement happened. In traditional-style Polynesian voyaging canoes, Hawaiians have traveled throughout the Pacific, navigating using only the constellations, wind, and wave patterns to guide their voyages over thousands of miles of open ocean.

The first Hawaiian voyaging canoe built in modern times was *Hōkūle'a*. Construction on *Hōkūle'a* started in 1973, and the canoe was finished in 1975. Since then, *Hōkūle'a* and its crew have sailed between Hawai'i and the South Pacific, visiting islands including Tahiti, Rapa Nui, Raratonga, and the Marquesas. In 1995, *Hōkūle'a* and another voyaging canoe, *Hawai'iloa*, were shipped to Seattle where they traveled up and down North America's Pacific coast from Juneau, Alaska, to San Diego, California.

Hōkūle'a (Photo: Steve Anderson)

tion, guiding the canoe to the general vicinity of the destination, locating land in that vicinity, and using known landmarks to find the destination.

In class, you will work with a team to create a sailing plan based on the reference course for a voyage of *Hōkūle'a* from Nuku Hiva in the Marquesas Islands to Hāna on the eastern coast of Maui. In the process, you will learn more about the ocean currents and winds that surround the Hawaiian Islands. And you'll need to know a bit more about the capabilities of *Hōkūle'a*. Here is some background that will help you as you learn this part of the art of wayfinding.

Sailing *Hōkūle'a*

Hōkūle'a has two 19-meter (62-foot) hulls, joined by eight crossbeams. No nails were used in constructing the canoe, so the decking is lashed to the crossbeams, and there are two masts. The 7.25-metric-ton (eight-ton) *Hōkūle'a* can be loaded with about 4990 kilograms (11,000 pounds), including a crew of 12-16 people, along with their equipment and supplies.

Unlike most modern sailing vessels, Polynesian voyaging canoes like *Hōkūle'a* have no keels or dagger boards at the bottom of their hulls to stabilize them in the water. This means that their "windward ability"—the ability to sail into the wind—is more limited than many modern craft. Still the canoes can sail in a broad range of wind conditions.

Hokule'a travels at an average of one-third of the wind speed. Wind speed is measured in "knots." One knot is equal to one "nautical mile" per hour. *Hokule'a* can make up to 10-12 knots under the best wind conditions. (A nautical mile is based on the length of a minute of arc of a great circle of the earth. According to the international standard, this distance is 1852 meters or 6076.115 feet.)

Crossing the Currents

The Hawaiian Islands are the northernmost and most isolated island group in Polynesia. Voyaging between Nuku Hiva in the South Pacific Ocean and the Hawaiian Islands in the North Pacific, you will pass through several zones characterized by particular current and wind conditions. There are three major current and wind zones (see the map on page 18):

South East Trade Wind Belt

Steady winds from the east/east south east (E/ESE) drive the south equatorial current, which flows westward through the trade wind belt.

Intertropical Convergence Zone

This area, where the southeast and northeast trade wind systems converge, is noted for its heavy cloud cover, squalls, light and variable winds, and dead calms—all of which make sailing and navigating less than ideal. The windless weather, known as the "doldrums," could stall *Hōkūle'a* for days. The heavy cloud cover hides the stars, so navigating by them is difficult. Under such conditions, you must use the ocean swells to orient the canoe. However, the seas in this area are often "confused." Because the winds (which cause ocean swells) are so variable, there are often no clear swell patterns by which to navigate.

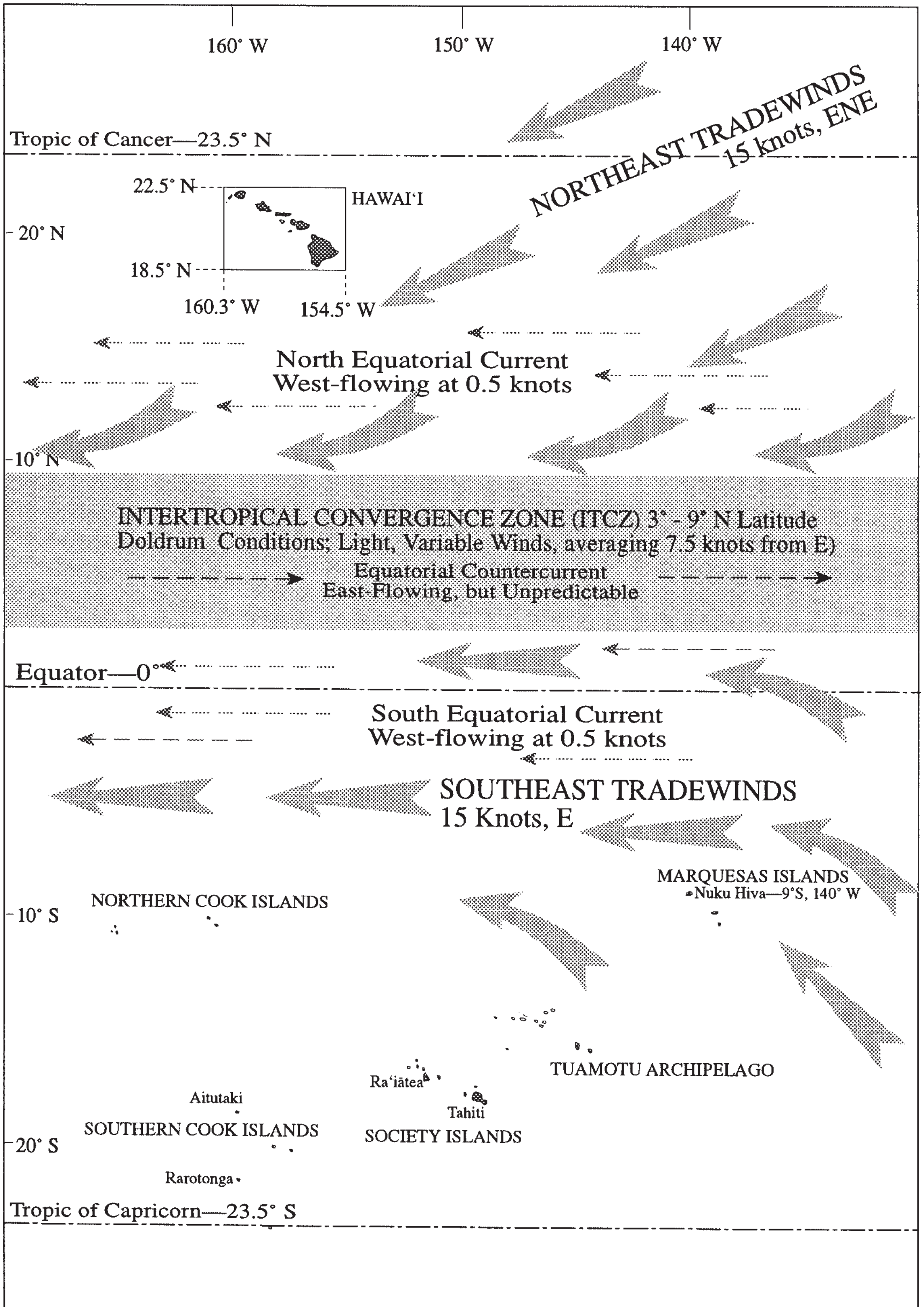
In this zone equatorial countercurrent flows eastward, between the two west-flowing equatorial currents. This countercurrent is formed as the water pushed west by the trade winds flows back east parallel to the equator. Like other conditions in this zone, the countercurrent is sporadic and shifting.

Northeast Tradewind Belt

The winds here are from the east north east (ENE), more reliable in the summer than in the winter. The northeast trade winds drive the north equatorial current, which flows westward.

Heading Home

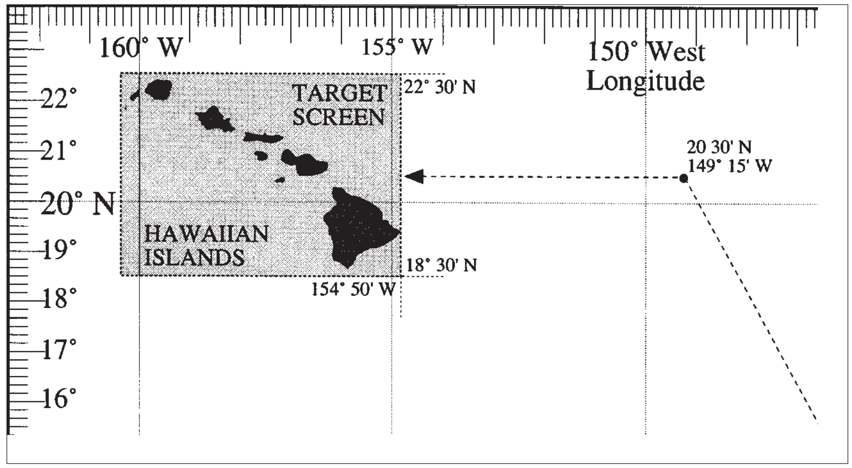
As you navigate through these major current and wind zones, you aim *Hōkūle'a* to the windward side of the Hawaiian Islands. That way, you



Pacific Ocean / Average Winds & Currents

Map:Dennis Kawaharada, Polynesian Voyaging Society will have the wind with you as you approach land and use landmarks to help guide *Hōkūle'a* to Hāna.

When you plan your reference course, you set an area called a "target screen," which is the area in which the highest points of the destination islands will be visible. During the voyage, as *Hōkūle'a* approaches the middle latitude of this target screen (from the windward side of course!) you make your final major course adjustment, turning west toward the Hawaiian Islands. Turning at the middle latitude of the target screen leaves the most margin for error in estimating the latitude or staying on course in approaching the islands.



Map section showing target screen and course turning for home at mid-latitude. (Map: Dennis Kawaharada, Polynesian Voyaging Society)

You and the crew of *Hōkūle'a* will also rely on other observations to assist you in finding land. For example, seabirds such as the *manu o Kū* (fairy tern or *Gygis alba rothschildi*) and the *noio* (black noddy or *Anous minutus malanogenys*) may indicate the presence of low-elevation islands even before the voyagers can see land. The average range of these seabirds is about 60 miles around each island.

As you develop your sailing plan summary, you will learn how to plan a course to navigate through the wind and current zones to reach your final destination . . . Maui.

From Nuku Hiva to Hawai'i: Charting a Course

Despite the hospitality of your Nuku Hivan hosts, the crew of *Hōkūle'a* is anxious to begin the journey home to Maui. As wayfinder, you are nearing the end of your preparations. You have already mapped a reference course based on average wind and current conditions you are likely to encounter along the way. Now, while the rest of the crew is provisioning the canoe, you must create a more detailed summary of your sailing plan for this trip, using the information and maps given below. The remaining work is divided into three tasks.

Assignment

Work with your team members to complete all three tasks quickly and accurately.

Task #1: Check the Weather

The crew is anxious to return home, but you need to make sure this is a good time of year to be sailing between Nuku Hiva and Hawai'i. Use the information below to determine the safest months in which to make this voyage and explain your reasoning.

- Hurricane seasons: Hurricanes are tropical cyclones with a wind speed exceeding 64 knots. They form in the warm waters of the equator and are steered away from the equator by surface winds. Chances of surviving a hurricane on a voyaging canoe are minimal, so hurricanes must be avoided.
  - The hurricane season in the southern hemisphere is December-February.
  - The hurricane season in the northern hemisphere is June-September.

- Winter storms: There is a greater likelihood of encountering storms during the winter than at other times of the year.
  - Winter season in the southern hemisphere is June-September.
  - Winter season in the northern hemisphere is December-March.

The safest month or months for Hōkūlea to sail:

Task #2: Confirm Your Target Screen

You have already set a "target screen." This is the general area that you'll be trying to reach on your voyage. Within this area, you'll be able to sight land. Once you sight land, you will use familiar landmarks to find your way to Hāna. Double-check how close to some of the major landmarks you would need to be in order to see them. In order to calculate these distances, you will need the following information:

- The formula for calculating the range for sighting land: Square root of h + square root of H = distance in nautical miles from which an object can be seen. (h = height above sea level of the observer in feet, H = height above sea level of the object in feet.)

- The deck of *Hōkūle'a* is about four feet high.

- The elevations of some these landmarks are:
  Hawai'i: Mauna Kea, 13,796 feet
  Maui: Haleakalā, 10,023 feet
  Kauai: Kawaikini, 5243 feet

Your answers:

Sighting distance from *Hōkūle'a* to Mauna Kea:

Sighting distance from *Hōkūle'a* to Haleakalā:

Sighting distance from *Hōkūle'a* to Kawaikini:

Given the average range of seabirds such as the *noio* and *manu o Kū*, would you be likely to see these landmarks first, or would seabirds likely give away the presence of islands nearby first? Explain.

Task #3: Finalize Your Sailing Plan

Using the reference course you have already charted, the currents map (from the Student Page "Navigating the Currents"), and the information provided below, fill in the blanks in the sailing plan for the trip from Nuku Hiva to Hāna, Maui.

Information You Will Need

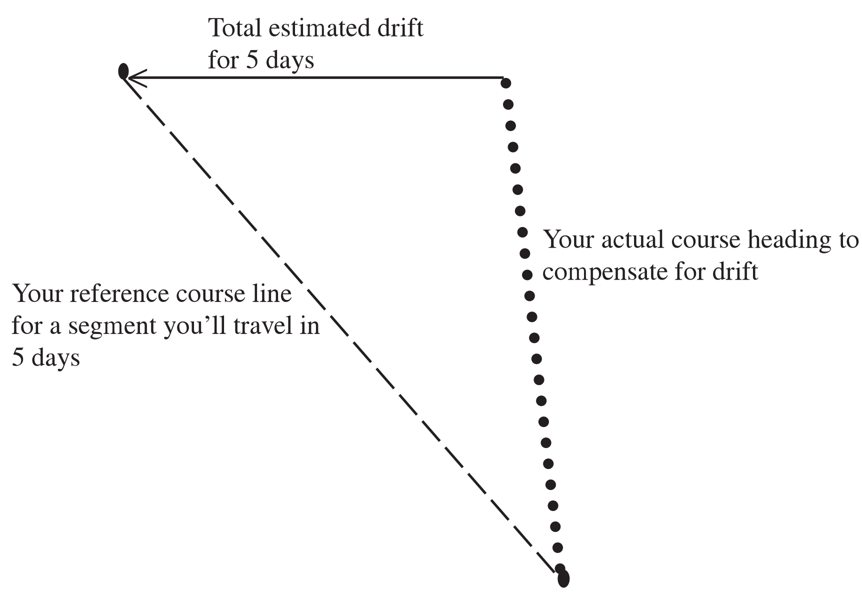
- The sailing plan is broken up into segments corresponding to each of the different wind and current zones you'll cross during the voyage:

  Southeast Trade Wind Belt (Nuku Hiva to 3°N latitude)
  Average wind speed: 15 knots (nautical miles per hour) from the east
  Average current speed: West-flowing at .5 knots

  Intertropical Convergence Zone (3°N latitude to 9°N latitude)
  Average winds: Doldrum conditions—light and variable winds averaging 7.5 knots from the east
  Average current: Unpredictable, cannot be factored into your course line

  Northeast Trade Wind Belt (9°N latitude to Hawai'i)
  Average wind speed: 15 knots from the ENE
  Average current speed: West-flowing at .5 knots

- The average speed of *Hōkūle'a* is 1/3 the wind speed. Wind speed is measured in knots. A knot is one nautical mile per hour.
- All distances are measured in nautical miles. One nautical mile = 6076 feet = one minute of latitude or longitude. Latitude and longitude are measured in degrees (°) and minutes ('). There are 60 minutes in a degree longitude or latitude.
- When you plot the actual heading, factoring in the total distance and direction of drift due to the current for the entire segment, you'll need to plot the distance and direction of the drift for the entire segment and adjust the actual heading accordingly. For example:



Sailing Plan Summary *Nuku Hiva to Hāna, Maui*

Write your sailing plan below. Include your calculations.

Segment 1: In the Southeast Tradewinds

Latitudes: __________ to ____________

Average canoe speed:

Average distance traveled per day:

Total distance to be traveled: 710.6 miles
Total number of days for this segment:

Expected total distance and direction of drift due to the current:

Heading: NNW
Determine the actual heading with current factored in and draw it on the reference course map (p. 27).

Segment 2: In the Intertropical Convergence Zone

Latitudes: __________ to ____________

Average canoe speed:

Average distance traveled per day:

Total distance to be traveled: 368.1 miles
Total number of days for this segment:

Expected total distance and direction of drift due to the current:

Heading: NNW
Determine the actual heading with current factored in and draw it on the reference course map (p. 27).

Segment 3: In the Northeast Tradewinds

Latitudes: __________ to ____________

Average canoe speed:

Average distance traveled per day:

Total distance to be traveled: 785.3 miles
Total number of days for this segment:

Expected total distance and direction of drift due to the current:

Heading: Between N by W and NNW
Determine the actual heading with current factored in and draw it on the reference course map (p. 27).

Segment 4: Westward to Hāna

Latitudes: 20° 30’ N to 20° 45’N

Average canoe speed based on wind speed:

Expected HOURLY distance and direction of drift due to the current:

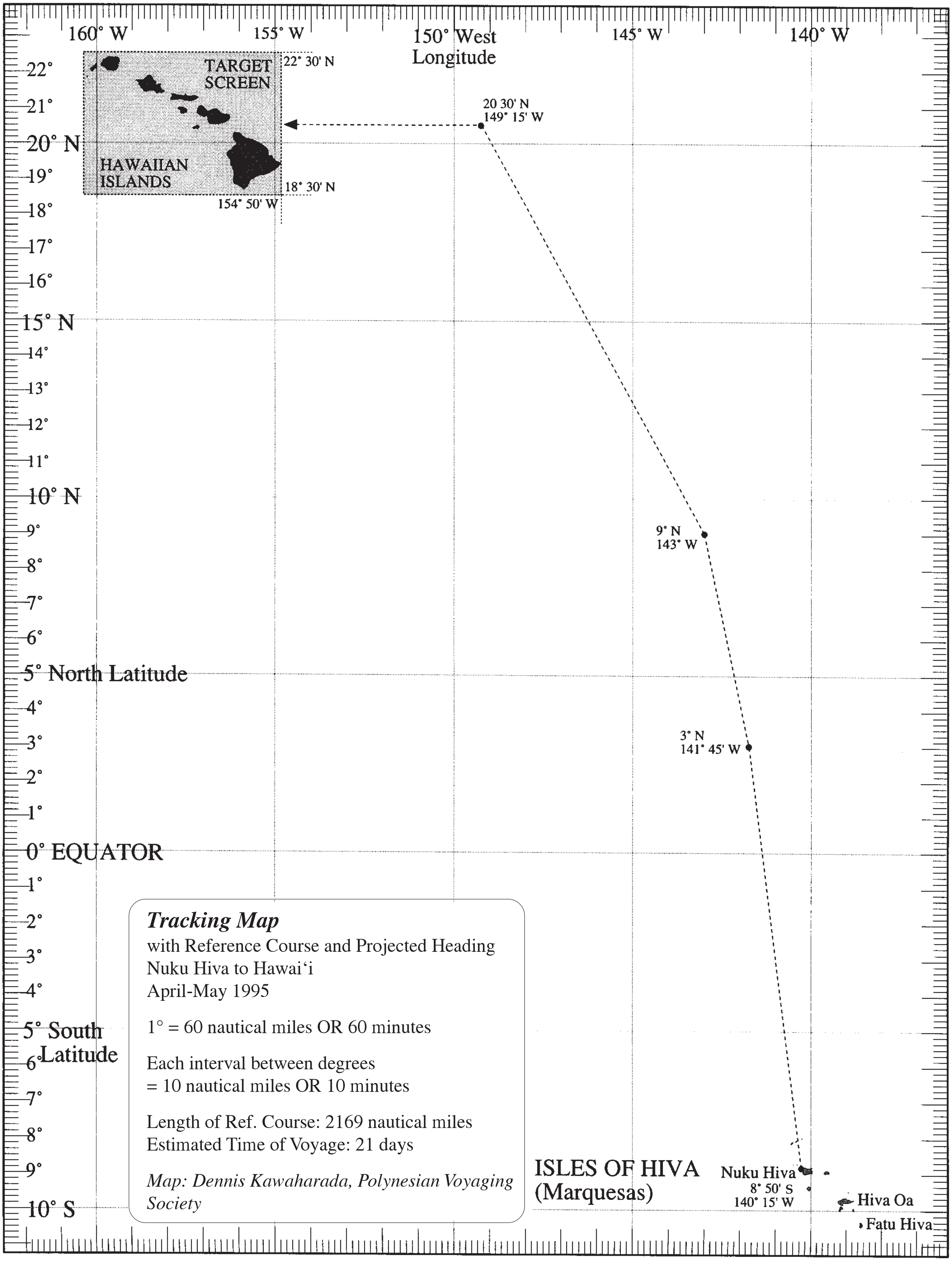
Expected actual performance of the canoe (add speed based on wind and current together):

Average distance traveled per day:

Total distance to be traveled: 405.3 miles
Total number of days for this segment:

Expected total distance and direction of drift due to the current:

Heading: W
Determine the actual heading with current factored in and draw it on the reference course map (p. 27).



Tracking Map
with Reference Course and Projected Heading
Nuku Hiva to Hawai‘i
April-May 1995

1° = 60 nautical miles OR 60 minutes

Each interval between degrees
= 10 nautical miles OR 10 minutes

Length of Ref. Course: 2169 nautical miles
Estimated Time of Voyage: 21 days

Map: Dennis Kawaharada, Polynesian Voyaging Society

Activity #2

Dispersing on the Currents

• • • Class Period One *Dispersal of Marine Life*

Materials & Setup

- *Coral Reefs: Their Health, Our Wealth* video, cued up to the segment on coral reproduction (This is a relatively short video, so fast-forward with the picture showing until you start to see close-ups of corals. This is the beginning of the section on coral biology and habitat. You may choose to show this short segment of a couple minutes or begin where the narrator says, "Like all other animals, corals must produce new individuals to make sure their populations survive." The six-minute reproductive segment ends when the narrator begins to talk about causes of death.)
- VCR
- "Map of Pacific Ocean Currents" acetate (master, p. 38)
- "Known and Estimated Numbers of Inshore Fish Species by Area and Likely Routes of Colonization" acetate (master, p. 39)
- Overhead projector and screen

For each of five student groups
- "Map of Pacific Ocean Currents" (master, p. 38)
- "Known and Estimated Numbers of Inshore Fish Species by Area and Likely Routes of Colonization" acetate (master, p. 39)
- One "Current Conundrums" card (master, p. 40)

For each student
- Student Page "Marine Life on the Move" (pp. 41-43)

Instructions

1) Display the "Map of Pacific Ocean Currents" acetate. Ask students to look at the currents depicted on this map and speculate about where most Hawaiian marine life originally came from. Note that ocean currents in the Pacific do not generally favor the dispersal of marine life from west to east, yet most of the marine life in the Hawaiian Islands seems to have originated in the western Pacific.

2) Lead a class discussion using the series of questions in the Teacher Background "Marine Life Reproduction and Dispersal" (pp. 31-33). During this class discussion, you will show the segment of *Coral Reefs: Their Health, Our Wealth* on coral reproduction. The discussion will cover the following points:
   - Common reproductive strategies among marine animals, and
   - How those reproductive strategies have allowed dispersal among islands in the Pacific.

3) After this discussion, divide the class into five groups. Give each group the "Map of Pacific Ocean Currents" and "Known and Estimated Numbers of Inshore Fish Species by Area and Likely Routes of Colonization" map, along with one of the five "Current Conundrums" cards.

4) Have groups work together to form a hypothesis in response to the question on the card.

5) Bring the class back together and have each group share its “Current Conundrum,” hypothesis, and reasoning. Use the Teacher Version of “Current Conundrums” (p. 34) to help groups fine-tune their responses if necessary.

6) As homework, assign the Student Page “Marine Life on the Move.”

Journal Ideas

- Would you say that planktonic larvae navigate the currents? Why or why not?
- Write a first-person narrative about the life of a coral polyp, incorporating the stages of development and the process of dispersal.
- Compare the process of planktonic dispersal through which much Hawaiian marine life arrived here with the settlement of the Hawaiian Islands by Polynesian voyagers.

Assessment Tools

- Participation in group work and class discussion
- Group responses to “Current Conundrums” (teacher version, p. 34)
- Student Page “Marine Life on the Move” (teacher version, pp. 35-37)
- Journal entries

Teacher Background

Marine Life Reproduction and Dispersal

Use these notes as you conduct a class discussion that covers:

- Common reproductive strategies among marine animals, and
- How those reproductive strategies have allowed dispersal among islands in the Pacific

Part 1 — Setting the Stage

Initiate a student discussion about sexual reproduction and dispersal. Begin with a quick review of dispersal in flowering plants and land animals, using the following questions:

1. Do flowering plants have eggs and sperm? (Yes)
2. Where are the sperm? (In the pollen)
3. Where is the egg? (In the bottom part of the flower)
4. How does the sperm get to the egg? (Flowers attract animals such as bees and birds with scents, colors and nectar. The pollen sticks to these animals and is carried to another flower.)
5. Once the egg is pollinated, what happens? (It forms into a seed.)
6. Many seeds are dispersed away from the parent; how does this happen? (Seeds can be eaten by an animal and the animal walks or flies away, blown in the wind, have hooks on them so they stick to animals, and float in the ocean.)
7. Can seeds be dispersed very far? How do you think plants got to Hawaiʻi before people? (Carried in the wind, stuck to migratory birds, carried in bird stomachs, and floated in ocean currents)
8. How is the egg fertilized by animals (mammals and birds) living on land? (Internal fertilization, copulation)
9. What are some of the strategies that ensure male and female animals get together and are ready to copulate at the same time? (Many species mate only in certain seasons, like spring; most animals have some sort of courtship ritual.)
10. How are the young dispersed from the parent? (They walk or fly away.)

Part 2 — Coral Reproduction

Once you have quickly reviewed the land plants and animals, turn the discussion to how marine animals reproduce and disperse their young. Focus first on corals.

Show the section of the video, *Coral Reefs: Their Health, Our Wealth*, on coral reproduction. Once the video segment is finished, lead a discussion on the following questions (or have students write down answers to these questions as a way of gauging how closely they watched the video).

1. How often do corals spawn? (Some spawn once a month; most spawn once a year. Each species spawns at the same time.)
2. What is a "larva"? (It is the early, free-living form of any animal that changes structurally when it becomes an adult or undergoes metamorphosis.)
3. Do you know any type of animal on land that goes through metamorphosis? (A caterpillar is the larva of a butterfly or moth, a tadpole is the larva of a frog or toad.)
4. What shape is a coral larva? (Pear-shaped)

5. Once it undergoes metamorphosis, what shape is it? (Polyp-shaped, like a flower)
6. How are the larvae dispersed? (They are free-swimming and are moved around in ocean currents.)

Part 3 — The Life Stages of a Marine Fish

Now, turn your attention to how most marine fish reproduce.

1. Do you know how marine fish reproduce? (Fish "spawn." Males and females release the eggs and sperm into the water, and fertilization is external, rather than internal. Sharks, rays, whales, and dolphins have internal fertilization.)
2. How do fish sychronize their spawning so that males and females are in the same place at the same time? (Environmental clues like water temperature, day length, moon phase, height of the tide, direction and intensity of the current, and courtship behaviors)

Part 4 — Dispersal of Marine Animals to Hawai'i

Show the "Map of Pacific Ocean Currents" acetate on an overhead projector, and use these questions:

1. Most marine animals and plants, including marine invertebrates, have planktonic larval stages. What does this mean? (The larval stages float in the open ocean currents for a while.)
2. What marine animals don't have this? (Examples include sharks, rays, whales, dolphins)
3. If some parrotfish (*uhu*) spawned off the coast of Japan, could their larval stages reach the Hawaiian Islands? If yes, how? (By floating in the North Pacific current)
4. What factors could affect whether the parrotfish could colonize Hawaiian waters?
   (• Whether their larval stage lasts long enough for viable larvae to reach Hawai'i adrift on the current,
   • Predation,
   • Water temperatures within the current or different water temperatures within Hawaiian waters,
   • Whether the current takes the larvae close to the islands or not,
   • Whether there is appropriate habitat for the larvae to settle and metamorphose, and
   • Whether the parent parrotfish produced enough offspring so that some would make it to the islands)

Now show the map of the Pacific showing most recent known and estimated numbers of inshore fish species by area and likely routes of colonization. An asterisk indicates an estimate. As needed, show the map of the Pacific currents that includes the names of the island groups and the Tropics of Cancer and Capricorn.

Work with the class to answer the following questions using these two maps:
1. What country has the most species of fish? (Indonesia)
2. The least? (Easter Island)
3. Do you see any trends in the number of marine fishes as you move from west to east? (In general, the number of species decreases.)

Use the following paragraph as background to help students understand the importance of the Indonesia-Malay Archipelago as a center of dispersal for marine life.

> The greatest concentration of species of marine life is found in the waters of the Indonesia-Malay Archipelago of the western Pacific Ocean. This area of shallow, warm water and intense tropical sunlight has offered a large, stable, and diverse habitat area that has nurtured marine life for millions of years. Consequently, it has acted as the center of dispersal for marine life inhabiting the tropical Indian and Pacific Oceans as far west as the coast of Africa and as far east as Hawaiʻi, the Line Islands, and Easter Island. Marine life in the Atlantic shares a common ancient origin in the Tethys Sea with that of the Indo-West Pacific, but because of land barriers formed when Africa joined with Eurasia approximately 65 million years ago, the two are separate biological entities. During that time the Indonesia-Malay Archipelago appears to have been quite hospitable for the evolution of new species, as it hosts many more kinds of marine life than the Caribbean and tropical Atlantic.

— *Ann Fielding and Ed Robinson,* An Underwater Guide to Hawaiʻi, *University of Hawaiʻi Press, Honolulu, 1987, pp. 15-18.*

Teacher Version

Current Conundrums

#1 — Tahitian Ancestry?

Would fish species from Tahiti be likely to colonize Hawai'i? Why or why not?

No, currents from Tahiti don't go north. However, that doesn't mean that the same species of fish may not live in Tahitian and Hawaiian waters, but these species would have reached both Tahiti and Hawai'i from somewhere else.

For an interesting side note, you could have students suggest complicated routes a larva would have to take to be transported by currents from Tahiti to Hawai'i.

#2 — Johnston Atoll

Why do you think Johnston Atoll has fewer species than Hawai'i?

The land and reef area is quite a bit smaller than Hawai'i, offering fewer kinds of habitat. Also, there is only one small current coming from Hawai'i.

Draw in the Tropics of Cancer and Capricorn on the overhead map with the fish species numbers. Between these two lines lie the tropics. As you go north or south you enter the temperate regions where the water is cooler.

#3 — Midway Atoll

Why do you think Midway Atoll has fewer fish species than the main islands, despite being closer to Japan, where many Hawaiian fish seem to originate?

Not as many different kinds of habitats on an atoll, smaller reef area, cooler water because it is further north

#4 — Hawaiian Endemics

About 25 percent of the fish found in Hawai'i are endemic to Hawai'i. This is the greatest percentage of endemic marine fishes in the world. Why would this be the case?

Hawai'i is very isolated. Fish arriving here would be separated from others of their species and changes would occur in their DNA over time.

#5 — Missing Fish Species

Some fishes, such as shallow-water snappers and groupers, are common on reefs in Pacific islands to the south and west of Hawai'i, yet they are almost non-existent in Hawai'i. What could cause this pattern of dispersal?

Some researchers have suggested that they must have short larval lives, meaning the time a larval fish can stay alive in the plankton is limited. The distance it can be dispersed would be similarly limited.

Teacher Version

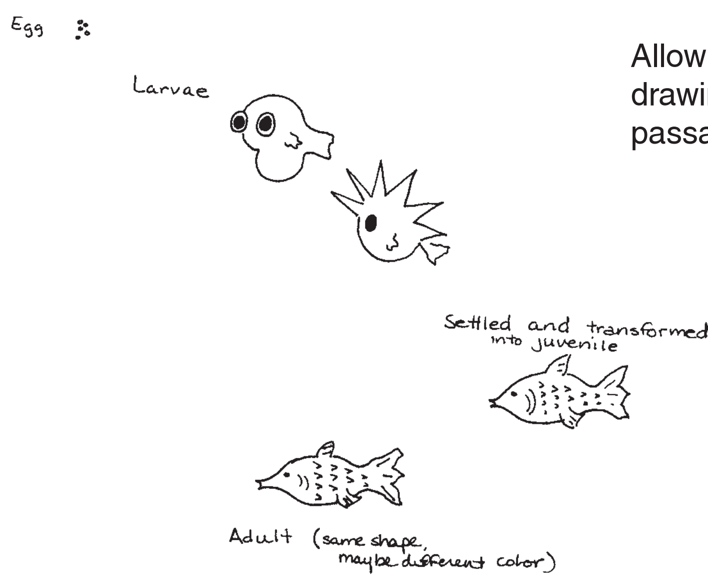
Marine Life on the Move

Reproduction among reef fishes is highly varied and often quite complex. The vast majority of fishes lay eggs. The birth of fully developed young is extremely rare among bony fishes and common only among cartilagenous fishes [fishes such as sharks and rays whose skeletons are largely composed of cartilage rather than bone]. Eggs of fishes are typically small (about 1 mm in diameter) and generally take about a week to hatch. The eggs hatch into larvae which bear little resemblance to the fishes familiar to most people. Larvae start out as tadpole-like creatures with large eyes, without pigment or scales, and often with an external yolk sac to nourish them until their gut develops.

Larvae are adapted to a pelagic life, drifting with the [ocean] currents and feeding on phytoplankton to progressively larger zooplankton as they grow. Some larvae actively swim, guided by environmental cues that may help them find a suitable settling site. In many species the larvae develop enlarged bony plates or spines that help protect them from predation [and make them more buoyant]. In some species larvae settle and transform into juveniles within days of hatching while in others they may go through a prolonged late larval stage that may last up to two months or more. Once they locate a suitable place to settle, larvae become bottom-oriented and rapidly acquire the pigments, scales, and full complement of fin rays characteristic of juveniles. Juveniles usually resemble adults in form but, in reef species, may often have a color pattern entirely different from that of adults.

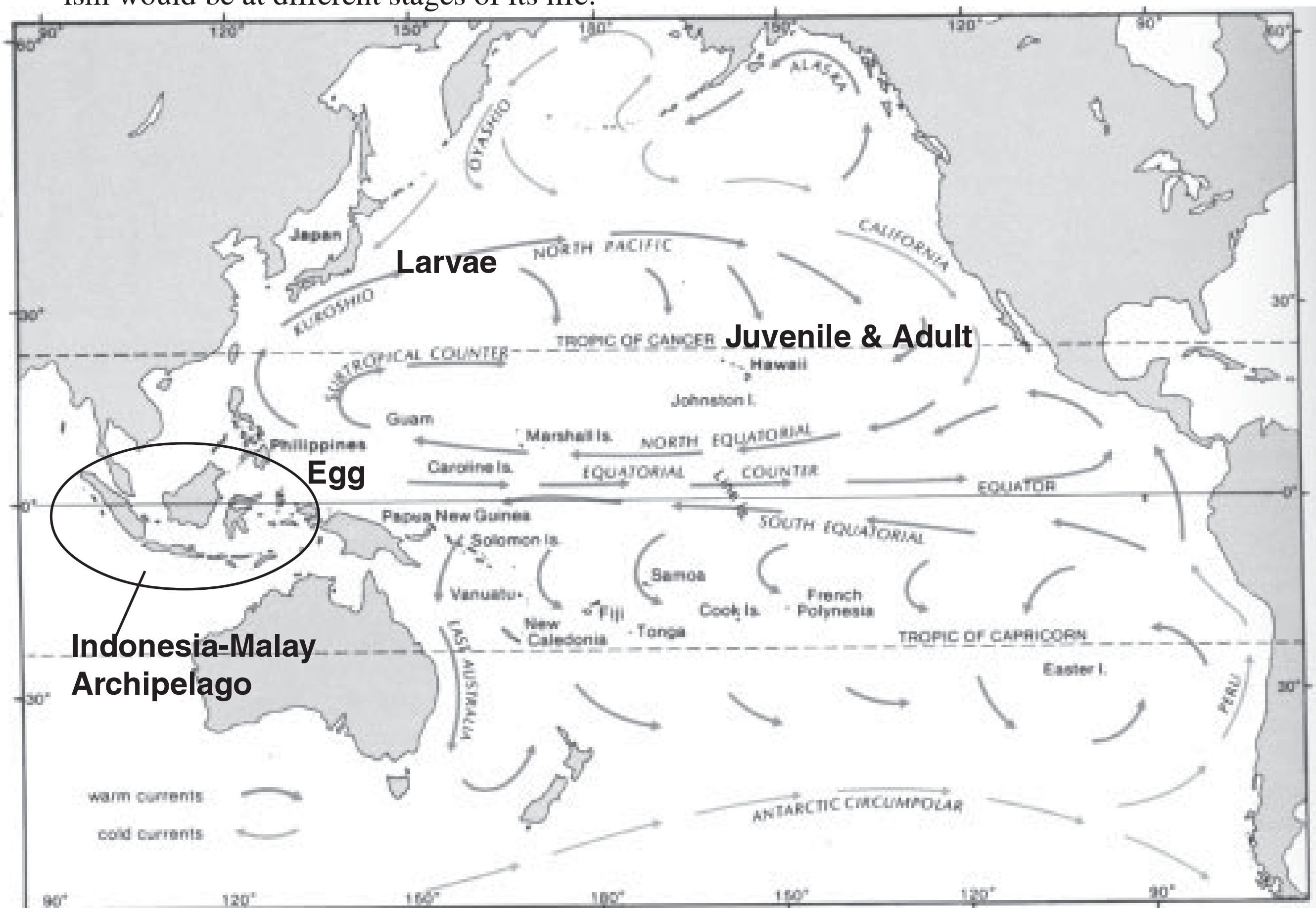
— Robert F. Myers, *Micronesian Reef Fishes: A Guide for Divers and Aquarists* 3rd ed., Sea Challengers, 1999, pp. 19-20.

1) In the space below, make a drawing that represents each phase of the reproductive cycle of most marine fishes, as described in the passage above.



Allow for creativity, as long as the drawings cover the stages listed in the passage, and fit with the descriptions.

2) Assume that your drawing represents a species of fish native to the Philippines that dispersed to Hawai‘i. Label each part of the reproductive cycle on the map below to indicate where the organism would be at different stages of its life.



Map: Ann Fielding and Ed Robinson, An Underwater Guide to Hawai‘i, *University of Hawai‘i Press, Honolulu, 1987*

3) Formulate a hypothesis to explain the difference in the rate of endemism in Hawaiian marine invertebrates and Hawaiian insects. Species that are “endemic” to Hawai‘i are found only in Hawai‘i and nowhere else on earth.

	Rate of endemism
Hawaiian marine invertebrates such as mollusks, sea stars, and brittle stars	Approx. 20 percent of species are endemic
Hawaiian insects	Approx. 94 percent of species are endemic

Endemism among Hawaiian terrestrial fauna, including invertebrates, is often linked to the islands’ isolation from other land masses and therefore from regular influxes of new organisms and genetic material. In contrast, marine invertebrate species receive more regular influxes of new organisms and genetic material arriving on ocean currents.

4) Do ocean currents favor the dispersal of marine life from the South Pacific to Hawai‘i? Why or why not?

    No, because the equatorial currents and counter currents run east-west and west-east, not from the south to the north

5) What part of the world has the greatest concentration of marine species and has acted as the center for dispersal for marine life in the tropical Indian and Pacific oceans, from Africa to Hawai‘i?

    The Indonesia-Malay Archipelago

    Circle and label this area on the map of the Pacific on the previous page.

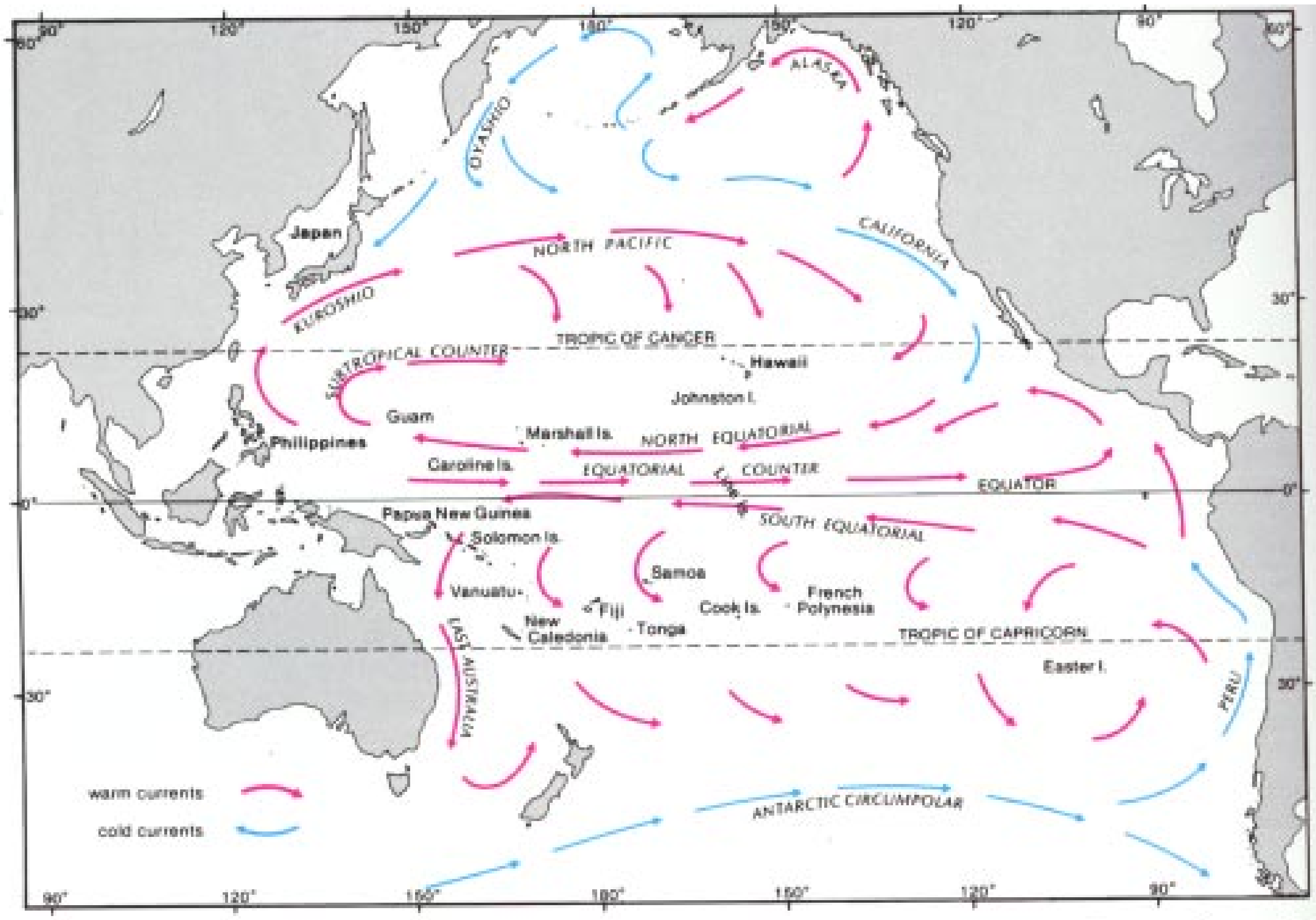
6) Name three factors that influence whether a coral species from Indonesia would be able to successfully colonize Hawaiian waters.

    Factors could include:
    • Whether their larval stage lasts long enough for viable larvae to reach Hawai‘i adrift on the currents,
    • Whether the larvae survive predation,
    • Water temperatures within the current or different water temperatures within Hawaiian waters,
    • Whether the current they are taken up in takes the larvae close to the islands or not,
    • Whether there is appropriate habitat for the larvae to settle and metamorphose, and
    • Whether the parent corals produced enough offspring that some would survive the trip to the islands.

7) Compare and contrast the means by which Polynesian voyagers and planktonic marine organisms travel on ocean currents to reach Hawai‘i.

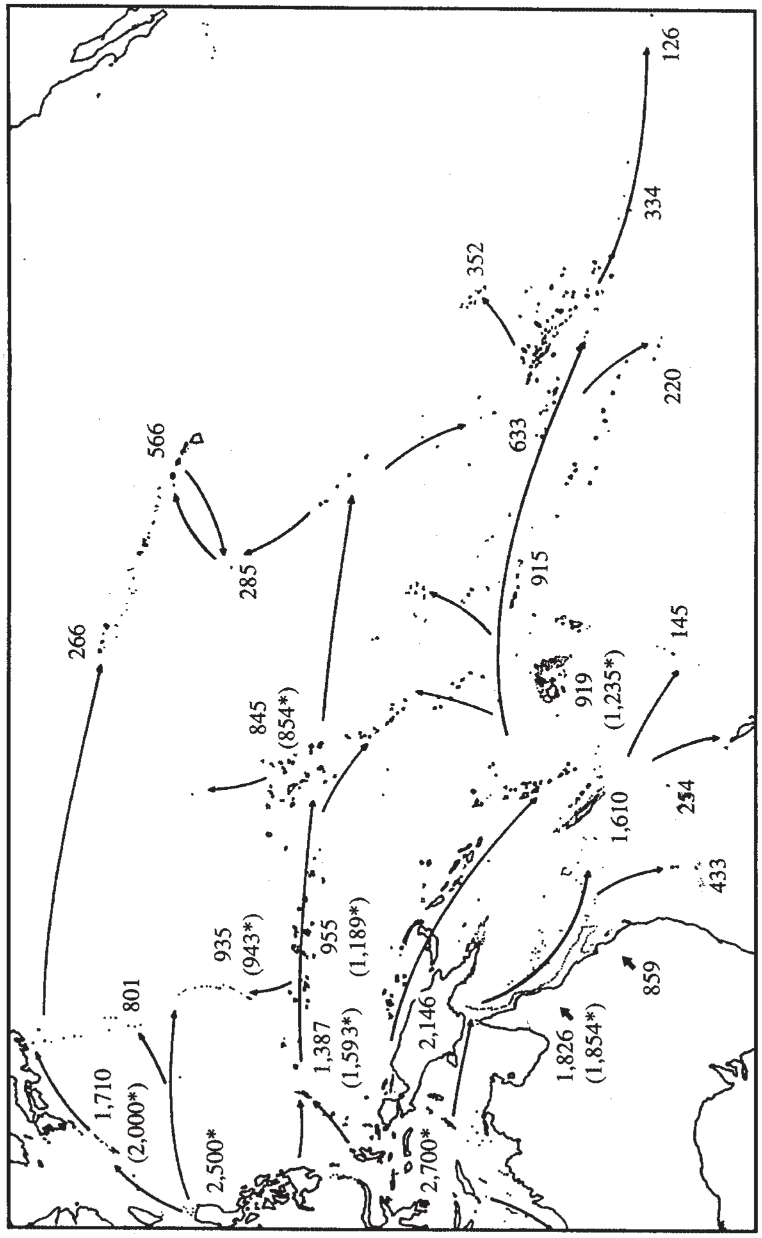
    Polynesian voyagers navigate in canoes that use sails and winds as well as ocean currents to power their travels. Unlike planktonic marine organisms, the voyagers navigate, guiding their own travels along a particular course.

Map of Pacific Ocean Currents



Map: Ann Fielding and Ed Robinson, An Underwater Guide to Hawai'i, *University of Hawai'i Press, Honolulu, 1987.*

Known and Estimated Numbers of Inshore Fish Species by Area and Likely Routes of Colonization



Map of the Pacific showing most recent known and estimated numbers of inshore fish species by area and likely routes of colonization. An asterisk indicates an estimate. Figures for the Marquesas, Pitcairn group, and the Hawaiian Islands provided by J. E. Randall.

Map: Robert F. Myers, Micronesian Reef Fishes: A Field Guide for Divers and Aquarists *3rd ed., Sea Challengers, 1999, p. 11.*

Current Conundrums Cards

Cut along dashed lines

#1 — Tahitian Ancestry?

Would fish species from Tahiti be likely to colonize Hawai‘i? Why or why not?

#2 — Johnston Atoll

Why do you think Johnston Atoll has fewer species than Hawai‘i?

#3 — Midway Atoll

Why do you think Midway Atoll has fewer fish species than the main islands, despite being closer to Japan, where many Hawaiian fish seem to originate?

#4 — Hawaiian Endemics

About 25 percent of the fish found in Hawai‘i are endemic to Hawai‘i. This is the greatest percentage of endemic marine fishes in the world. Why would this be the case?

#5 — Missing Fish Species

Some fishes, such as shallow-water snappers and groupers, are common on reefs in Pacific Islands to the south and west of Hawai‘i, yet they are almost non-existent in Hawai‘i. What could cause this pattern of dispersal?

Marine Life on the Move

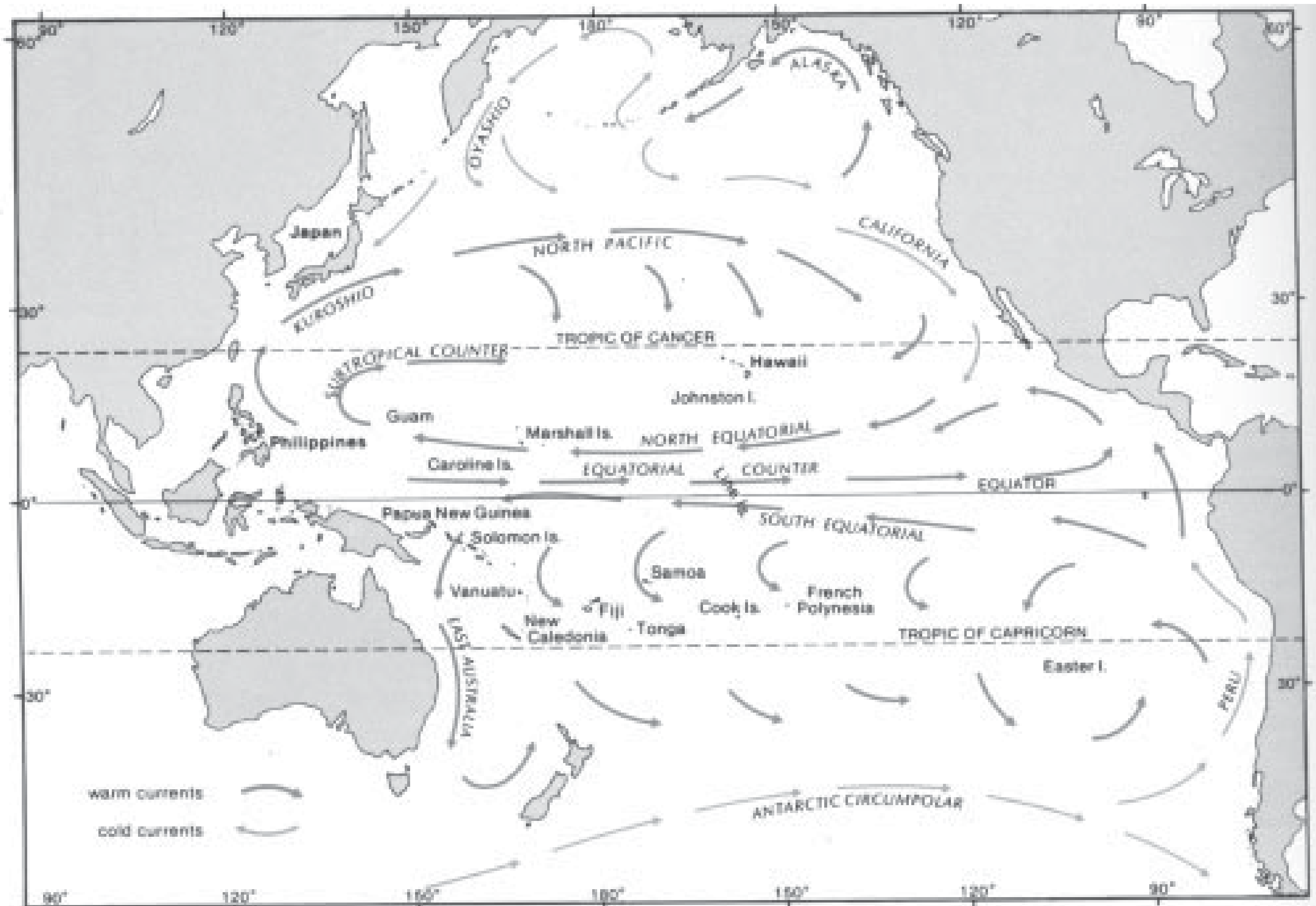
Reproduction among reef fishes is highly varied and often quite complex. The vast majority of fishes lay eggs. The birth of fully developed young is extremely rare among bony fishes and common only among cartilagenous fishes [fishes such as sharks and rays whose skeletons are largely composed of cartilage rather than bone]. Eggs of fishes are typically small (about 1 mm in diameter) and generally take about a week to hatch. The eggs hatch into larvae which bear little resemblance to the fishes familiar to most people. Larvae start out as tadpole-like creatures with large eyes, without pigment or scales, and often with an external yolk sac to nourish them until their gut develops.

Larvae are adapted to a pelagic life, drifting with the [ocean] currents and feeding on phytoplankton to progressively larger zooplankton as they grow. Some larvae actively swim, guided by environmental cues that may help them find a suitable settling site. In many species the larvae develop enlarged bony plates or spines that help protect them from predation [and make them more buoyant]. In some species larvae settle and transform into juveniles within days of hatching while in others they may go through a prolonged late larval stage that may last up to two months or more. Once they locate a suitable place to settle, larvae become bottom-oriented and rapidly acquire the pigments, scales, and full complement of fin rays characteristic of juveniles. Juveniles usually resemble adults in form but, in reef species, may often have a color pattern entirely different from that of adults.

— *Robert F. Myers,* Micronesian Reef Fishes: A Guide for Divers and Aquarists, *3rd ed., Sea Challengers, 1999, pp. 19-20.*

1) In the space below, make a drawing that represents each phase of the reproductive cycle of most marine fishes, as described in the passage above.

2) Assume that your drawing represents a species of fish native to the Philippines that dispersed to Hawai‘i. Label each part of the reproductive cycle on the map below to indicate where the organism would be at different stages of its life.
3) Formulate a hypothesis to explain the difference in the rate of endemism in Hawaiian marine



Map: Ann Fielding and Ed Robinson, An Underwater Guide to Hawai‘i, *University of Hawai‘i Press, Honolulu, 1987*

invertebrates and Hawaiian insects. Species that are “endemic” to Hawai‘i are found only in Hawai‘i and nowhere else on earth.

	Rate of endemism
Hawaiian marine invertebrates such as mollusks, sea stars, and brittle stars	Approx. 20 percent of species are endemic
Hawaiian insects	Approx. 94 percent of species are endemic

4) Do ocean currents favor the dispersal of marine life from the South Pacific to Hawaiʻi? Why or why not?

5) What part of the world has the greatest concentration of marine species and has acted as the center for dispersal for marine life in the tropical Indian and Pacific oceans, from Africa to Hawaiʻi?

Name the area here, and circle it on the map of the Pacific on the previous page.

6) Name three factors that influence whether a coral species from Indonesia would be able to successfully colonize Hawaiian waters.

7) Compare the means by which Polynesian voyagers and planktonic marine organisms travel on ocean currents to reach Hawaiʻi.

Marine Unit 2

Marine Relationships

Overview

This unit revolves around the theme of relationships in the Hawaiian marine environment. This unifying theme gives students a context in which to learn about many marine species and their role in the marine environment.

First, students explore the relationships between animals and their marine environment by learning about characteristics and adaptations of many Hawaiian marine fish species. Then, students examine trophic levels and how food webs in Hawaiian waters can represent one type of relationship among marine plants and animals. Finally, students explore relationships between people and marine plants and animals important in traditional Hawaiian culture and in the other cultures that shape today's Hawaiian society.

Length of Entire Unit

Four class periods plus research time for student projects

Unit Focus Questions

1) How are Hawaiian marine animals adapted to their environment?

2) How do food web relationships help to explain ciguatera fish poisoning among humans?

3) What is the cultural significance of Hawaiian marine life?

Unit at a Glance

Activity #1
Adaptation Concentration

Students watch a video and play a game to learn about native Hawaiian marine animals and how they are adapted to the marine environment.

Length
One class period followed by homework reading and questions

Prerequisite Activity
None

Objectives

- Identify native Hawaiian marine animals and characteristics that help them survive in particular habitats.
- Identify, explain, and give examples of characteristics exhibited by Hawaiian marine animals that suit them to particular marine environments and ecological roles.

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.

Activity #2
Marine Food Webs

Students create food webs using native Hawaiian marine organisms and examine the effect of bioaccumulation on the flow of toxic organisms through these webs.

Length
Two class periods

Prerequisite Activity
None

Objectives

- Illustrate trophic levels using examples of Hawaiian marine species.
- Illustrate the concept of bioaccumulation using ciguatera fish poisoning as an example.

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.

- MODEL: Design or create a model to represent a device, a plan, an equation, or a mental image.

Activity #3
Marine Life Scrapbooks

Students assemble scrapbooks about the natural history and cultural significance of native Hawaiian marine species.

Length
One class period plus research time

Prerequisite Activity
None
This activity could be a culminating activity for the first two activities in this unit.

Objectives
- Summarize prior learning about native Hawaiian marine species.
- Research, represent, and describe the cultural significance of one or more Hawaiian marine species.
- Conduct library research and personal interviews to gather historical and cultural information.

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.
- SELF-DIRECTED: Use research techniques and a variety of resources to complete a report on a project of one's choice.

Enrichment Ideas

- Make fish prints or rubbings using several different types of fish purchased from a local fish market.

- Find images and descriptions of marine habitats in *An Underwater Guide to Hawai'i* (Ann Fielding and Ed Robinson, University of Hawai'i Press, Honolulu, 1987). Pages 21-23 describe a variety of underwater habitats, and there are many photos that show aspects of habitats. Design a marine organism to fit a depicted habitat.

- Do the "Designer Fish" activity from the Aquatic Project WILD curriculum guide (available by attending an Aquatic Project WILD workshop offered by the Hawai'i Department of Land and Natural Resources Division of Aquatic Resources).

- Form a circle with each student holding one of the Food Chains and Webs cards from Activity #2. Tie the end of a ball of string to someone's waist and have that person toss the ball to another student holding an organism card to which they are linked in a food web. Continue until all students are part of the web. Have the entire circle lean back and feel the strength of the web supporting the whole group. Then cut one link with a scissors, showing the impact of a small action on the whole web. Discuss what this activity demonstrates to students about food webs.

- Have students research what happens to energy at each step of the food chain and explain why energy would be lost at each level.

- Research occurrences of ciguatera poisoning on Maui and the other Hawaiian Islands. Look for patterns such as where many ciguatoxic fish are caught and which fish species seem to be implicated the most often.

- Culminate the unit with a *hō‘ike* or series of class presentations. Each student or group could report on what they learned about the natural history and cultural significance of marine species in Hawai‘i (Activity #3 “Marine Life Scrapbooks”). Portions of audio and videotaped sessions could be included, as well as examples of items or food dishes made with marine species. Students researching seaweed or species with shells could bring specimens to class.

- Teach younger students about native Hawaiian marine life by presenting scrapbooks at nearby elementary schools.

Resources for Further Reading and Research

On Ciguatera Poisoning

Epidemiology Branch, *Fish Poisoning in Hawai‘i*, State of Hawai‘i, Department of Health, Honolulu, 1997.

Hawai‘i Department of Health online public health resources, “Ciguatera Fish Poisoning” at <www.hawaii.gov/doh/resource/comm_dis/cddcigua.htm>.

Cigua-Check Fish Poison Test Kit website at <www.cigua.com>.

Shirai, J. L., L. K. Shirai, and Y. Hokama, *Seafood Poisoning: Ciguatera*, Yosh Hokama Family Trust, Gardena, California, 1991.

On Marine Species and Their Cultural Significance

Abbott, Isabella, and E. H. Williamson, *Limu — An Ethnobotanical Study of Some Edible Hawaiian Seaweeds,* Pacific Tropical Botanical Garden, Lawai, Hawai‘i, 1974.

Fortner, Heather J., *The Limu Eater* Sea Grant Misc. Report, UNIHI-SEAGRANT-MR-79-01, 1978.

Hobson, Edmund S. and E. H. Chave, *Hawaiian Reef Animals*, University of Hawai‘i Press, Honolulu, 1990

Hoover, John P., *Hawaii’s Fishes, A Guide for Snorkelers, Divers and Aquarists*, 3rd ed., Mutual Publishing, Honolulu, 1996.

____________, *Hawai‘i’s Sea Creatures*, Mutual Publishing, Honolulu, 1998.

Kamakau, S. M., *The Works of the People of Old*, Bishop Museum Press, Honolulu, 1976.

Randall, John E., *Shore Fishes of Hawaii*, Natural World Press, Honolulu, 1996.

Taylor, Leighton, *Sharks of Hawai‘i, Their Biology and Cultural Significance.* Honolulu: University of Hawai‘i Press, 1993.

Titcomb, Margaret, *Native Use of Fish in Hawaii*, University of Hawai‘i Press, Honolulu, 1992.

______________, “Native Use of Marine Invertebrates in Old Hawai‘i,” *Pacific Science*, Vol. 32, No. 4., 1979, pp. 325-386.

Wyban, Carol Araki, *Tide and Current: Fishponds of Hawai‘i,* University of Hawai‘i Press, Honolulu, 1992.

Activity #1

Adaptation Concentration

● ● ● **Class Period One** *Adaptation Concentration Game*

Materials & Setup

- *Far from the Cradle* video by Waikiki Aquarium (included with this curriculum)
- VCR

For each group of four to six students

- One set of 20 "Adaptation Concentration" cards (laminated cards included with this curriculum, master, pp. 8-13)
- One "Adaptation Concentration Instructions and Scoring Sheet" (master, pp. 14-15)

For each student

- Student Page "What Good Is It?" (pp. 16-17)

Instructions

1) Show the video, *Far from the Cradle* (20 minutes). Tell students to pay careful attention because they will be playing a game about how marine animals are adapted to their environment using the information from the video.

2) Divide the class into groups of four to six students. Hand out the Adaptation Concentration game materials and have groups play the game according to the instructions given.

3) Play as many rounds as time permits.

4) Play options:
    - Instead of having students fill in the scoring grid, incorporate a simpler assessment component by having students track how many cards they collect in each game.

    - Play the game with teams. Have tournaments by pairing winning teams against each other until a champion emerges. You can structure "double-elimination" tournaments, or use any other tournament structure that makes sense, such as a round robin.

    - If students are playing as individuals, try mixing up the groups for subsequent rounds by placing all of the first-round winners in a new group, second-placers in another group, and so on.

5) Assign the Student Page "What Good Is It?" as homework.

Journal Ideas

- Think about a fish or another marine animal you've seen. Using what you've learned in this activity, describe how it seems to be adapted to its environment.
- Some adaptations, such as the leaf scorpionfish's swaying motions, are called "behavioral adaptations." Instead of being a structural feature such as body shape or eye placement, these adaptations are exhibited in what the animal does. Describe some things that you do that, like behavioral adaptations, help you fit into different physical or social environments.

Assessment Tools

- Student Page "What Good Is It?" (teacher version, p. 7)
- Participation and conduct during the game
- Adaptation Concentration Scoring Grids
- Journal entries

Teacher Version

What Good Is It?

Fill in this grid. Use what you learned about how marine organisms are behaviorally and physically adapted to their environment to spark your thinking.

Fill in the advantage you think each characteristic gives to the marine organisms pictured. Explain your reasoning.

Note: Well-reasoned responses are acceptable, even if they do not match the answers given on this key.

ADAPTATION	ADVANTAGE	EXAMPLE
Upturned mouth & eyes close to mouth	Pick out plankton swimming freely in the water	Hawaiian dascyllus *ʻĀloʻiloʻi*
Many fang-like teeth	Grasp fish and other prey	Viper moray *Pūhi kauila*
Thin, elongate body shape	Makes the fish hard to see	Trumpetfish *Nūnū*
Light coloration all over	Provides camouflage in sand or surf	Hawaiian flagtail *Āholehole*
Light-colored belly	Makes the fish hard to see from from below (especially by prey)	Whitetip reef shark *Manō lālā kea*
Brooding eggs in mouth	Keeps the eggs protected	Cardinalfishes *ʻUpāpalu*

Adaptation Concentration Cards

Cut on solid lines, fold on dashes

Larvae in plankton

Makes the larvae difficult to see floating in the water, reduces chance of predation

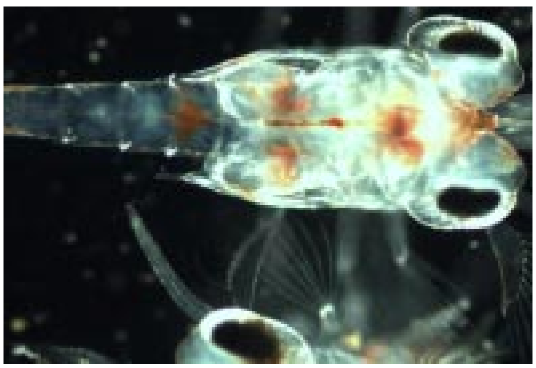


Photo: Karl Embleton, Sir Alister Hardy Foundation for Ocean Science

Transparency

Juvenile convict tang - *Manini*

(Acanthurus triostegus)

Protects from predators, provides abundance of algae and small invertebrates for food

Photo: Waikiki Aquarium

Seeking out sheltered backwater areas or tidepools

Zebra blenny - *Pāoʻo*

(Istiblennius zebra)

Reduces predation by birds and land animals while feeding on algae in tidepools

Photo: Marjroie L. Awai in John P. Hoover *Hawaii's Fishes*, Mutual Publishing

Quick, darting movements, constant movement

Zebra blenny - *Pāoʻo*

(Istiblennius zebra)

Reduces predation by birds and land animals by blending in with the dark rock and shadowy holes and crevices in the lava rock of tidepools

Photo: Marjroie L. Awai in John P. Hoover *Hawaii's Fishes*, Mutual Publishing

Dark color

Adaptation Concentration Cards

Cut on solid lines, fold on dashes

Parrotfish - *Uhu*

(*Scarus perspicillatus* pictured)

Scrape algae from the surface of coral reef

Photo: *John P. Hoover*
Hawaii's Fishes, *Mutual Publishing*

Teeth fused into strong, beaklike plates

Moorish idol - *Kihikihi*

(Zanclus cornutus)

Reaches sponges and similar invertebrates living in crevices and holes

Photo: *John P. Hoover*
Hawaii's Fishes, *Mutual Publishing*

Elongated, tubular mouth

Convict tang - *Manini*

(Acanthurus triostegus)

Makes the fish more difficult to drive off than a single fish feeding on algae

Photo: *John P. Hoover*, A Pocket Guide to
Hawai'i's Underwater Paradise, *Mutual Publishing*

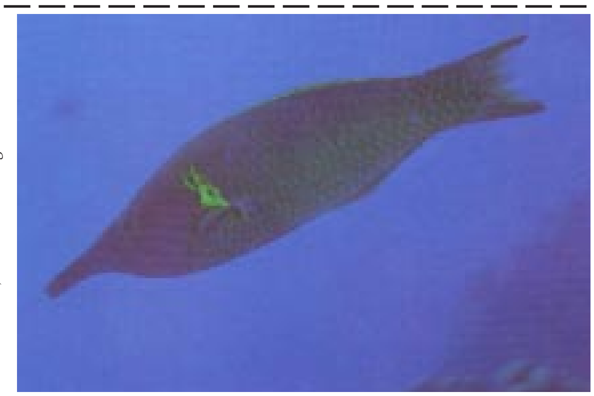
Schooling

Bird wrasse - *Hīnālea ʻiʻiwi*

(*Gomphosus varius* - terminal phase pictured)

Reaches small crabs and other prey in crevices and holes

Photo: *John P. Hoover*
Hawaii's Fishes, *Mutual Publishing*



Tubular snout

Adaptation Concentration Cards

Cut on solid lines, fold on dashes

Forcepsfish (or Common Longnose Butterflyfish)
Lau wiliwili nukunuku oi'oi
(*Forcipiger flavissimus*)

Reaches small worms and other invertebrates in crevices and holes

Photo: John P. Hoover
Hawaii's Fishes, Mutual Publishing

Long, tubular snout

Goatfish - *Weke*
(*Parupeneus porphyreus* pictured)

Help to detect food in sand

Photo: John P. Hoover
Hawaii's Fishes, Mutual Publishing

Whisker-like barbels

Goatfish - *Weke*
(*Parupeneus porphyreus* pictured)

Helps fish swim close to the bottom, to use barbels better in the sand

Photo: John P. Hoover
Hawaii's Fishes, Mutual Publishing

Flat underside

Jack - *Ulua*
(*Caranx ignobilis* pictured)

Helps fish swim swiftly, moving in on small fishes and invertebrates before they can escape

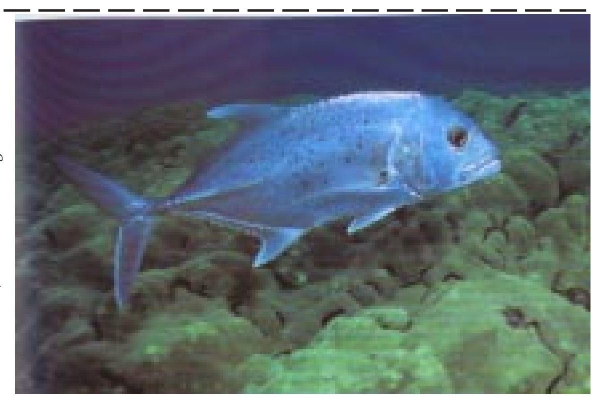


Photo: David R. Schichte in John P. Hoover,
Hawaii's Fishes, Mutual Publishing

Deep, narrow, streamlined body; scythe-like tail

Adaptation Concentration Cards

Cut on solid lines, fold on dashes

Dragon Moray - *Pūhi kauila*
Enchelycore pardalis

Helps to maneuver easily in crevices, an advantage in stalking prey; provides quickness, an advantage in striking at prey

Photo: David R. Schrichte in John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Muscular, serpentine body

Devil scorpionfish
Nohu ʻomakaha
Scorpaenopsis diabolus

Conceal the fish from prey, which may swim very close to it

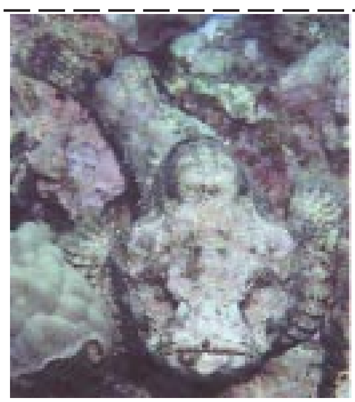
Photo: John P. Hoover Hawaii's Fishes, *Mutual Publishing*

Humped, irregular body shape; coral- and rock-colored camoflauge

Devil scorpionfish
Nohu ʻomakaha
Scorpaenopsis diabolus

Defend against predators

Photo: John P. Hoover Hawaii's Fishes, *Mutual Publishing*



Venomous spines along the back

Leaf scorpionfish
Nohu
Taenianotus triacanthus

Camoflauges and allows the fish to closely approach prey

Photo: Marjorie L. Awai in John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Swaying from side to side like a piece of seaweed in the current

Adaptation Concentration Cards

Cut on solid lines, fold on dashes

Leaf scorpionfish
Nohu
(Taenianotus triacanthus)

Allows the fish to strike quickly at prey

Photo: Marjorie L. Awai in John P. Hoover, Hawaii's Fishes, Mutual Publishing

Streamlined body

Spotted trunkfish or boxfish
Moa
(*Ostracion meleagris* - male pictured)

Defends against predators

Photo: John P. Hoover Hawaii's Fishes, Mutual Publishing

Body armored with rigid scales

Spotted trunkfish or boxfish
Moa
(*Ostracion meleagris* - male pictured)

Defends against predators

Photo: John P. Hoover Hawaii's Fishes, Mutual Publishing

Secreting toxin through skin

Hawaiian sergeant
Mamo
(Abudefduf abdominalis)

Allows male to protect eggs against predators

Photo: John P. Hoover Hawaii's Fishes, Mutual Publishing

Attaching eggs to rocks

Adaptation Concentration Cards

Cut on solid lines, fold on dashes

Spotted coral blenny (or shortbodied blenny)
Pāo'o kauila
(Exallias brevis)

Allows male to protect eggs against predators

Photo: John P. Hoover
Hawaii's Fishes, *Mutual Publishing*

Attaching eggs to rocks

Butterfly fish (Butterfly fish are variously called *lau hau, lau wiliwili,* and *kīkākapu*)
(Chaetodon lunula)

Helps fish sprint quickly for refuge from predators with additional thrust, like foot fins on humans

Photo: John P. Hoover
Hawaii's Fishes, *Mutual Publishing*

Placement of dorsal and anal fins back on the body

Wrasses - *Hīnālea*
(Coris gaimard - initial phase pictured)

Helps the fish disperse eggs in high numbers, instead of concentrating them where predators can easily find them

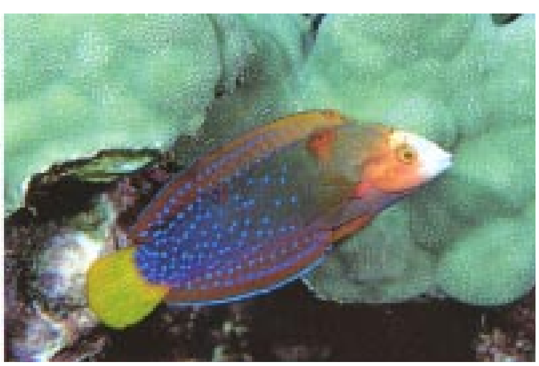


Photo: John P. Hoover
Hawaii's Fishes, *Mutual Publishing*

Broadcasting eggs and sperm into the water

Adaptation Concentration

Game Instructions

Object

To collect cards from the table by correctly identifying:

- The common or Hawaiian species name AND
- The “advantage” conferred by the adaptation listed on the front of the card.

How to Play

Groups of four to six

1) Deal the cards, photo side up, in a grid on the table. All of the cards should be fully visible.

2) Play begins with the player to the left of the dealer and continues clockwise around the table.

3) Point to a card on the table and state the species name (either common or Hawaiian) and the advantage conferred to the species by the characteristic on the front of the card. Then turn over the card in its spot on the table so everyone can see it. If you correctly stated both the species name and the advantage, take the card and begin a collection pile on the table.

   Continue in this way until you have an incorrect answer. Turn the incorrectly identified card back over, and continue play with the next player to your left.

4) The next player cannot begin his or her turn by pointing to the card that was just incorrectly identified. He or she must correctly identify at least one card before being allowed to select that card.

5) Play ends when all cards have been collected from the table OR when the play goes all the way around the table twice without any player collecting a card. If the latter happens, take turns turning over one card at a time and reviewing the species names and adaptive advantages so the whole group can hear them.

6) At the end of the game, fill out the Adaptation Concentration Scoring Grid by writing your name in the box that corresponds to each card you collected.

7) The player with the most cards wins!

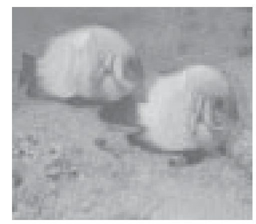
Adaptation Concentration Scoring Grid

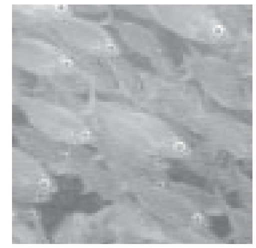
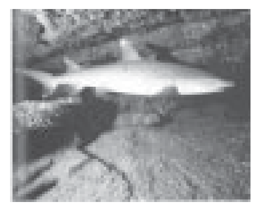
Adaptation	Round 1	Round 2	Round 3
Transparency			
Seeking out sheltered backwater areas or tidepools			
Quick, darting movements; constant movement			
Dark color			
Teeth fused into strong, beaklike plates			
Schooling			
Elongated, tubular mouth			
Tubular snout			
Long, tubular snout			
Whisker-like barbels			
Flat underside			
Deep, narrow, streamlined body; scythe-like tail			
Muscular, serpentine body			
Venomous spines along the back			
Humped, irregular body shape; coral- and rock-colored camoflauge			
Swaying from side to side like a piece of seaweed			
Streamlined body			
Body armored with rigid scales			
Secreting toxin through skin			
Attaching eggs to rocks			
Attaching eggs to rocks			
Broadcasting eggs and sperm into the water			
Placement of dorsal and anal fins back on the body			

What Good Is It?

Fill in this grid. Use what you learned about how marine organisms are behaviorally and physically adapted to their environment to spark your thinking.

Fill in the advantage you think each characteristic gives to the marine organisms pictured. Explain your reasoning.

ADAPTATION	ADVANTAGE	EXAMPLE
Upturned mouth & eyes close to mouth		Hawaiian dascyllus *ʻĀloʻiloʻi*  *Photo: John Hoover*
Many fang-like teeth		Viper moray *Pūhi kauila*  *Photo: John Hoover*
Thin, elongate body shape		Trumpetfish *Nūnū*  *Photo: John Hoover*

ADAPTATION	ADVANTAGE	EXAMPLE
Light coloration all over		Hawaiian flagtail *Āholehole*  *Photo: John Hoover*
Light-colored belly		Whitetip reef shark *Manō lālā kea*  *Photo: David R. Schrichte*
Brooding eggs in mouth		Cardinalfishes *‘Upāpalu*  *Photo: John Hoover*

Activity #2

Marine Food Webs

● ● ● Class Period One *Constructing Marine Food Webs*

Materials & Setup

For each group of four to six students

- Marine Food Chains and Webs Cards (master, pp. 23-28)
- Student Page "Living and Eating On the Web" (pp. 29-30)
- Three large pieces of paper (at least the size of a flip chart page)
- Colored marking pens, at least three colors per group
- Scotch tape

For each student

- Student Page "Poison Pathways" (pp. 31-33)
- Student Page "Poison Pathways: Questions on the Reading" (pp. 34-35)

Instructions

1) Divide students into groups of four to six.

2) Give each group a set of cards, paper, and marking pens.

3) Have students follow the instructions on the Student Page "Living and Eating on the Web" to create one or more marine food chains (15 minutes).

4) Have each group present its food chain to the whole class, allowing each group two minutes to present.

5) Have students follow the instructions on the student activity sheet to create a marine food web, using all of the cards in the set. NOTE: Groups may want to tape the two remaining sheets of paper together for their food web, since it will be larger than the food chain (20 minutes).

6) Have each group present its food web to the class, allowing each group two minutes to present. If there is time at the end of the class, discuss questions and observations from the activity.

7) Keep the food webs intact for the next class period.

8) As homework, assign the Student Page "Poison Pathways."

● ● ● Class Period Two *Poison Pathways*

Materials & Setup

For each group of four to six students

- Food webs from the previous class period
- One colored marker (of a different color than they used to create their food webs, if possible)

Instructions

1) Divide the class into the same groups as in the previous class. Have each group add to its food web to show how ciguatoxin is transferred between organisms and bioaccumulates in the food chain until it reaches humans. Groups should show how people could get ciguatera poisoning from eating herbivorous fishes as well as from carnivorous fishes. They will need to use information from the Marine Food Chains and Webs Cards as well as the Student Page "Poison Pathways" and will need to draw additional species onto their food webs to illustrate the transfer of ciguatoxin.

2) When groups have finished their work, have each present its results to the class.

3) Discuss student responses to and questions about the homework assignment.

4) As a wrap-up to the "Poison Pathways" activity, share with students the following information from J. L. Shirai, L. K. Shirai, and Y. Hokama, *Seafood Poisoning: Ciguatera*, Yosh Hokama Family Trust, Gardena, California, 1991. This passage provides some insight into the third homework question, which asked students to hypothesize about how *ʻūʻū* or soldierfish might be implicated in cases of ciguatera poisoning:

> Examination of the clinical symptoms in patients with pufferfish, shellfish (red tide due to dinoflagellates) and polyether type toxin (ciguatoxin, okadaic acid, brevetoxin and other polyether) poisonings shows that the symptoms overlap and the causative toxins can't be distinguished. In other words, there is no unique feature that separates the clinical effect. The temperature reversal was supposedly unique for ciguatoxin. This is no longer the case as…okadaic adid, palytoxin, brevetoxin and other ciguatoxin-like compounds including organophosphates and botulism toxin can produce this clinical effect (p. 9).

Journal Ideas

- Draw a food web that includes some of your favorite foods and illustrates their relationship with other organisms when they (or their constituent ingredients) were alive.
- If you got ciguatera poisoning or another kind of seafood poisoning, would you change anything about your fishing or eating habits? If so, what? If not, why not?

Assessment Tools

- Group food chains and webs and in-class presentations (Evaluate based on reasoning, consistency with information given on the cards, and clarity of presentation.)
- Student Page "Poison Pathways: Questions on the Reading" (teacher version, pp. 21-22)
- Group ciguatoxin bioaccumulation illustrations and in-class presentations
- Journal entries

Teacher Version

Poison Pathways: Questions from the Reading

1) Draw a food chain showing how a person could get ciguatera poisoning from eating one of the herbivorous fishes.

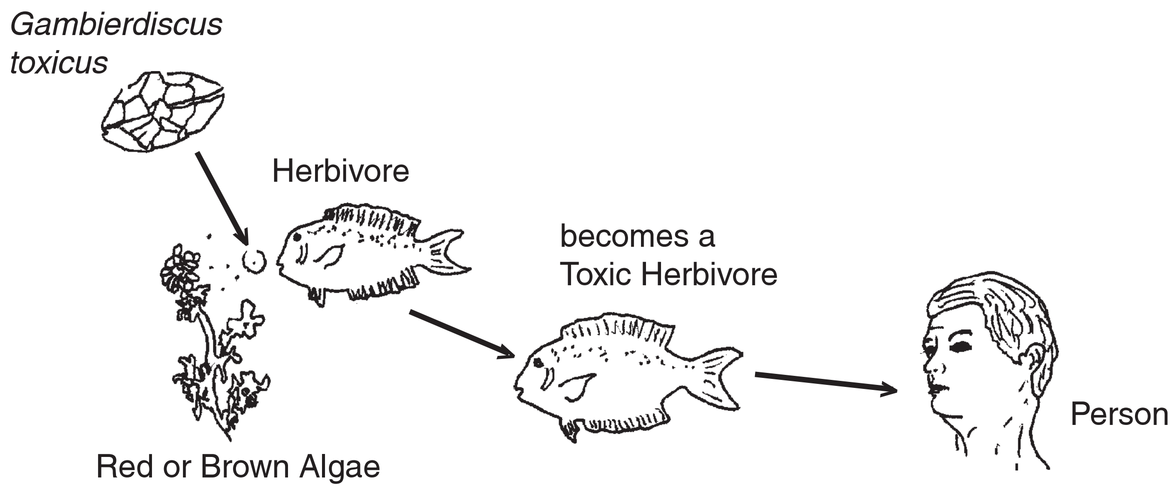


Image after J. L. Shirai, L. K. Shirai, and Y. Hokama, Seafood Poisoning: Ciguatera, *Yosh Hokama Family Trust, Gardena, California, 1991*

2) Draw a food chain showing how a person could get ciguatera poisoning from eating one of the carnivorous fishes.

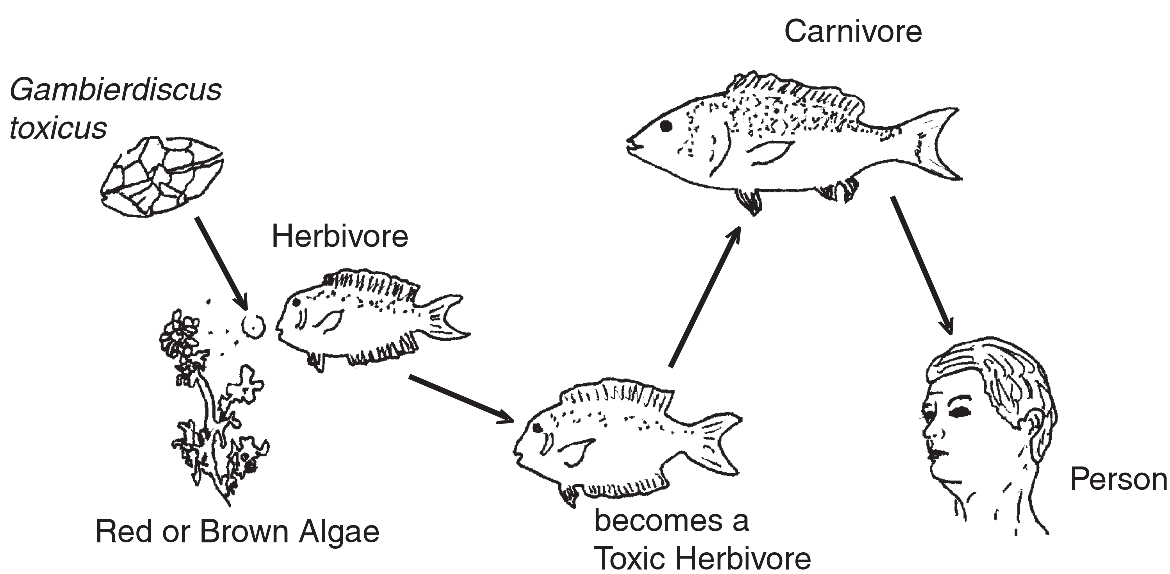


Image after J. L. Shirai, L. K. Shirai, and Y. Hokama, Seafood Poisoning: Ciguatera, *Yosh Hokama Family Trust, Gardena, California, 1991*

3) *ʻŪʻū* or soldierfish do not fit into the two categories of fish that become ciguatoxic: herbivores that graze on “toxic” algae, and carnivores that feed on toxic herbivores. *ʻŪʻū* feed on plankton in midwater—away from the algae growth. Come up with one possible explanation for the fact that *ʻūʻū* have been implicated in at least one case of ciguatera poisoning in Hawaiʻi and describe it below in as much detail as you can. (You do not need to do additional research to formulate your explanation, but make sure you clearly explain your idea and your reasoning.)

Possible answers include:

- It was a case of mistaken reporting by the person who got ciguatera.
- As *ʻūʻū* feed on plankton, they may ingest *Gambierdiscus toxicus* dinoflagellates that dislodged from the algae, perhaps by wave action, and are floating freely in the water.
- There may be other toxins that are chemically similar to the ciguatoxin and cause the same symptoms but come from other sources, for example, within the plankton.
- There may be other types of dinoflagellates that produce ciguatoxin, and these may be found in the plankton that *ʻūʻū* feed on.

Marine Food Chains and Webs Cards

Cut on solid lines

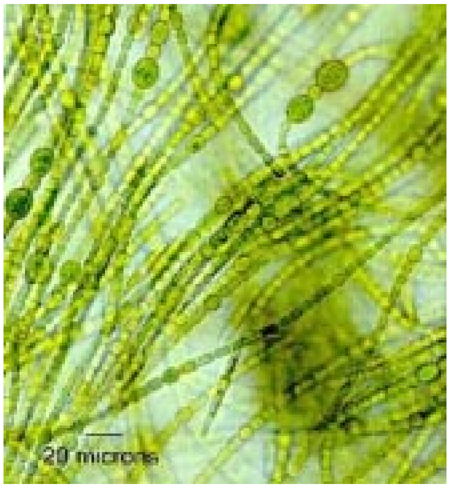


Photo: Roger Burks (University of California, Riverside), Mark Schneegurt (Wichita State University), Cyanosite (www-cyanosite.bio.purdue.edu/index.html)

Blue-green algae (Cyanobacteria)

These are primitive plant-like organisms which receive energy from the sun for photosynthesis. Some live on the surface of *limu* and are eaten along with the algae.

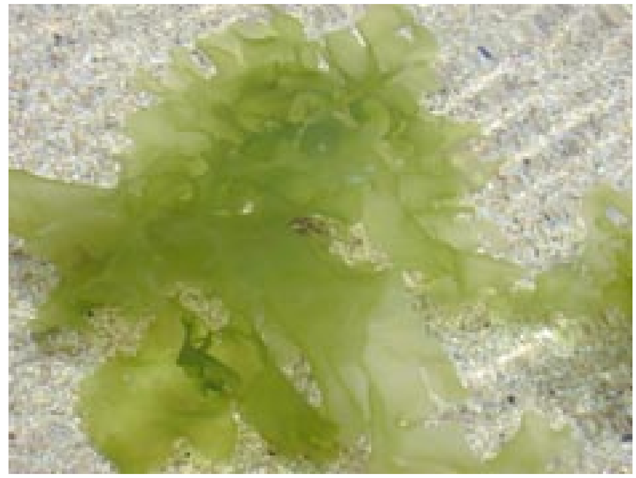
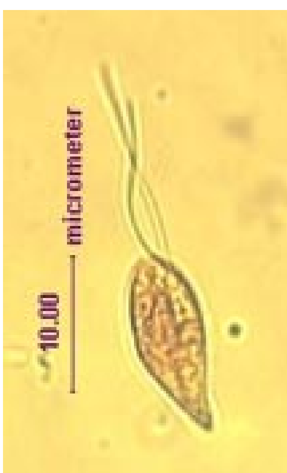


Photo: Kim Martz and Forest Starr

Limu (various species of seaweed)

Grows on rocks
Receives energy from the sun for photosynthesis



Photos: Karl Embleton, Sir Alister Hardy Foundation for Ocean Sciences

Phytoplankton

These are microscopic plants floating in the water which receive energy from the sun.

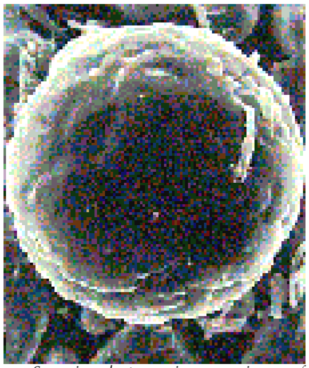
Photo: Karl Embleton, Sir Alister Hardy Foundation for Ocean Sciences

Zooplankton

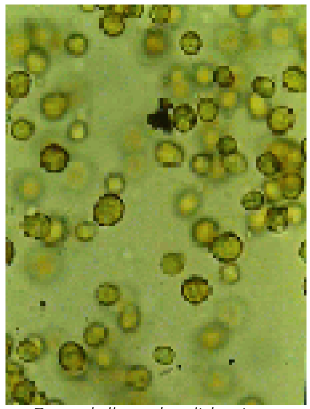
Most are tiny animals floating in the water, but some are larger, like jellyfish. The smallest ones feed on phytoplankton; larger ones eat smaller zooplankton.

Marine Food Chain and Web Cards

Cut on solid lines



Scanning electron microscope image of zooxanthellae (Photos: Scott R. Santos, SUNY at Buffalo)



Zooxanthellae under a light microscope

Zooxanthellae

Single-celled algae cells living in coral tissue that photosynthesize and provide the coral with 90% of its food

Photo: Jan Barosh in John P. Hoover, Hawaii's Fishes, Mutual Publishing

Spiny porcupinefish - *Kōkala* (*Diodon holocanthus*)

Feeds on snails and crabs

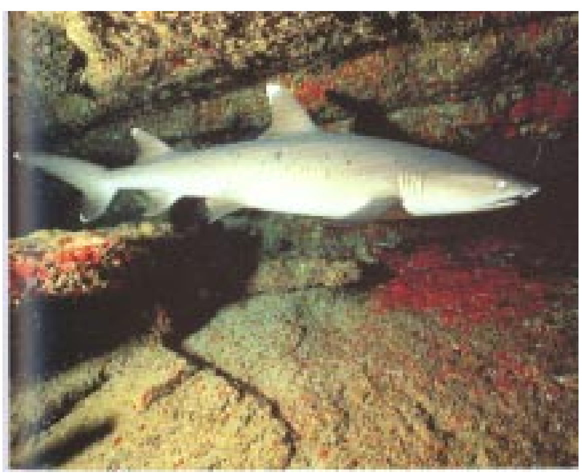


Photo: David R. Schrichte in John P. Hoover, Hawaii's Fishes, Mutual Publishing

Whitetip reef shark - *Manō lālā kea* (*Triaenodon obesus*)

Feeds at night on reef fish, octopus, lobster and crabs

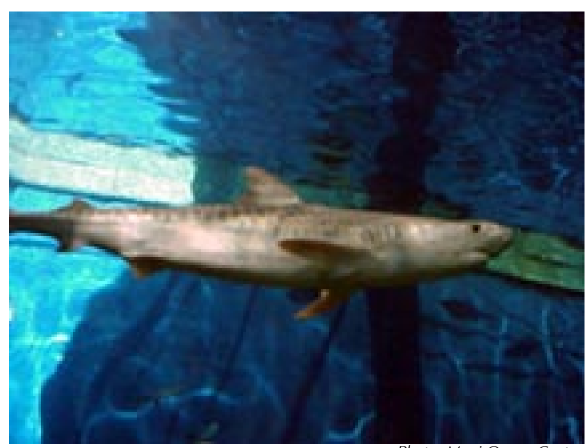


Photo: Maui Ocean Center

Tiger shark - *Niuhi* (*Galeocerdo cuvier*)

Feeds on octopuses, crabs, sharks, rays, porpoises, seabirds, turtles, lobsters, slow-swimming fishes

Marine Food Chain/Web Cards

Cut on solid lines

Photo: John P. Hoover, Hawaii's Fishes, Mutual Publishing

Bigeye scad - *Akule*
(*Selar crumenophthalmus*)
Feeds on zooplankton

Photo: John P. Hoover, Hawaii's Fishes, Mutual Publishing

Hawaiian dascyllus - *ʻĀloʻiloʻi*
(*Dascyllus albisella*)
Feeds on zooplankton

Photo: Scott Johnson in John P. Hoover, Hawaiʻi's Sea Creatures, Mutual Publishing

Penniform cone snail - *Pūpū pōniuniu* (*Conus pennaceus*)
Feeds on other snails

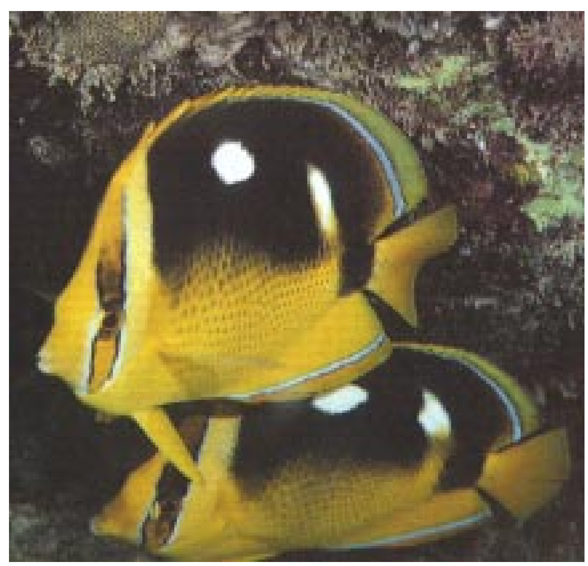


Photo: John P. Hoover, Hawaii's Fishes, Mutual Publishing

Fourspot butterflyfish - *Lau hau*
(*Chaetodon quadrimaculatus*)
Feeds on coral polyps

Marine Food Chain/Web Cards

Cut on solid lines

Photo: *Philip Thomas*

Yellowmargin moray eel - *Pūhi paka* (*Gymnothorax flavimarginatus*)
Feeds on reef fish and octopus

Photo: John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Eyestripe surgeonfish - *Palani* (*Acanthurus dussumieri*)
Feeds on algae

Photo: David R. Schrichte in John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

Day octopus - *He'e mauli* (*Octopus cyanea*)
Feeds on crabs and snails

Photo: Kim Martz and Forest Starr

Green sea turtle - *Honu* (*Chelonia mydas*)
Feeds on algae

Marine Food Chain/Web Cards

Cut on solid lines

Photo: John P. Hoover, *Hawaii's Fishes*, Mutual Publishing

Manta ray - *Hāhālua*
(*Manta* spp.)

Feeds on zooplankton

Photo: Philip Thomas

Cauliflower coral - *ʻĀkoʻakoʻa* or *Puna kea*
(*Pocillopora meandrina*)

Take energy primarily from zooxanthellae (which produce energy directly from the sun) in their tissues and also feed on zooplankton

Photo: John P. Hoover, *Hawaii's Fishes*, Mutual Publishing

Bluefin trevally - *ʻOmilu*
(*Caranx melampygus*)

Feeds on fishes

Photo: John P. Hoover, *Hawaii's Fishes*, Mutual Publishing

Spectacled parrotfish - *Uhu uliuli*
(*Scarus perspicillatus*)

Feeds on algae found on the surface of dead coral and on the zooxanthellae in live coral

Marine Food Chain/Web Cards

Cut on solid lines

Photo: John P. Hoover, Hawai'i's Sea Creatures*, Mutual Publishing*

Cowries - *Leho* (*Cypraea spp.*)

(Tiger Cowrey, *Cypraea tigris*, shown)
Most eat algae.

Living and Eating On the Web

As on land, the sun provides the energy for photosynthesis in the ocean. All photosynthesis takes place in relatively shallow water—or in the top layer of the ocean where the water is deeper. Sunlight is filtered out as it passes through water and does not reach the deep sea.

Plants are the "primary producers" in the ocean and form the first trophic level. Some are fleshy seaweeds or *limu*, some form hard skeletons similar to the structure created by coral and that help build the coral reef ("coralline algae"), some are single cells that live in the tissue of corals and provide energy to the corals ("zooxanthellae"), and some are microscopic single-celled plants that float in the ocean ("phytoplankton").

The "primary consumers" are "herbivores" (animals that feed only on plants). Primary consumers are the animals that eat algae, either phytoplankton or seaweed. They form the second trophic level.

"Secondary consumers" are "carnivores" (animals that eat other animals). Secondary consumers are the animals that eat the animals that eat algae. They form the third trophic level.

"Tertiary consumers" are predators on carnivores. They form the fourth trophic level.

You will be constructing food chains and webs that reflect these "trophic levels," the levels through which nutrients and energy flow, within a typical Hawaiian coral reef community.

Creating a Marine Food Chain

1) Read the cards provided.

2) Construct a food chain using some of the cards.
   a) On one sheet of paper, draw horizontal lines to indicate the first, second, third and fourth trophic levels. Designate one color to indicate the first trophic level (plants).
   b) Identify organisms on the cards that are in the various trophic levels.
   c) Tape a picture of one organism in each trophic level on the paper. Draw arrows from the plant or animal being eaten towards the animal doing the eating. These arrows represent the flow of energy between organisms. Use the designated color to draw the arrow to any animal eating a plant.

   ### Note
   A food chain is linear. For example: seaweed is eaten by snail, snail is eaten by crab, crab is eaten by fish, fish is eaten by shark.

3) At this point, your teacher will ask you to present your food chain to the class.

Creating a Marine Food Web

1) Dismantle your food chain and construct a marine food web using all of the cards.

2) On another large piece of paper draw horizontal lines to indicate four trophic levels, again designating one color to indicate the first trophic level (plants).

3) Place each card in a trophic level. Build the whole food web with the 20 cards before you tape down the cards. Add trophic levels if you need to do so.

Note

A food web is not linear, there may be multiple connections among organisms in a food web.

4) Draw arrows from the plant or animal being eaten towards the animal doing the eating. Again, use the designated color to connect plants to any animal eating them. There may be more than one animal eating a plant or animal. Show as many connections as you can.

5) There are two other categories having to do with an organism's role in cycling energy through an ecosystem:
   - "Detritivores" or scavengers are animals that feed on organic materials on the seafloor. "Detritus" refers to the remains of dead organisms or cast-off material from living organisms.
   - "Decomposers" are bacteria that break down organic material further, into its inorganic components, so it can be recycled back into the system.

   Using the above information, represent detritivores and decomposers on your food web (they won't necessarily fit into a trophic level). You may also wish to use the following information:

   - The black sea cucumber (*loli okuhi kuhi* or *Holothuria atra*) is an example of a detritivore. It lives in shallow water on sand.

Photo: John P. Hoover, Hawai'i's Sea Creatures*, Mutual Publishing*

   - The partridge tun snail (*pū'ōni'oni'o* or *Tonna perdix*), which is also found in shallow water and generally seen at night, feeds on sea cucumbers.

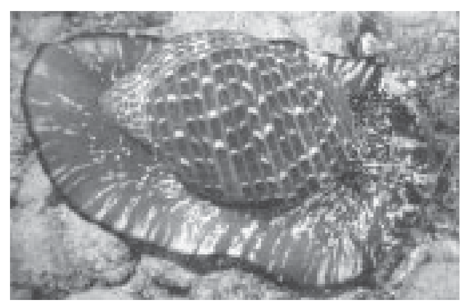


Photo: John P. Hoover, Hawai'i's Sea Creatures*, Mutual Publishing*

6) Next, add a human to the food web. Draw the arrows to the human in a different color than you have used before. Which animal has the most links to it in the food web?

Poison Pathways

Ciguatera fish poisoning is an illness caused by eating seafood—mostly reef fishes—that have accumulated a poison called "ciguatoxin." Each year, about ten to twenty people in Hawai'i get ciguatera poisoning, the symptoms of which may last a week or so in mild cases. In some cases, the symptoms may persist for several months or longer.

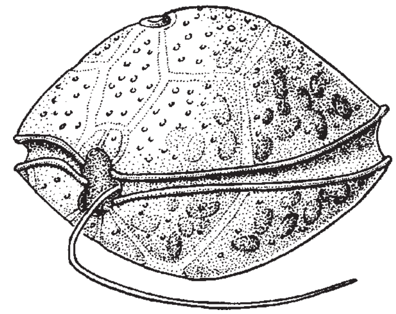
What does it feel like to have ciguatera fish poisoning? Your mouth, hands, and feet may go numb and tingly. Your joints and muscles might hurt, cramp up, or become weak. You could have chills, itching, headaches, sweating, dizziness, vomiting, or diarrhea. None of that is very pleasant—and your symptoms may range from mild to severe, beginning two to five hours after eating contaminated fish. There's another symptom that doesn't usually kick in until two to five days after eating a toxic fish. It's known as "temperature sensation reversal." Cold objects feel hot, and hot objects feel cold.

If ciguatera poisoning sounds like something you want to avoid, use these precautions:

- Do not eat the head, guts, or roe (eggs) of any reef fish. The ciguatoxin is concentrated up to 100 times in these parts of the fish, compared to other parts.
- Thoroughly clean reef fish as soon as possible after they are caught. This is to prevent the toxin that has accumulated in the organs from further contaminating the flesh.
- Remember that ciguatoxin is not destroyed by cooking, drying, salting, or freezing fish.
- Avoid eating fish caught at sites known to have a ciguatoxic algae problem.

Toxic Algae?

What is ciguatoxic algae? Ciguatoxin is produced by microscopic marine organisms called "dinoflagellates." Dinoflagellates of a particular species, *Gambierdiscus toxicus*, bloom among and on the algae on which herbivorous fish such as *kole* (gold-ring surgeonfish) and *palani* (eyestripe surgeonfish) feed. As they forage through the algae, these fish ingest the dinoflagellates and the ciguatoxin they produce. The algae itself is not toxic, but it may as well be.



Gambierdiscus toxicus *magnified approximately 400 times*
Image: The Epidemiology Branch, State of Hawai'i

Accumulating up the Food Chain

The ciguatoxin accumulates in the flesh and organs of herbivorous fish. When these fish are eaten by carnivorous fish, the toxin travels up the food chain, accumulating in the bodies of the carnivores as well. Through this process of "bioaccumulation," carnivores may end up with greater concentrations of ciguatoxin than herbivores because they may repeatedly eat animals with the toxin concentrated in their tissues.

Humans can be carnivores, too. When people eat toxic fish—either herbivorous or carnivorous fish—they are exposed to ciguatoxin. Depending on the individual's sensitivity and prior exposure to ciguatoxin, a person may become mildly to severely ill.

You can reduce your chances of a run-in with ciguatoxin by knowing how ciguatoxin fits in to Hawaiian marine food chains. Use the information on the next two pages to answer the questions that follow.

Fish Species to Watch Out For

Most incidents of ciguatera poisoning in Hawai'i have been caused by four types of fish: *ulua* (jack), *kāhala* (amberjack), *kole* (gold-ring surgeonfish), and *pō'ou* (ringtail wrasse). But other fish species have been implicated in incidents of ciguatera poisoning, too. Here is a list of these species, along with a brief description of what they eat. You will use this information to help you answer the questions that accompany this reading.

The Big Four

Ulua or Jack (*pāpio* = juvenile)

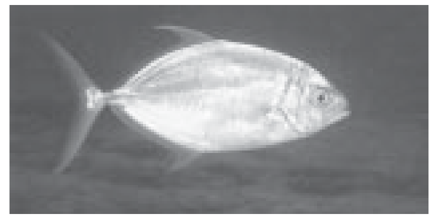


Photo: John P. Hoover

Caranx sexfasciatus (Bigeye jack), *Carangoides orthogrammus* (Yellowspotted jack), among others

Length: Maximum one meter (three feet), depending on the species

Feeding: These swift, strong-swimming predators, which frequent open water near dropoffs or over reefs, feed primarily on other fishes, and forage on the bottom for crustaceans and other invertebrates.

Kāhala or Amberjack

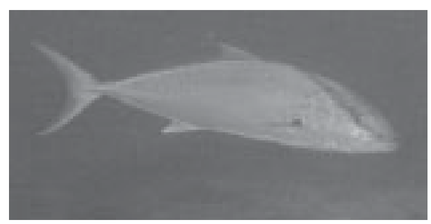


Photo: John P. Hoover

Seriola dumerili

Length: Up to two meters (six feet)

Feeding: These large predators occasionally come inshore to feed off schooling fishes in shallow water.

Kole or Gold-ring surgeonfish

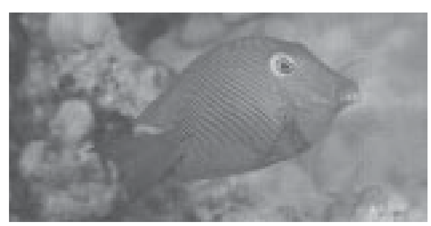


Photo: John P. Hoover

Ctenochaetus strigosus

Length: Up to 17 centimeters (seven inches)

Feeding: Algae feeders

Pō'ou or Ringtail wrasse

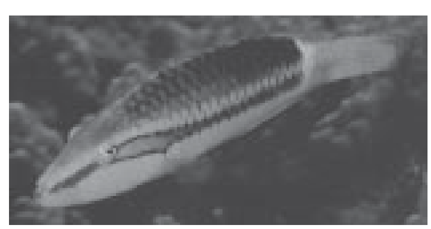


Photo: John P. Hoover

Cheilinus unifasciatus

Length: Up to 45 centimeters (18 inches)

Feeding: Predators of fishes, they typically hover several feet off the bottom, head angled down, ready to strike.

Other Species to Watch

ʻAmaʻama or Striped mullet

Mugil cephalus

Length: Up to 50 centimeters (20 inches)
Feeding: They feed primarily off the bottom, taking in sand or mud and filtering out the organic material through their gills.

Palani or Eyestripe surgeonfish

Acanthurus dussumieri

Length: Up to 45 centimeters (18 inches)
Feeding: These are algae feeders.

Kākū or Great barracuda

Sphyraena barracuda

Length: Up to two meters (six feet)
Feeding: These lean, fast, and powerful predators hunt in schools or alone and are often found in shallow water close to shore.

Uku or Gray snapper

Aprion virescens

Length: Up to one meter (three feet)
Feeding: These are long, powerful-looking, greenish to bluish gray predators.

Roi or Peacock grouper

Cephalopholis argus

Length: Up to about 40 centimeters (16 inches)
Feeding: These are large-mouthed, bottom-dwelling predators introduced from Moorea, French Polynesia in 1956. They rely on ambush or careful stalking to get within striking distance of their prey. When the prey is sufficiently close, the grouper opens its large expandable mouth and takes in water, along with its meal.

Weke or Goatfish

Mulloidichthys spp.

Length: Up to 60 centimeters (24 inches), depending on species
Feeding: They probe the sand with their whisker-like barbels, searching for worms, molluscs, and other invertebrates.

Pūhi or Moray eel

Gymnothorax flavimarginatus (Yellowmargin moray) and others

Length: Up to 2.5 meters (eight feet), depending on species
Feeding: These predators feed on fish and crustaceans.

Taʻape or Bluestripe snapper

Lutjanus kasmira

Length: Up to 37 centimeters (15 inches), but usually smaller
Feeding: These predators range from shallow water to deeper waters. Introduced from the Marquesas in 1958, they are low priced and compete with more favored food fish.

Wahanui or Forktail snapper

Aphareus furca

Length: Up to .3 meters (one foot)
Feeding: These predators typically scout the reef from a position well off the bottom, often near dropoffs.

ʻŪʻū or Soldierfish

Myripristis spp.

Length: Up to 27 centimeters (11 inches), depending on the species
Feeding: These medium-sized nocturnal fishes are usually red, with big scales and large dark eyes. They favor plankton in the water away from the bottom.

Sources

Epidemiology Branch, *Fish Poisoning in Hawaiʻi,* State of Hawaiʻi, Department of Health, Honolulu, 1997.

Hawaiʻi Department of Health, "Ciguatera Fish Poisoning" at <www.hawaii.gov/doh/resource/comm_dis/cddcigua.htm>.

Cigua-Check Fish Poison Test Kit website at <www.cigua.com>.

Shirai, J. L., L. K. Shirai, and Y. Hokama, *Seafood Poisoning: Ciguatera*, Yosh Hokama Family Trust, Gardena, California, 1991.

Poison Pathways: Questions from the Reading

1) Draw a food chain showing how a person could get ciguatera poisoning from eating an herbivorous fish. Use specific examples based on the reading.

2) Draw a food chain showing how a person could get ciguatera poisoning from eating a carnivorous fish. Use specific examples based on the reading.

3) *‘Ū‘ū* or soldierfish do not fit into the two categories of fish that become ciguatoxic: herbivores that graze on “toxic” algae, and carnivores that feed on toxic herbivores. *‘Ū‘ū* feed on plankton in midwater—away from the algae growth. Come up with one possible explanation for the fact that *‘ū‘ū* have been implicated in at least one case of ciguatera poisoning in Hawai‘i and describe it below in as much detail as you can. (You do not need to do additional research to formulate your explanation, but make sure you clearly explain your idea and your reasoning.)

Activity #3

Marine Life Scrapbooks

● ● ● In Advance *Assembling Research Resources*

You may want to pull together a reference collection for your classroom or to place on reserve in the library, prior to beginning this activity. See the "Resources for Further Research and Reading" list in the unit overview (p. 4) for suggested books and articles.

● ● ● Class Period One *Beginning the Scrapbooks*

Materials & Setup

For each student

- Student Page "Marine Life Scrapbooks" (pp. 40-41)

Instructions

1) Hand out the Student Page "Marine Life Scrapbooks." Explain to students that this is a starting point for researching and assembling a scrapbook on the natural history and cultural significance and use of Hawaiian marine plant and animal species.

2) You may have students work individually or allow small groups to work together.

3) Determine how long you will allow for students to complete this assignment, and let students know the due date. One week is a suitable length of time.

4) Allow students the rest of the class period to work on their scrapbook ideas. Have groups of students brainstorm ideas, and/or allow students to begin library and Internet research.

Journal Ideas

- Think of a marine plant or animal that is important to you or your family. Describe the significance of this organism to you.
- What kinds of information can you learn by listening to people's stories that you cannot learn from library or Internet research?

Assessment Tools

- Student scrapbooks
  - Use guidelines and rules on the Student Page "Marine Life Scrapbooks" as pointers for assessment.
  - Another assessment aid is the Teacher Background "Importance of Some Marine Species in Hawaiian Culture" (pp. 38-39) which includes brief notes about Hawaiian cultural significance from the sources recommended in the unit overview (p. 4).

Teacher Background

Importance of Some Marine Species in Hawaiian Culture

Since Hawaiian cultural significance of marine species was not covered in other activities in this unit, students may need more guidance in their research. This information is not as readily available in written form as information about biology and natural history. This list contains brief notes about a selection of marine species that are significant in traditional Hawaiian culture. The notes are taken from the books in the resource list on the Student Page “Marine Life Scrapbooks.” You may use this list to help guide student species selection, as well as to help assess cultural information in student scrapbooks.

Limu (Seaweeds)

Limu kala (*Sargassum echinocarpum*)
- ‘Loosens’ evil spirits causing illness
- Used in the ho’oponopono process and in the purification ceremony after the death of a relative
- Used for food

Limu kohu (*Asparagopsis taxiformis*)
- Used for food
- The subject of a legend
- Tended in gardens

Invertebrates

Kūpe‘e (Polished nerite, *Nerita polita*)
- Meat used for food
- Shell used for body ornaments

Leho ahi (Humpback cowry, *Cypraea mauritiana*)
- Meat used for food
- Shell used for food scrapers and octopus lures

‘Opihi (Hawaiian limpet, *Cellana* spp.)
- Meat used for food and medicine
- Shell used for scooping, peeling, scraping

He‘e (Octopus, *Octopus* spp.)
- Used for food

Wana (Long-spined sea urchin, *Echinothrix calamaris* and *diadema*)
- Used for food

Vertebrates

Manō (Sharks)
(Tiger shark *Galeocerdo cuvier,* Whitetip reef shark *Triaenodon obesus*, Gray reef shark *Carcharhinus amblyrhynchas*, and others)
- Found in Hawaiian proverbs
- Teeth used as the cutting edge on weapons
- Skin used for drumheads
- Various Hawaiian gods associated with sharks

‘Ahi (Yellowfin tuna, *Thunnus albacares*)
- Sportfishing for chiefs
- Used for food, often dried for later use

Āholehole (Hawaiian flagtail, *Kuhlia sandvicensis*)
- A favored food of chiefs
- Used in ceremonies

Akule (Bigeye scad, *Selar crumenophthalmus*)
- Used for food, a favorite for drying

‘Ama‘ama (Striped mullet, *Mugil cephalus*)
- Used for food
- Featured in legends

ʻĀweoweo (Hawaiian bigeye, *Priacanthus meeki*)
- Used for food
- Found in stories

Kūmū (Whitesaddle goatfish, *Parupeneus porphyreus*)
- Used for food
- Offered to the gods

Manini (Convict tang, *Acanthurus triostegus*)
- Used for food

Moi (Six-fingered threadfin, *Polydactylus sexfilis*)
- Used for food

Mū (Bigeye emperor, *Monotaxis grandoculis*)
- Used for food
- Check other uses of the name, *mū*, for an interesting connection.

Palani (Eyestripe surgeonfish, *Acanthurus dussumieri*)
- Used for food
- Featured in a legend

Pūhi (Moray eels, including Yellowmargin moray eel, *Gymnothorax flavimarginatus,* and others)
- Used for food
- Captured using a variety of fishing methods

Uhu (Parrotfishes, including Bullethead parrotfish, *Chlorurus sordidus,* Palenose parrotfish, *Scarus psittacus,* Spectacled parrotfish, *Scarus perspicillatus,* and others)
- Used for food
- Captured using a variety of fishing methods
- Appear in legends

Marine Life Scrapbooks

Your assignment is to make a scrapbook about Hawaiian marine plant and animal species. Your scrapbook will include a summary of what you have learned about these species as well as more information based on research.

Guidelines for Your Scrapbook

1) Include three or more different marine species, using at least one page for each species.

2) For each species, include the following information:
   - All of the names for this species you can find, including scientific, common, Hawaiian, and other languages
   - A summary of the biology and natural history of this species
     (The summary for each species should include information about its trophic level, relationships with other marine organisms, habitat, and adaptations.)
   - Information about the cultural significance and uses of this species
     (You do not need to limit this information to the traditional Hawaiian significance and uses of these species. Other cultures that have been important in creating the modern Hawaiian culture and society may also attach significance to these species and use them in different ways.)
   - Drawings or photographs of the species and other images that help convey what you have learned about this species

Ideas

- Use species you studied in this unit or species that are significant to you or members of your family, or start by looking at “Marine Species Important in Hawaiian Culture” below as a starting point. It lists many marine species that are important in traditional Hawaiian culture.

- Research the natural history and cultural significance of plants and animals by doing library or Internet research. As you find information, add it to your scrapbook. See the “Resources List” below for suggested starting points.

- Look for stories or legends having to do with marine species.

- Ask family members and friends (especially *kūpuna*) for information, stories, recipes, or any sort of personal experiences that they have with the species.

- Include your own personal experiences in the scrapbook.

- If you find a good “informant,” you may audio- or videotape that person, in addition to taking notes. This can become part of your scrapbook, too.

Marine Species Important in Hawaiian Culture

Limu (Seaweeds)

- *Limu kala* (*Sargassum echinocarpum*)
- *Limu kohu* (*Asparagopsis taxiformis*)

Invertebrates

- *Kūpe'e* (Polished nerite, *Nerita polita*)
- *Leho ahi* (Humpback cowry, *Cypraea mauritiana*)
- *'Opihi* (Hawaiian limpet, *Cellana* spp.)
- *He'e* (Octopus, *Octopus* spp.)
- *Wana* (Long-spined sea urchin, *Echinothrix calamaris* and *diadema*)

Vertebrates

- *Manō* (Sharks)
  (Tiger shark *Galeocerdo cuvier,* Whitetip reef shark *Triaenodon obesus*, Gray reef shark *Carcharhinus amblyrhynchas*, and others)
- *'Ahi* (Yellowfin tuna, *Thunnus albacares*)
- *Āholehole* (Hawaiian flagtail, *Kuhlia sandvicensis*)
- *Akule* (Bigeye scad, *Selar crumenophthalmus*)
- *'Ama'ama* (Striped mullet, *Mugil cephalus*)
- *'Āweoweo* (Hawaiian Bigeye, *Priacanthus meeki*)
- *Kūmū* (Whitesaddle goatfish, *Parupeneus porphyreus*)
- *Manini* (Convict tang, *Acanthurus triostegus*)
- *Moi* (Six-fingered threadfin, *Polydactylus sexfilis*)
- *Mū* (Bigeye emperor, *Monotaxis grandoculis*)
- *Palani* (Eyestripe surgeonfish, *Acanthurus dussumieri*)
- *Pūhi* (Moray eels, including Yellowmargin moray eel *Gymnothorax flavimarginatus* and others)
- *Uhu* (Parrotfishes, including Bullethead parrotfish *Chlorurus sordidus,* Palenose parrotfish *Scarus psittacus,* Spectacled parrotfish, *Scarus perspicillatus,* and others)

Resource List

Abbott, Isabella, and E. H. Williamson, *Limu — An Ethnobotanical Study of Some Edible Hawaiian Seaweeds* Pacific Tropical Botanical Garden, Lawai (Hawaii), 1974.

Fortner, Heather J., *The Limu Eater*, Sea Grant Misc. Report, UNIHI-SEAGRANT-MR-79-01, 1978.

Hobson, Edmund S. and E. H. Chave, *Hawaiian Reef Animals*, University of Hawai'i Press, Honolulu, 1990.

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Marine Unit 3

On the Edge: Living in the Intertidal Zone

Overview

The intertidal area, that part of the shoreline that is underwater at high tide and exposed when the tide is low, offers a harsh environment for organisms. Salinity, temperature, and moisture vary widely, and wave action can displace or destroy habitat. These conditions vary within the intertidal area and create different zones or vertical banding of habitat and organisms. In this unit, students learn about the variation in environmental conditions and organisms adapted to live within the intertidal zone. This unit focuses on the intertidal zone of rocky shorelines, providing a complement to the focus on sandy beaches in Coastal Unit 1.

Length of Entire Unit

Three class periods

Unit Focus Questions

1) How do environmental conditions vary within the intertidal zone, and how does that variation affect the organisms that live in this zone?

2) How are Hawaiian marine organisms adapted to conditions within the intertidal zone?

Unit at a Glance

Activity #1
Intertidal Zonation

Students work in groups to understand environmental conditions within the five subzones represented in intertidal areas, and how Hawaiian marine organisms are adapted to survive in these conditions.

Length
One class period

Prerequisite Activity
None

Objectives
- Identify and explain environmental conditions in the intertidal zone and their effects on organisms that live in this zone.
- Identify, be able to explain, and give examples of adaptations to these conditions exhibited by Hawaiian marine species.
- Describe and explain the concept of "zonation" using the intertidal zone and its inhabitants as examples.

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.

Activity #2
A Day in the Neighborhood: Skits About the Intertidal Zone

Student groups develop and perform skits to teach the class about environmental conditions, organisms, and adaptations within an intertidal subzone.

Length
Two class periods

Prerequisite Activity
Activity #1 "Intertidal Zonation"

Objectives
- Dramatize environmental conditions within the intertidal zone and the responses of organisms to these conditions.

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.

Enrichment Ideas

- Play the "Adaptation Concentration" game (see Marine Unit 2, Activity #1) using the "Life on the Edge" species cards.
- Using the "Life on the Edge" species cards, do in-class identification drills in which students, or groups of students, match photos and the information provided on the back of each card.
- Adapt the "Adaptations Game Show" (see Alpine/Aeolian Unit 3, Activity #3) using the "Life on the Edge" species cards.
- Research traditional Hawaiian uses of intertidal areas and organisms. (See "Resources for Further Reading and Research" for resources.)
- Consult a tide chart to determine a good day and time for exploring tidepools. Go to an intertidal area, such as the tidepools at Mākena, gathering evidence of zonation and making species observations.
- Research how different intertidal and marine organisms regulate salt concentrations in their body in an environment that is saline or characterized by fluctuating salinity.
- Add a lab in which students study the effects of varying salinity levels on marine animals that are osmoregulators and osmoconformers. There are many straightforward labs written up in biology textbooks and on the Internet.

Resources for Further Reading and Research

Fielding, Ann, *Hawaiian Reefs and Tidepools*, Island Explorations, Makawao, Hawai‘i, 1998.

Hoover, John P., *Hawaii's Fishes: A Guide for Snorkelers, Divers and Aquarists*, Mutual Publishing, Honolulu, 1993.

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The Intertidal Zone video, Bullfrog Films, 1986. 17 minutes. Available for purchase or rental at (800) 543-3764 or <www.bullfrogfilms.com/catalog/zone.html>.

Merlin, Mark, *Hawaiian Coastal Plants: An Illustrated Field Guide*, Pacific Guide Books, Honolulu, 1999.

Randall, John E., *Shore Fishes of Hawaii*, Natural World Press, 1996.

Traditional and Hawaiian Cultural Uses of Marine Life

Abbott, Isabella, and E. H. Williamson, *Limu — An Ethnobotanical Study of Some Edible Hawaiian Seaweeds,* Pacific Tropical Botanical Garden, Lawai, Hawai‘i, 1974.

Fortner, Heather J., *The Limu Eater* Sea Grant Misc. Report, UNIHI-SEAGRANT-MR-79-01, 1978.

Hobson, Edmund S. and E. H. Chave, *Hawaiian Reef Animals*, University of Hawai‘i Press, Honolulu, 1990.

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Activity #1

Intertidal Zonation

● ● ● Class Period One *Intertidal Subzones*

Materials & Setup

- "Hāmākua Poko" acetate (master, p. 13)
- "Intertidal Subzones Table" acetate (master, p. 14)
- "Intertidal Images" acetates (master, pp. 15-16)
- One copy of "Subzone Conditions Cards" (master, pp. 17-21)
- One set of "On the Edge Species Cards" (master, pp. 22-37), divided into five subzone categories using the "Subzones Species Key" (p. 38)
- Overhead projector and screen

Instructions

1) Show the photo of Hāmākua Poko (near Mama's Fish House on Maui, between Kū'au and Ho'okipa) on the overhead. The photograph generally illustrates the concept of zonation. Ask students to look at the photo and see if they can figure out what "zonation" means. This is the lead-in question to a brief class overview of the intertidal zone. (NOTE: You can find more background for leading this discussion in Teacher Background "Intertidal Conditions," pp. 9-12.)

2) Lead the discussion to this definition of zonation: the distribution of plants and animals according to environmental conditions. The pattern of vertical banding that is shown in the photograph is similar to that seen along rocky shorelines where there are bands of "microhabitats" or "subzones" within a relatively narrow shoreline area.

3) The part of the shore that is underwater at high tide and exposed when the tide is low is called the "intertidal zone." What factors do students think would influence the width of this zone? (Use "Intertidal Images" acetates to show variations in slope and tidal range.)

4) Ask students what the physical conditions would be like for species in the intertidal zone. As they answer, make the following points:

    - Conditions vary in the intertidal zone, changing hour to hour, day to day, season to season. This is because of the ebb and flow of the tide, different seasonal wave patterns, light and temperature changes through the course of a day or night.
    - Conditions vary within the intertidal zone itself, depending upon the beach slope, relationship to the high and low tide lines, and the terrain.
    - Much of the intertidal zone should be alternately wet and dry, exposing organisms to fluctuations in moisture, wind exposure, etc.
    - In tidepools the salt water can be concentrated by evaporation or diluted by rain water, so organisms are exposed to fluctuations in salinity.

- Wave action can displace or destroy habitat, and can also crush, break, or tear organisms. Wave action has different effects depending upon the location in the intertidal zone.

- Saltwater splash from waves can expose organisms to dessication (drying out).

5) Ask students if the intertidal zone is such a difficult place to live, why would any organisms live there at all? What are the benefits to organisms that can survive here? As students answer, make the following points:

   - One advantage is avoiding many of the predators common in the more stable environmental conditions of the deeper waters at the edge of the intertidal. So snails, for example, can graze with less risk of predation.

   - Under certain conditions (e.g., high tides at night) larger predators such as octopuses and eels can gain access to tidepools, but not consistently. Other predators include crabs, birds, and humans. Even experienced marine life observers have little specific information about predation. The intertidal zone seems to be a pretty safe place to live for organisms that can tolerate the environmental extremes.

   - Also, through much of the intertidal zone, regular inundations by ocean water bring nutrients for algae growth, new food sources, and an abundant supply of oxygen.

6) Because of the variations in conditions, there are "sub-zones" within the intertidal zone. Show the "Intertidal Subzones Table" acetate and review the zonation within the intertidal area. Leave the "Intertidal Subzones Table" up on the overhead. Divide students into five groups. Give each group the Hypothesis Card for one of the subzones, from the "Subzone Conditions Cards."

7) Have groups hypothesize about the environmental conditions in the subzone it was assigned. Students will consider three variables: fluctuations in salinity, wave action, and exposure to air. Have them write their hypotheses in the corresponding columns on the Hypothesis Card. Then, on the back of the card, have them write at least two hypotheses about how organisms that live in this subzone are adapted to live in these conditions.

8) After groups are finished recording their hypotheses, hand out the Comparison Card (from the "Subzones Conditions Cards") and "On the Edge Species Cards" that correspond to each group's subzone (see the "Subzones Species Key"). Have groups compare their hypotheses with actual conditions listed on the Comparison Card and compare their adaptations hypotheses with information available on the species cards. Students should make notes about these comparisons on the card or on a separate piece of paper.

9) Have each group share its hypotheses with the rest of the class, explaining similarities and differences between the Comparison Card and Species Cards.

10) Wrap up the class with a discussion based on the following questions:

- Which one or two of these subzones do you think would be the harshest environment for marine organisms? Why?

  Well-reasoned responses are acceptable. In general, the splash zone and upper intertidal zones are considered the harshest zones because the organisms in these zones are exposed to greater extremes than those in other zones.

- In which subzone or subzones would you expect to find the most organisms and greatest diversity of marine organisms? Explain your answer.

  Again, well-reasoned responses are acceptable. The lower intertidal and subtidal zones, being the most reliably submerged, are home to more and a greater variety of organisms than the others.

- Many of the plant and animal species in the intertidal zone were used for food and medicine in traditional Hawaiian culture. Many are still used today. Why do you think so many of these species would be used for food—other than how *ono* they are?

  Well-reasoned responses are acceptable. The primary reason is probably that these species are accessible and relatively easy to gather or hunt.

- Are there any species that seem better adapted to avoid "human predation" than others? Why?

  Well-reasoned responses are acceptable. Some possible answers include:

  - Animals that live in the subtidal zone may be more difficult for humans to gather.
  - Animals that grip tightly and are difficult to get off the rocks may be less vulnerable.
  - Animals that are spiny or have sharp shells may be more difficult for humans to gather.
  - Plants or animals that taste bad would discourage humans collecting food.
  - Animals that quickly hide (such as rock crabs or zebra blennies) may be more difficult for humans to trap.

Journal Ideas

- Have you ever collected *‘opihi*, *limu*, or other plants or animals in the intertidal zone? Or do you know someone who does? What is your (or their) favorite part of collecting?
- Hawaiians were careful observers of their environment. What observations do (or would) you make as you enter the intertidal zone? How would these observations affect your actions?
- Describe what conditions would be like in various parts of the intertidal zone if the following traditional Hawaiian prayer for surf were successful. This prayer would be chanted while lashing at the ocean’s edge with a length of *pohuehue* vine or after building a mound of sand and wrapping the *pohuehue* vine around it.

Ku mai! Ku mai!
Ka nalu nui mai Kahiki mai.
‘Alo po‘i pu!
Ku mai i ka pohuehue
Hu! Kaiko‘o loa!

Arise! Arise!
Great surfs from Kahiki.
Waves break together!
Rise with the *pohuehue*
Well up, raging surf!

Jane Gutmanis, Na Pule Kahiko: Ancient Hawaiian Prayers, *Editions Limited, Honolulu, Hawai‘i, 1983, p. 101.*

Assessment Tools

- Hypothesis Cards
- Participation in group work and class discussion
- Journal entries

Teacher Background

Intertidal Conditions

Conditions

The intertidal zone, also known as the “littoral zone,” is the transition area between land and the ocean. This is the area between the normal limits of high and low tides.

The intertidal zone is a harsh habitat, exposed to environmental extremes of temperature, water oxygen level, salinity, moisture/water level, and wave stress. Conditions here can change dramatically over the course of a day in response to tidal ebb and flow, wind, solar exposure, and rainfall. Conditions in the intertidal zone also vary over longer time scales with tidal fluctuations (e.g., highly variable spring tides and the smaller fluctuations of neap tides) and seasonal changes in wave action.

Despite these environmental challenges, much of the intertidal zone is densely populated with living organisms. Competition within the intertidal zone is keen, and organisms are highly specialized and adapted to unique conditions within this zone.

Temperature

Normal air temperatures vary seasonally and within each 24-hour period. Lower temperatures can also be caused by wind and evaporative cooling. Temperature increases are also seen on hot, windless days. When organisms are exposed to the air, they must withstand these temperature variations.

Even when organisms are covered by water, as in a tidepool, temperature has an effect. One effect of temperature fluctuations is on dissolved oxygen. Elevated temperatures create oxygen-poor conditions. The water may become so warm that the oxygen content drops to near zero.

Salinity

The concentration of salts in the water captured in tidepools varies with factors such as exposure to sun and heavy rainfall. When a tidepool is exposed to the sun for many hours, the water evaporates and salinity increases. During periods of heavy rainfall, the water in exposed tidepools will be diluted and salinity will decrease.

Wave stress

The entire intertidal zone is subject, to one extent or another, to wave action. Waves have a variety of effects on habitat conditions in the intertidal zone, ranging from splashing water to strong forces that drag and lift at organisms and scour habitats. Tidal changes exacerbate wave action—water movement and wave pounding increase as the tide comes in. There are also seasonal variations in the size and strength of waves.

Tidal changes in water level

When the tide is out, intertidal organisms are exposed to the air. Depending upon where they are in relation to the high and low tide lines, organisms may spend periods of up to several hours in dry conditions. Parts of the intertidal zone are alternately exposed and immersed by tides twice each day.

Zonation

Zonation is the distribution of plants and animals based on environmental conditions. Natural communities found within the intertidal zone are good examples of zonation because the spatial variation in environmental conditions can be so extreme.

The rocky marine seashore is commonly divided into several subzones based on proximity to the ocean and, therefore, usual patterns of immersion and exposure.

Subzone	Alternate name	Description
Splash zone		The splash zone is a barren, rocky area frequently exposed to ocean spray but not typically immersed, even by high tides.
Upper intertidal zone	Eulittoral zone	The upper intertidal zone is covered by water only at high tide.
Lower intertidal zone	Sublittoral zone	The lower intertidal zone is underwater most of the time, except at extremely low tide. When exposed, strong waves and currents buffet this area.
Subtidal zone		The subtidal zone is always submerged. This subzone is usually considered to be the deeper water at the edge of the shoreline, the subtidal zone also includes many tidepools.
Tidepools		Tidepools are permanent and ephemeral collections of water.

Adaptations

The table below outlines a few of the environmental extremes of the intertidal zone, their potential effects on plants and animals in the zone, and ways in which organisms are adapted to live in these conditions.

Conditions	Potential Effects	Adaptations
Tidal ebb and flow; saltwater splash from wave action	Organisms exposed to the air during ebb tides, or that live in the splash zone, are subject to dessication (drying). Exposure to variable air temperatures	— Protective body structures such as shells (Snails withdraw into their shells and some secrete a mucous seal. Mollusks close their shells to retain moisture.) — “Limpets” (snails with conical, caplike shells) grind small depressions in rocks and clamp the underside of their body to the rock, leaving only their shell exposed. — Some algae have waxy coatings. — Anemones gather in large masses to reduce exposed body surface. — Seaweeds grow in dense colonies. The upper layers shelter the lower layers.
Wave action	Displacement and loss of habitat Crushing, breaking, or tearing the organism	— Streamlined or flattened shapes (e.g., *‘opihi*) — Smooth surfaces that reduce friction and deflect wave force (e.g., *pipipi* or black nerites) — Clustering to reduce surface area exposure (e.g., barnacles) — Hiding or growing in crevices, or under sheltering rocks or plants (e.g., *nahawele* or black purse shells) — Burrowing in the sand (e.g., many types of crabs) — Strong structures to attach to a solid substrate Root-like “holdfasts” in plants and tube feet (suction cups) in animals are two examples. — Flexibility (e.g. many algae, sea palms)
Tidal ebb and flow, hot conditions that cause evaporation, rainfall that dilutes tidepools	Rapid changes in water salinity	— Retain sea water inside shell to maintain constant salinity (e.g., black purse shells) — Quickly adjust their internal salt balance (e.g., tidepool fishes) — Burrow to escape large fluctuations in salinity (e.g., worms)

Osmoconformers and Osmoregulators

Animals in the intertidal zone exhibit a range of adaptations to fluctuating salinity levels in the water that surrounds them. These adaptations can be divided into two general categories: osmoconformation and osmoregulation. “Osmoconformers” are not able to control salt concentrations in their bodily tissues. “Osmoregulators” can control internal salt concentrations.

Many marine invertebrates are osmoconformers. The result of this adaptive strategy is that these organisms do not expend energy regulating salt concentrations. Many, however, do have behavioral patterns that help them maintain relatively consistent internal salinity levels even when environmental salinity fluctuates dramatically, as it often does, particularly in the upper intertidal zone. Some, like mussels, enclose seawater in their shells; other animals, such as limpets, seal out the effects of fluctuating salinity by clamping tightly to rocks. (These strategies can be thought of as behavioral osmoregulation as opposed to physiological osmoregulation.)

Marine invertebrates are usually osmoconformers and have a fair tolerance to changes in salt concentration.These animals can generally survive in brackish water that is diluted to around 80 percent of normal salinity. Marine invertebrates that survive in fresh or more diluted brackish water are osmoregulators. These animals include crabs and other crustaceans.

Osmoregulators use a variety of strategies to maintain internal salinity levels and to quickly adjust to changing environmental salinity. All of these strategies involve transporting ions across cell membranes. The direction and mechanisms of transport depend on whether the organism’s optimal internal salinity is higher or lower than that in the environment. Aquatic vertebrates, including the marine fish found in the intertidal zone, are all osmoregulators.

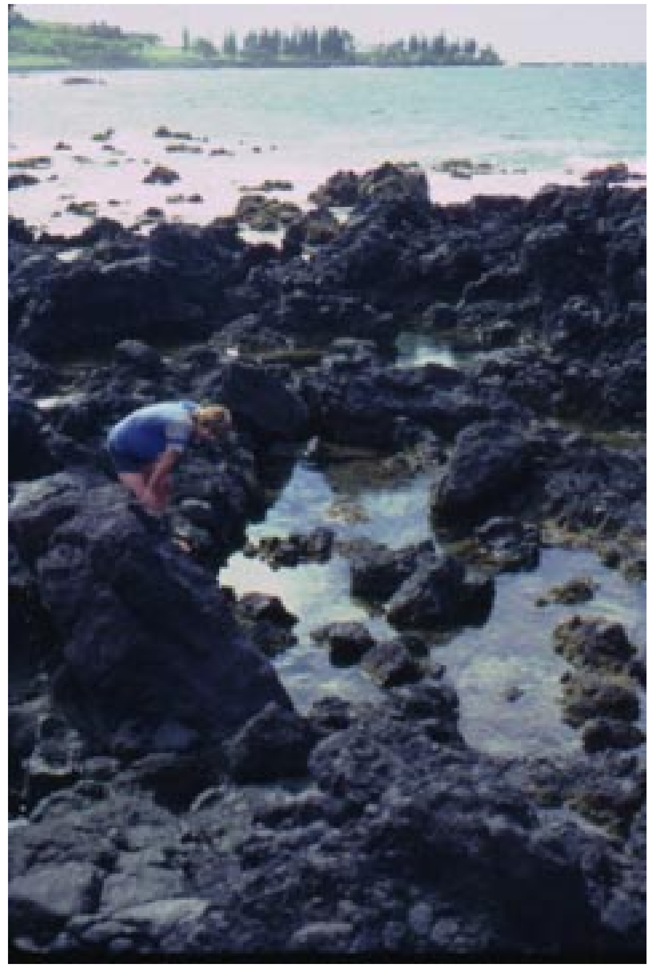
Hāmākua Poko

Photo: Ann Fielding

Intertidal Subzones Table

Subzone	Alternate name	Description
Splash zone		The splash zone is a barren, rocky area frequently exposed to ocean spray but not typically immersed, even by high tides.
Upper intertidal zone	Eulittoral zone	The upper intertidal zone is covered by water only at high tide.
Lower intertidal zone	Sublittoral zone	The lower intertidal zone is underwater most of the time, except at extremely low tide. When exposed, strong waves and currents buffet this area.
Subtidal zone		The subtidal zone is always submerged. This subzone is usually considered to be the deeper water at the edge of the shoreline, the subtidal zone also includes many tidepools.
Tidepools		Tidepools are permanent and ephemeral collections of water.

Intertidal Images



Intertidal area at Hāna (Photo: Ann Fielding)

Intertidal area at Ho'okipa (Photo: Ann Fielding)

Intertidal area at Makapu'u (Photo: Ann Fielding)

Intertidal area at La Pérouse (Photo: Ann Fielding)

Subzone Condition Cards

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Hypothesis Card: Subtidal Zone

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
The subtidal zone is always submerged. This subzone is usually considered to be the deeper water at the edge of the shoreline, the subtidal zone also includes many tidepools.			

Comparison Card: Subtidal Zone

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
The subtidal zone is always submerged. This subzone is usually considered to be the deeper water at the edge of the shoreline, the subtidal zone also includes many tidepools.	There is little or no fluctuation in salinity since the area is always covered by water.	Effects from pounding waves are minimal since the area is always covered by water. Surge or strong currents can be a factor here, how-ever.	Exposure to air is rare.

Cut on dashed lines

Hypothesis Card: Tidepools

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
Many tidepools are permanent, always filled with water. Others may dry up between tides.			

Comparison Card: Tidepools

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
Many tidepools are permanent, always filled with water. Others may dry up between tides.	Salinity may fluctuate greatly as water evaporates between tides or rainwater dilutes the salt water in a pool.	Wave action is an insignificant factor when the tide is out. But when the tide comes in, heavy surge causes significant water movement in these pools.	As water evaporates, parts of tidepools are occasionally exposed to air. Air exposure is most frequent around the edges of pools and in pools that tend to dry out between high tides.

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Hypothesis Card: Lower Intertidal Zone

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
The lower intertidal zone is underwater most of the time, except at extremely low tide.			

Comparison Card: Lower Intertidal Zone

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
The lower intertidal zone is underwater most of the time, except at extremely low tide.	There is little fluctuation in salinity because the area is almost always submerged	When this area is exposed at extremely low tide, strong waves and currents buffet it.	Exposure to air is infrequent, occuring only during unusually low tides

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Hypothesis Card: Upper Intertidal Zone

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
The upper intertidal zone is covered by water only at high tide.			

Comparison Card: Upper Intertidal Zone

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
The upper intertidal zone is covered by water only at high tide.	Fluctuations in salinity can occur when exposed organisms are rained on.	Rough waves buffet this area, which is exposed to them for longer durations than is the lower intertidal zone.	The upper intertidal zone is frequently exposed to air.

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Hypothesis Card: Splash Zone

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
The splash zone is a barren, rocky area frequently exposed to ocean spray but not typically immersed, even by high tides.			

Comparison Card: Splash Zone

When/how often covered by water	Fluctuations in salinity	Wave action	Exposure to air
The splash zone is a barren, rocky area frequently exposed to ocean spray but not typically immersed, even by high tides.	Salinity fluctuates as salt spray accumulates on organisms and as rainwater occasionally washes it off.	Wave action is typically not a factor in this area.	The splash zone is almost always exposed to air.

Species Cards for the Life on the Edge Activity

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Pipipi Kōlea or Dotted Periwinkle

Littoraria pintado

Where in the Intertidal Zone?

- Abundant in the splash zone on most rocky shores
- Live just above the nerites, where they are only occasionally splashed by waves

What They Eat

- Feed on algae film on wet rocks

Behaviors, Characteristics, and Adaptations

- Breathe air through wet gills
- When rocks are dry, shut shell doors to retain moisture and use mucus to glue shells to rock

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

Pipipi or Black Nerite

Nerita picea

Where in the Intertidal Zone?

- Abundant on rocky shores in the splash zone
- Live closer to the water than the *pipipi kōlea*

What They Eat

- Feed on algae film on wet rocks

Behaviors, Characteristics, and Adaptations

- Breathe air through wet gills
- When rocks are dry, shut shell doors to retain moisture

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

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'Opihi 'Awa or False *'Opihi*

Siphonaria normalis

Where in the Intertidal Zone?
- Live on rocks above the water
- Can be abundant in the mid-intertidal zone

What They Eat
- Feed on algae film on wet rocks

Behaviors, Characteristics, and Adaptations
- Breathe with both gills and lungs
- More closely related to land snails than true *'opihi*
- Clamp tightly to rocks to maintain moisture

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

'Opihi Makaiaūli or Black-Foot *'Opihi*

Cellana exarata

Where in the Intertidal Zone?
- Live in the mid-intertidal zone in areas where the waves pound
- Live higher on the rocks than the other types of *'opihi*

What They Eat
- Graze on algae

Behaviors, Characteristics, and Adaptations
- Clamp tightly to the rock with a muscular foot
- Sometimes, on warm, sunny days, lift their shells off the rock, perhaps to cool down
- Have "home scars" to which they return after feeding

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

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Nahawele or *Pāpaua* or Black Purse Shells

Isognomon californicum

Where in the Intertidal Zone?

- Live in clusters in crevices around the high tide line
- Often live in brackish water that is trapped in these crevices

What They Eat

- Feed on organic matter suspended in water, which they filter through their gills

Behaviors, Characteristics, and Adaptations

- Attach to rocks using filaments called "byssal threads"
- Typically occur in dense clusters that help protect individual animals from the pounding of waves

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

Maka'awa or Granular Drupe

Morula granulata

Where in the Intertidal Zone?

- Found in abundance on rocky shores with good water movement
- Totally exposed during low tide

What They Eat

- Drill into and eat limpets, snails, oysters, barnacles, and possibly other organisms

Behaviors, Characteristics, and Adaptations

- Adhere to wet rocks with a muscular foot
- Make neat holes in the shells of other molluscs using the boring "drills" on their feet, then inject enzymes to digest the organism in its own shell before consuming the liquified tissues
- Taste bitter, prompting the Hawaiian name, which means "sour face"

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

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'Opihi 'Ālinalina or Yellow-Foot *'Opihi*

Cellana sandwicensis

Where in the Intertidal Zone?
- Live at the low tide mark and just below in rocky areas where the waves pound

What They Eat
- Graze on algae

Behaviors, Characteristics, and Adaptations
- Need constant splash and do not tolerate drying out as much as the black-foot *'opihi*
- Clamp tightly to the rock with a muscular foot
- Often wear "caps" of seaweed

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

Hā'uke'uke Kaupali or Shingle or Helmet Urchin

Colobocentrotus atratus

Where in the Intertidal Zone?
- Live low in the intertidal zone where the waves pound
- Cling to exposed, rocky shores, where few other animals survive

What They Eat
- Feed on algae

Behaviors, Characteristics, and Adaptations
- Have little tolerance to drying
- Clamp onto rocks with many strong tube feet (suction cups)
- Have flat spines, allowing water to flow over them easily

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

Cut on dashed lines, fold on solid line

ʻAʻama or Thin-Shelled Rock Crab

Grapsus tenuicrustatus

Where in the Intertidal Zone?
- Live on rocky shores with strong waves
- Forage for algae in the splash zone
- Cast molted shells, which are red and found high on the rocks above the intertidal zone

What They Eat
- Feed on algae

Behaviors, Characteristics, and Adaptations
- Have long legs and spines on legs, which are used for gripping rocks
- Retreat to water or crevices when approached

Photo: John P. Hoover, Hawaiʻi's Sea Creatures, *Mutual Publishing*

Pāoʻo or Zebra Blenny

Istiblennius zebra

Where in the Intertidal Zone?
- Live in tidepools

What They Eat
- Feed on detritus

Behaviors, Characteristics, and Adaptations
- Can leap from pool to pool
- Are bottom dwellers

Photo: Marjorie L. Awai in John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Cut on dashed lines, fold on solid line

'O'opu Ohune or Cocos Frill Goby

Bathygobius cocosensis

Where in the Intertidal Zone?
- Live in tidepools

What They Eat
- Carnivorous

Behaviors, Characteristics, and Adaptations
- Have pelvic fins that form sucking discs for holding on to rocks in surf
- Are bottom-dwellers
- Have dark mottled colorings that blend well with the black volcanic rock and can lighten to match other backgrounds

Photo: Marjorie L. Awai in John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Loli Okuhi Kuhi or Black Sea Cucumber

Holothuria atra

Where in the Intertidal Zone?
- Are found in sandy areas in tidepools
- Are bottom dwellers, found lying fully exposed on sand or rubble bottoms from the shallows to depths of at least 100 feet

What They Eat
- Swallow sand and digest organic matter in sand

Behaviors, Characteristics, and Adaptations
- Are related to sea stars
- Secrete skin toxin when handled roughly
- Have black bodies, covered with a camoflauging layer of sand

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

Cut on dashed lines, fold on solid line

Āholehole or Hawaiian Flagtail
Kuhlia sandvicensis

Where in the Intertidal Zone?
- Juveniles abundant in tidepools
- Common in brackish water

What They Eat
- Adults feed on plankton at night.

Behaviors, Characteristics, and Adaptations
- Adults found in dense schools by day, often on top of the reef in areas of heavy surge, where they are safe from predators
- Swim away and hide in crevices when approached by predators

Photo: John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Āholehole or Hawaiian Flagtail
Kuhlia sandvicensis

Where in the Intertidal Zone?
- Young are abundant in tidepools
- Common in brackish water

What They Eat
- Adults feed on plankton at night.

Behaviors, Characteristics, and Adaptations
- Adults found in dense schools by day, often on top of the reef in areas of heavy surge, where they are safe from predators
- Swim away and hide in crevices when approached by predators

Photo: John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Cut on dashed lines, fold on solid line

Loli or
White-Spotted Sea Cucumber
Actinopyga mauritiana

Where in the Intertidal Zone?
- Found under rocks in shallow water, their bodies almost totally buried
- Live in areas of high surge in the lower intertidal or subtidal zones

What They Eat
- Swallow sand and digest organic matter in sand

Behaviors, Characteristics, and Adaptations
- Have strong tube feet that stick to rocks where other organisms might be swept away
- Have an anus ringed with five tiny teeth that may offer protection against pearlfishes and other animals that live in the intestines of sea cucumbers
- Have mottled, camoflauging coloration

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

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Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

Cut on dashed lines, fold on solid line

ʻIna or Oblong Urchin

Echinometra oblonga

Where in the Intertidal Zone?

- Found on shallow, rocky shores exposed to constant wave action, way down in the lower intertidal or upper subtidal zones
- Often the dominant urchins in these areas
- Also found on reef flats, at less than ten feet in depth

What They Eat

- Feed on algae

Behaviors, Characteristics, and Adaptations

- Use spines and teeth to bore hollows into soft rock where they live
- Protect their soft undersides from predator by burrowing and create depressions that hold water when exposed at low tide
- Have tube feet for attaching to rocks

Photo: John P. Hoover, Hawaiʻi's Sea Creatures, *Mutual Publishing*

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Photo: John P. Hoover, Hawaiʻi's Sea Creatures, *Mutual Publishing*

Cut on dashed lines, fold on solid line

ʻIna Kea or Rock-Boring Urchin

Echinometra mathaei

Where in the Intertidal Zone?
- Found in tidepools and deeper, often anchoring themselves under branching finger coral
- Found on shallow, rocky shores exposed to constant wave action, down low in the lower intertidal or upper subtidal zones
- Almost always submerged

What They Eat
- Feed on algae

Behaviors, Characteristics, and Adaptations
- Use spines and teeth to bore hollows into soft rock where they lives
- Protect their soft undersides from predators by burrowing
- Have tube feet for attaching to rocks

Photo: Philip Thomas

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Photo: Philip Thomas

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What They Eat
- Feed on algae

Behaviors, Characteristics, and Adaptations
- Use spines and teeth to bore hollows into soft rock where they lives
- Protect their soft undersides from predators by burrowing
- Have tube feet for attaching to rocks

Photo: Philip Thomas

Kaunaʻoa or Variable Worm Snail
Serpulorbis variabilis

Where in the Intertidal Zone?
- Found in environments exposed to waves and surge, such as the lower intertidal zone, including tidepools and wave-exposed reef flats

What They Eat
- Feed by trapping suspended food particles in strands or a net of mucous

Behaviors, Characteristics, and Adaptations
- Permanently cement themselves to rocks or other hard surfaces
- Have sharp shell openings that may cut feet or hands

Photo: John P. Hoover, Hawaiʻi's Sea Creatures, *Mutual Publishing*

Cut on dashed lines, fold on solid line

Seurat's Hermit Crab

Calcinus seurati

Where in the Intertidal Zone?
- Live in rocky tidepools in the splash zone, amongst the periwinkles and nerites
- Common in rocky areas with strong surf

What They Eat
- Scavenge and eat algae

Behaviors, Characteristics, and Adaptations
- Can tolerate warm stagnant water
- Live in discarded periwinkle and nerite shells
- Use their left claws to block openings when they withdraw into their shells

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

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Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

Cut on dashed lines, fold on solid line

Limu Kala or *ʻAkala*

Sargassum echinocarpum

Where in the Intertidal Zone?

- Grows on rocks in the middle to lower part of the intertidal zone, usually lower down than *limu pālahalaha*

Behaviors, Characteristics, and Adaptations

- Is a brown seaweed that grows up to 50 centimeters (20 inches) high
- Produces small, inflated bladders for flotation

Photo: Jennifer Smith

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Photo: Jennifer Smith

Cut on dashed lines, fold on solid line

Limu ʻAkiʻaki

Ahnfeltia concinna

Where in the Intertidal Zone?

- Grows on *pāhoehoe* lava boulders in the upper intertidal zone, higher than the other kinds of *limu*

Behaviors, Characteristics, and Adaptations

- Grows upright to .3 meters (one foot) tall
- Has tough, rubbery branches that grow close together in dense bunches

Photo: Kim Martz and Forest Starr

Bubble Algae

Dictyosphaeria spp.

Where in the Intertidal Zone?

- Found in tidepools and on shallow reefs

Behaviors, Characteristics, and Adaptations

- Is a green seaweed composed of tiny, round cells

Photo: Ed Robinson ©1984

Cut on dashed lines, fold on solid line

Limu Pālahalaha or Sea Lettuce

Ulva fasciata

Where in the Intertidal Zone?

- Commonly grows on lava rock and old coral in the middle part of the intertidal zone
- Uncovered at low tide

Behaviors, Characteristics, and Adaptations

- Its base resembles a lettuce leaf, with ribbon-like blades that can grow longer than 75 centimeters (30 inches).

Photo: Kim Martz and Forest Starr

Spiny Brittle Star

Ophiocoma erinaceus

Where in the Intertidal Zone?

- Live under rocks in tidepools and in deeper water, too

What They Eat

- Feed on detritus

Behaviors, Characteristics, and Adaptations

- Have flexible arms, making them fast-moving
- Have tube feet but no gripping suction cups
- Can drop an arm for a quick getaway when a predator attacks

Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing*

Cut on dashed lines, fold on solid line

Kūpīpī or Blackspot Sergeant

Abudefduf sordidus

Where in the Intertidal Zone?

- Young found in tidepools, inlets, and even in brackish water
- Adults found around boulders and rocks in the shallow surge zone

What They Eat

- Feed on algae

Behaviors, Characteristics, and Adaptations

- Young protected from larger predators in the tidepools
- Swim away and hide in crevices when approached by predators

Photo: John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

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Photo: John P. Hoover Hawaii's Fishes, *Mutual Publishing*

Subzones Species Key

Splash Zone

- *Pipipi Kōlea* or Dotted Periwinkle
- *Pipipi* or Black Nerite
- Seurat's Hermit Crab
- *ʻAʻama* or Thin-Shelled Rock Crab

Upper Intertidal

- *ʻOpihi ʻAwa* or False *ʻOpihi*
- *ʻOpihi Makaiaūli* or Black-Foot *ʻOpihi*
- *Nahawele* or *Pāpaua* or Black Purse Shells
- *Makaʻawa* or Granular Drupe
- *Limu ʻAkiʻaki*
- *Limu Pālahalaha* or Sea Lettuce
- *Limu Kala* or *ʻAkala*

Lower Intertidal

- *Limu Kala* or *ʻAkala*
- *Hāʻukeʻuke* or Shingle or Helmet Urchin
- *ʻOpihi ʻĀlinalina* or Yellowfoot *ʻOpihi*
- *ʻIna Kea* or Rock-Boring Urchin
- *Loli* or White-spotted Sea Cucumber
- *ʻIna* or Oblong Urchin
- *Kaunaʻoa* or Variable Worm Snail

Subtidal

- *Loli* or White-spotted Sea Cucumber
- *ʻIna* or Oblong Urchin
- *ʻIna Kea* or Rock-Boring Urchin
- *Kūpīpī* or Blackspot Sergeant
- *Āholehole* or Hawaiian Flagtail

Tidepools

- *Pāoʻo* or Zebra Blenny
- *ʻOʻopu Ohune* or Cocos Frill Goby
- Juvenile *Kūpīpī* or Blackspot Sergeant
- Juvenile *Āholehole* or Hawaiian Flagtail
- *Loli Okuhi Kuhi* or Black Sea Cucumber
- Spiny Brittle Star
- *ʻIna Kea* or Rock-Boring Urchin
- Bubble Algae
- Seurat's Hermit Crab
- *Kaunaʻoa* or Variable Worm Snail

Activity #2

A Day in the Neighborhood: Skits about the Intertidal Zone

● ● ● Class Period One *Skit Preparation*

Materials & Setup

For each student

• Student Page "A Day in the Neighborhood: Skits About the Intertidal Zone" (p. 42)

Instructions

1) Divide students into the same groups they were in during the previous activity.

2) Hand out the Student Page "A Day in the Neighborhood: Skits About the Intertidal Zone." Using this sheet as a guide, student groups will plan and perform a five-minute skit about life in a particular subzone of the intertidal zone.

3) Review the instructions and guidelines with students, and give them the rest of the class period to work in their small groups to plan the skit.

Recommendation

Give students longer than just overnight to research, write, and prepare their skits. If this is possible, schedule the performances to take place in several days (or after a weekend), and move on to another topic during the intervening periods.

● ● ● Class Period Two *Skit Performances*

Materials & Setup

- Twenty-five copies, "Skit Assessment Chart" (master, p. 41)

Instructions

1) Have students sit together in their groups. Give each group four copies of the "Skit Assessment Chart." Group members will use these charts to assess other groups' skits. Different group members should take responsibility for assessing each skit.

2) Have student groups put on their skits, beginning at either the top (splash zone) or bottom (subtidal zone) and taking the subzones in order. You may place tidepools at the beginning or the end, regardless of which zone you begin with.

3) After all skits have been performed, ask students to discuss what they learned about the intertidal zone from the skits. Begin this discussion by having students make comparisons between the subzone they studied and other subzones. Then ask students to identify commonalities and patterns among all of the subzones.

Journal Ideas

- Write a first-person narrative about a day in the life of a plant or animal in the subzone that you studied.
- Look around you and find some other examples of zonation. Describe them and the conditions that create them.

Assessment Tools

- Student skits: Use the "Skit Assessment Chart" (p. 41) to help gauge students' performance.
- Groups' assessments of other groups' skits
- Participation in the class discussion
- Journal entries

Skit Assessment Chart

Group members

Subzone

Assessment Criteria	Notes
Explains environmental conditions in the subzone	
Dramatizes at least three examples of how organisms in the subzone respond to or protect themselves from changing environmental conditions throughout the day and night	
Dramatizes at least three examples of how organisms interact with each other in the intertidal zone These organisms may include plants, animals, and humans.	
Involves everyone in the group	
Is five minutes long	
Other (e.g., originality)	

A Day in the Neighborhood: Skits About the Intertidal Zone

Work with your group to write and perform a five-minute skit about a typical day in the intertidal zone. Your skit should:

1) Explain environmental conditions in the subzone.

2) Dramatize at least three examples of how organisms in the intertidal zone respond to or protect themselves from changing environmental conditions throughout the day and night.

3) Dramatize at least three examples of how organisms interact with each other in the intertidal zone. These organisms may include plants, animals, and humans.

4) Involve everyone in your group.

Use the information on the intertidal zone species cards and what you learned from the class discussion and homework assignment as the basis for your skit. You may also do additional research to bring in information that other groups in your class may not think of or include in their skits. Your skit might include dance, songs, chants, reflections of cultural significance, and other creative elements.

Research Resources

Tide charts

Fielding, Ann, *Hawaiian Reefs and Tidepools*, Island Explorations, Makawao, Hawai‘i, 1998.

Fielding, Ann and Ed Robinson, *An Underwater Guide to Hawai‘i*, University of Hawai‘i Press, Honolulu, 1993.

Hobson, Edmund S. and E. H. Chave, *Hawaiian Reef Animals*. University of Hawai‘i Press, Honolulu, 1990.

Hoover, John P., *Hawaii’s Fishes: A Guide for Snorkelers, Divers and Aquarists*, Mutual Publishing, Honolulu, 1993.

__________, *Hawai‘i’s Sea Creatures: A Guide to Hawaii’s Marine Invertebrates*, Mutual Publishing, Honolulu, 1998.

Merlin, Mark, *Hawaiian Coastal Plants: An Illustrated Field Guide*, Pacific Guide Books, Honolulu, 1999.

Randall, John E., *Shore Fishes of Hawaii*, Natural World Press, 1996.

Suggested Internet Keywords

Algae
Intertidal
Marine invertebrate
Marine fish
Tidepool
Species name (scientific, Hawaiian, or common)

You may add “Hawaii” to any of the above search terms to narrow your findings.

Marine Unit 4

Keeping an Eye on Coral Reefs

Overview

Coral reefs are found throughout the tropical oceans of the world. These ecosystems are among the most diverse in the world. In many parts of the world, coral reefs are severely degraded and threatened by a range of human-caused impacts including pollution, overfishing, and direct destruction through activities such as dredging and contact during recreational activities.

Around the world, there is growing concern over reef health. The Coral Reef Initiative is a new international effort to reverse the trends that have damaged about ten percent of the world's coral reefs beyond recovery. An initial assessment suggests that Hawaiian coral reefs are generally in better shape than reefs in many other parts of the world. Still, people are putting pressure on Hawaiian coral reefs, and the extent of our impact is not always known. In this unit, students learn why coral reef monitoring is done, practice some essential reef-monitoring skills, and research problems with coral reefs around the world.

Length of Entire Unit

Three class periods

Unit Focus Questions

1) How and why do scientists monitor coral reefs?

2) What are some of the essential skills of coral reef monitoring?

3) What are the main threats to coral reef health around Maui and around the world?

Unit at a Glance

Activity #1

Coral Reef Monitoring Simulations

Through simulated exercises, students learn some fundamental skills and techniques used in monitoring coral reefs.

Length
Two class periods

Prerequisite Activity
None

Objectives
- Describe, critique, and apply skills and techniques associated with coral reef monitoring, including:
  - Estimating percent cover,
  - Performing cover assessments on photographs, and
  - Identifying corals and other reef-related plant and animal species.

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

Activity #2

Protecting Coral Reefs

Students perform Internet research on one of the main threats to coral reefs in Hawai‘i and around the world.

Length
One class period preceded by homework reading and a research assignment

Prerequisite Activity
None

Objectives
- Describe threats to local coral reefs or other reefs around the world.
- Describe actions people are taking to protect coral reefs from these threats.

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.

RELATING THE NATURE OF TECHNOLOGY TO SCIENCE: Students use the problem-solving process to address current issues involving human adaptation in the environment.
- Identify and explain current issues or problems based on evidence found in available information.

Enrichment Ideas

- Research a favorite coral reef to learn more about whether it has been studied, what the studies reported, the current health of the coral reef, current threats, and so forth.

- Apply sampling methods to estimate the number of students, numbers of males and females, or ethnic composition of students in the school. Check against enrollment figures.

- Participate in volunteer opportunities to monitor local coral reefs. (See the introduction to this module for organizations that offer these opportunities.)

- Watch the video *Coral Reefs: Their Health, Our Wealth* (included with this curriculum or see "Resources for Further Reading and Research" for ordering information). Use the information in the video, which focuses on Guam coral reefs, as the basis for a research project that compares the status of and threats to Guam coral reefs with those in Hawai'i.

Resources for Further Reading and Research

- Klemm, E. Barbara, Francis M. Pottenger III, Thomas W. Speitel, S. Arthur Reed, Ann E. Coopersmith, *The Living Ocean: Biological Science and Technology in the Marine Environment,* Curriculum Research and Development Group, University of Hawai'i, Honolulu, 1995.

  The chapter on corals and coral reefs covers how a coral grows; symbiosis; coral identification; reef formation, structure, and evolution; biological and physical agents of change on reefs; and the worldwide distribution of coral reefs.

- University of Guam Marine Laboratory, and Guam Department of Agriculture Division of Aquatic and Wildlife Resources, *Coral Reefs: Their Health, Our Wealth.* This 24-minute video is available from the Guam Department of Agriculture Division of Aquatic and Wildlife Resources,192 Dairy Road, Mangilao, Guam 96923, Facsimile (671) 734-6570.

- Basic information about coral reef ecology is available on the Coral Reef Ecology website at <www.uvi.edu/coral.reefer/index.html> and on the Coral Reef Alliance website at <www.coral.org/faq.html>.

- Resources related to coral reef monitoring and volunteer opportunities in Hawai'i is available on the Reef Environmental Education Foundation website at <www.reef.org>, the Coral Reef Assessment and Monitoring Project website at <cramp.wcc.hawaii.edu>, and the Reef Check website at <www.reefcheck.org>.

- Hawai'i Sea Grant has published an online bibliography of reference works related to coral reefs at <www.soest.hawaii.edu/SEAGRANT/iyorbib.html#monitor>.

Activity #1

Coral Reef Monitoring Simulations

● ● ● Class Period One *Observing Reef Fish Underwater*

Materials & Setup

- *Hawai'i's Reefs: Oceanic Oasis* video (included with this curriculum)

For each student

- Student Page "Reef Fish Checklist" (pp. 12-14)
- "Reef Fish Identification Chart" (master, p. 11 — Options: laminate these charts for durability, divide students into small groups to share a chart.)

Instructions

1) Show the video, *Hawai'i's Reefs: Oceanic Oasis* (8 minutes). Rewind the tape when you finish, so it's ready to be played again later in the class.

2) Hold a brief discussion about the video: Did students learn anything new? What struck them from the video?

3) Pass out a copy of the Student Page "Reef Fish Checklist" to each student and review the instructions. Also pass out the "Reef Fish Identification Chart" to each student or small group.

4) Play the video again, this time with the sound off. Students will be filling in the 1st Survey Column of the "Reef Fish Checklist" as they watch the video. Once again, rewind the tape when you finish, so it's ready to be played again.

5) Briefly discuss students' experience with this exercise by asking, "What are some of the challenges facing divers who do underwater fish surveys?"

   Some of the answers might include the numbers of fish to count, the fact that the fish are moving, uncertainty about whether a particular fish has been counted before, and having to recognize species quickly.

6) Ask students whether they think it would be easier to accurately count fish if they could see the video again.

7) Test their predictions by playing the video again (with the sound off) and having students fill in the 2nd Survey column of the "Reef Fish Checklist."

8) Ask students whether they see a difference in their counts. If so, do they think their counts were more accurate the first time or the second time? Why?

   For anyone conducting fish surveys, there is a learning curve during which they become more familiar with the species of fish they are likely to see. Their observations become more accurate as they learn.

9) Have students pair up with a partner and compare their findings by filling in the second page of the Student Page "Reef Fish Checklist." Students should simply compare observations with each other. Each student should fill in his or her partner's tallies from the *second* video survey where indicated on the student page. Students should not complete the calculations at this time.

10) Bring the class back together and ask whether they saw differences in their partner's observations and theirs. If so, why do students think these differences might occur? How do they think that differences between observers might influence the results of a coral reef monitoring study? How could researchers compensate for those effects?

   This effect is called "observer bias" in research studies. Even with extensive training, underwater observers generally do not record exactly the same data. One way to compensate for observer bias is to pair researchers to make observations and adjust the data to reflect the differences in data sets.

11) Assign the remainder of the student page as homework.

● ● ● **Class Period Two** *Coral Reef Monitoring Simulations*

Materials & Setup

For each student

- Student Page "Estimating Percent Cover" (pp. 15-17)
- Ruler (If you do not have enough rulers to go around, have students share in small groups.)
- Black pen

For each pair of students

- Student Page "Get the Point" Note: Color photocopies are best for this activity, but black and white will work, as well. (pp. 18-21)

Instructions

1) Hand out the Student Page "Estimating Percent Cover."

2) Tell students that researchers often use "percent cover" as a way of estimating the species composition of a coral reef. This means they are looking at how much of the ocean's floor is covered by corals, and which types of corals. Tracking changes over time helps them describe and evaluate the health of the coral as well as growth and change within the reef community. Changes in the relative proportions of coral reef species, as well as in total coral coverage, are both important. Percent cover is used to evaluate other types of marine and terrestrial habitats, as well.

3) Have students work through the activity, making all estimates and calculations.

4) Write the actual percent black cover for each of the figures on the board. Figure #1 is 36 percent black. Figure #2 is 34.5 percent black.

5) Review student results using the following discussion questions:
   a) Were students more accurate at estimating cover when the shapes have straight sides or when they are rounded? What implications might this have for the study of coral reefs?

      Coral reef researchers must estimate percent cover of irregularly shaped coral, adding difficulty to an already tricky task.

   b) Were students more accurate at estimating cover with or without the grid? What might explain this? What implications does it have for studying percent cover on coral reefs?

      Breaking up a larger area into smaller areas typically increases accuracy. For even more accurate analysis, many studies of coral cover use a system in which slides of the reef taken at designated locations along a transect are projected over an image containing many randomly selected coordinates. At each set of coordinates, the substrate/cover is recorded and an average made based on those data.

   c) Which was more accurate, using all of the cells in the grid, or just a sample?

      Although using all of the cells may be more accurate than just a sample, it is not feasible for researchers to examine every bit of the extensive coral reefs they study. The trick is to make the sample size large enough to estimate coverage with confidence but small enough to be manageable. Researchers have spent much effort testing the validity of their sampling schemes.

6) Divide students into pairs. Give each pair one copy of the Student Page “Get the Point.”

7) Explain that researchers collect data about the presence and abundance of marine species in different ways.

   • One way is to set up a “transect” (a line across the reef) and swim along it, counting and recording fish and other species, or stopping at predetermined points to make and record observations. The exercise with the video observations was something like this, only there was not a continuous transect.

     In the “visual strip-transect search” method, for example, two divers swim side-by-side down either side of a transect, counting all fishes seen within a corridor three meters wide and extending to the surface. In another method, divers make one pass along the transect, recording fish they see swimming above the reef and a return pass to search for organisms sheltered in cracks and crevices.

   • Another approach, most often used when looking at coral cover or at invertebrate species that live on the reef, is to set up a transect and then to sample at points along that transect.

     One sampling method, called the “point-intercept” method, involves identifying the type of cover at various sampling points along the transect.

     Another sampling method is called the “photoquadrat” method. With this method, researchers use an underwater camera fitted with a square frame that enables researchers to take a picture of a small square portion of the ocean bottom, and then to analyze what is in that photograph later. Researchers may set up fixed locations for these photoquadrats that they return to again and again to track changes over time. This is called the "fixed photoquadrat" method.

When researchers analyze the photographs, they generate a number of points that they overlay onto the photograph, recording the type of cover that lies directly underneath each point. Researchers then extrapolate percent cover of various corals based on this sample.

8) Have student partners work through the photo analysis exercise on the student page. (Note: The area in the photo not covered by the blue leather coral is the rock substratum and small growths of algae, sponges, or other organisms.)

9) If there is time left, briefly discuss the photo analysis by asking, "Why is this a good way to estimate percent cover?" and "What do researchers need to know or do to make this technique accurate?"

   Photo analysis is a good way to estimate percent cover because the analysis itself takes place out of the water and can be more rigorous than analyses conducted underwater. It also allows researchers to track changes in particular areas over time. To make this technique accurate, researchers must take all photographs from the same distance away from the ocean bottom and must be able to identify organisms based on the photographs.

10) If students need more time to finish their photo analysis, have each partner take home the photo he or she was working on during class, and allow partners some time during the following class period to compare results. During this time, you may also wish to discuss student responses to the questions in the Student Page "Get the Point."

Journal Ideas

- In traditional Hawaiian society, fishing areas were declared *kapu* (off-limits) either seasonally or as they became depleted and needed time to recover so they could support fishing again. What would you look underwater for if you were determining when the *kapu* would begin and end?
- Do you think it is possible to eliminate observer bias in underwater research? If so, how? If not, why not?

Assessment Tools

- Student Page "Reef Fish Checklist" (teacher version, p. 9)
- Student Page "Estimating Percent Cover" (correct answers in unit instructions, p. 7)
- Student Page "Get the Point" (teacher version, p. 10)
- Participation and conduct during pairs exercises
- Journal entries

Teacher Version

Reef Fish Checklist

Questions

1) Which set of observations—your first or your second—do you think is more accurate? Why?

   The second is likely to be more accurate because students are likely to become more familiar with the species of fish they are likely to see. Their observations may become more accurate as they learn.

2) If you had to use both data sets for a study, how confident would you be in the precision of your results (i.e., in how well they reflect the real underwater situation). Explain your answer.

   Well reasoned answers are acceptable. If there are significant differences between the two sets of data, one possible answer is that the second set of data could reflect the underwater situation more accurately than the first set, leading to questionable precision.

3) Name two factors that could help explain differences between your counts and your partner's counts. Describe how each might influence the accuracy of an underwater fish survey that is conducted as part of a scientific research project.

   Well reasoned answers are acceptable. Possible responses include:

   - There could be difficulties in seeing and recording every fish, especially when there are many fish congregated in an area.
   - Different observers may tend to see certain kinds of fish, or fish in certain parts of the transect, and miss others.
   - There may be difficulties counting fish accurately when they move in and out of the area being observed.

   All of these factors could cause imprecision in scientific research. These sources of imprecision may be partially countered by comparing or compiling data from more than one observer.

Teacher Version

Get the Point

3) Do you think that one method was more accurate than the other? Why or why not?

Well reasoned responses are acceptable.

4) How would you test to see whether one method was more accurate than the other?

Well reasoned responses are acceptable. A possible response is to analyze cover in the photograph using a large number of points to achieve a response of greater precision against which to compare the results of both methods used.

5) How could you make both of these methods more accurate?

Well reasoned responses are acceptable. One way to increase accuracy is to increase the number of sampling points used.

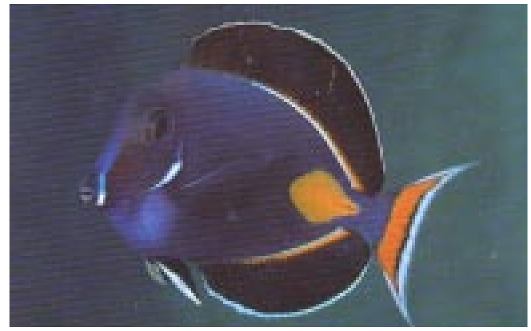
6) How do you think this kind of analysis could help scientists studying coral reefs? Why?

Well reasoned responses are acceptable. A possible response is that this kind of analysis can help scientists monitor changes in the composition of the coral community over time.

Reef Fish Identification Chart

Photos: Leaf scorpionfish, Marjorie L. Awai, all others John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Hawaiian cleaner wrasse
Labroides phthirophagus



Pākuʻikuʻi or Achilles tang
Acanthurus achilles

Leaf scorpionfish
Taenianotus triacanthus
(color varies from grayish white to yellow, red, brown, or black)

Manini or Convict tang
Acanthurus triostegus

ʻŪʻū or Big-scale soldierfish
Myripristis berndti

Lauʻīpala or Yellow tang
Zebrasoma flavescens

Reef Fish Checklist

Based on the video *Hawai'i's Reefs: Oceanic Oasis*, fill in the following reef fish checklist. For each "survey" or fish count that you do, tally the number of separate times you see each species, and how many fish you see each time. If you need to estimate how many fish you see, do so. Use hash marks to keep count, rather than numerals (e.g., ||| instead of 3).

	1st Survey		2nd Survey	
	# of Sightings	# of Fish	# of Sightings	# of Fish
Hawaiian cleaner wrasse *Labroides phthirophagus*				
Leaf scorpionfish *Taenianotus triacanthus* (can be grayish white, yellow, red, brown, or black)				
'Ū'ū or Big-scale soldierfish *Myripristis berndti*				
Pāku'iku'i or Achilles tang *Acanthurus achilles*				
Manini or Convict surgeonfish or tang *Acanthurus triostegus*				
Lau'īpala or Yellow tang *Zebrasoma flavescens*				

Reef Fish Checklist Comparison Table

Compare the results of your second survey with a partner. Notice whether there are differences between your tallies. Fill in the first two appropriate columns in this table with your results (following the "Y") and your partner's results (following the "P"). If there is not time in class, you may complete the "Quantifying Comparisons" section and the questions that follow as your homework assignment.

	2nd Survey Results		Percent Difference	
	# of Sightings	# of Fish	%Difference # of Sightings	% Difference # of Fish
Hawaiian cleaner wrasse *Labroides phthirophagus*	Y P	Y P		
Leaf scorpionfish *Taenianotus triacanthus* (can be grayish white, yellow, red, brown, or black)	Y P	Y P		
'Ū'ū or Big-scale soldierfish *Myripristis berndti*	Y P	Y P		
Pāku'iku'i or Achilles tang *Acanthurus achilles*	Y P	Y P		
Manini or Convict surgeonfish or tang *Acanthurus triostegus*	Y P	Y P		
Lau'īpala or Yellow tang *Zebrasoma flavescens*	Y P	Y P		

Quantifying the Comparisons

Fill in the third and fourth columns of this table using the numbers from the first two columns. Use the formula below to calculate the percent difference between your results and your partner's results.
Note: Your calculations may result in negative or positive numbers.

Percent difference = (Your result – Partner result/Your result) x 100

Questions

1) Which set of observations—your first or your second—do you think is more accurate? Why?

2) If you had to use both data sets for a study, how confident would you be in the precision of your results (i.e., in how well they reflect the real underwater situation). Explain your answer.

3) Name two factors that could help explain differences between your counts and your partner's counts. Describe how each might influence the accuracy of an underwater fish survey that is conducted as part of a scientific research project.

-

-

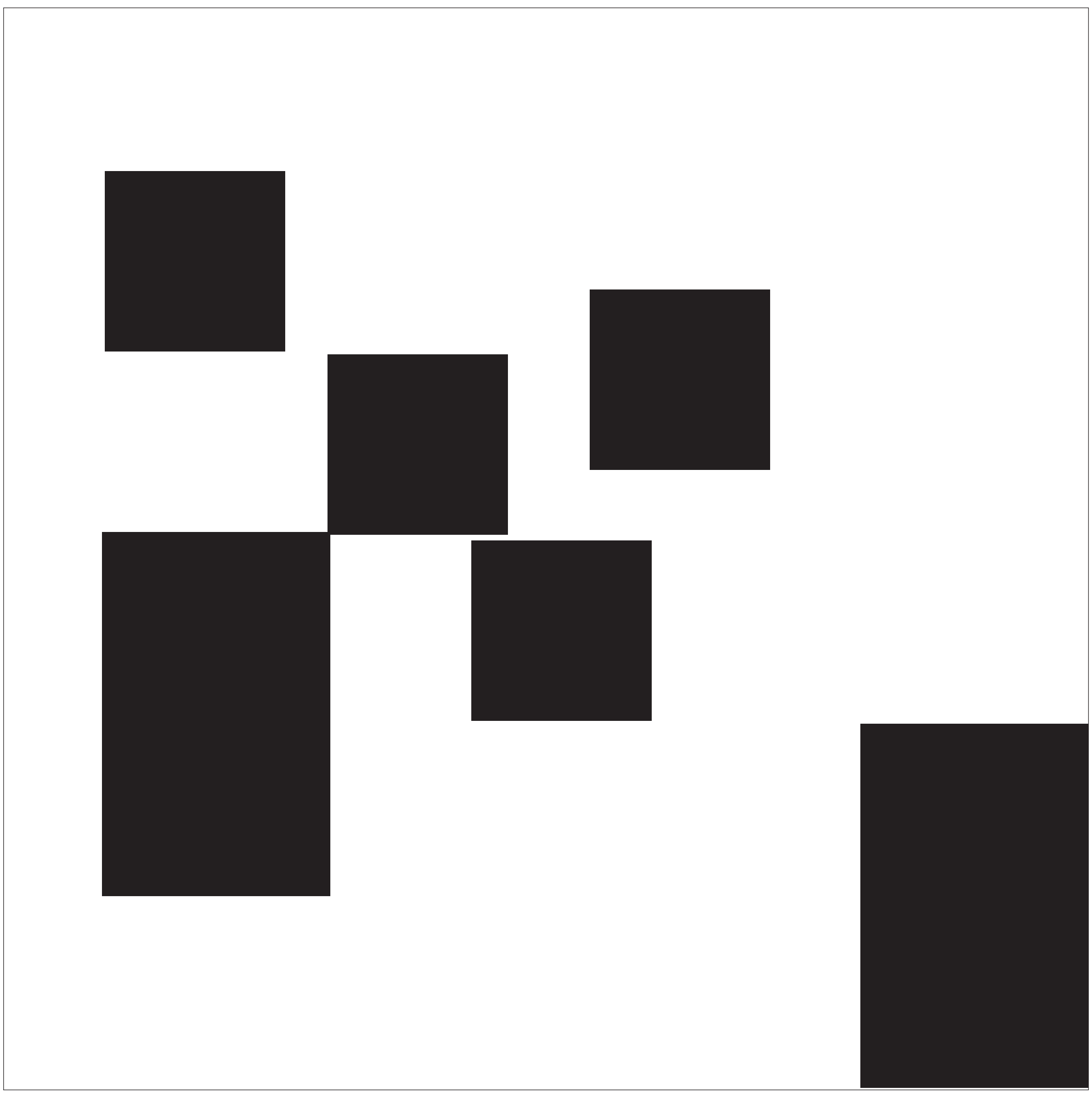
Estimating Percent Cover

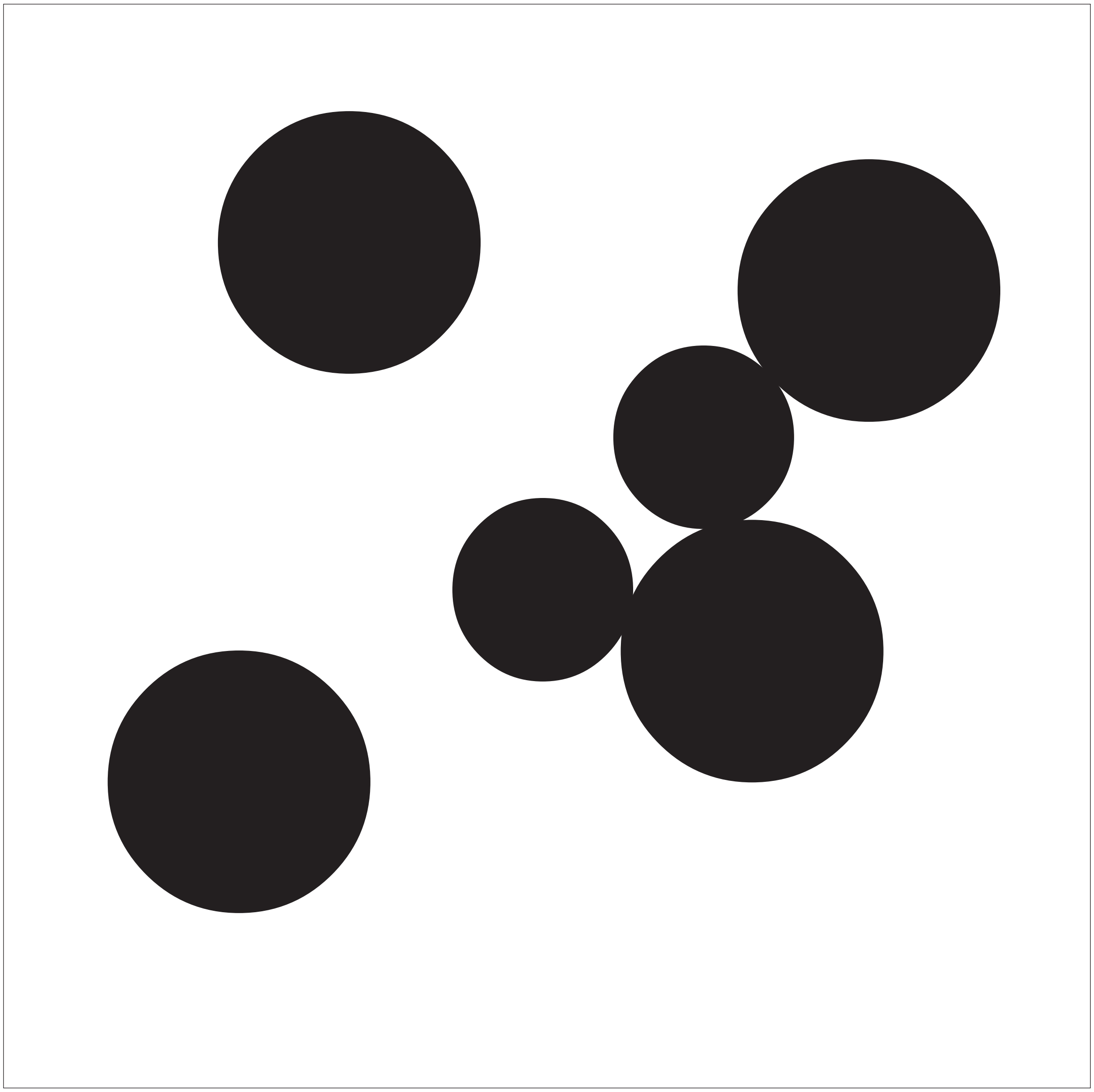
Researchers often estimate "percent cover" as a way of approximating the species composition of a coral reef. Percent cover simply refers to the proportion of a given area covered by a particular species of coral.

Tracking changes in percent cover over time helps scientists describe and evaluate the health of the coral as well as growth and change within the reef community. Changes in the relative proportions of coral reef species, as well as in total coral coverage, are both important because they help scientists understand the natural life cycle of coral reefs and may be signs of changes in factors such as water quality, temperature, numbers and types of predatory marine animals on the reef, or disease.

In this exercise, you'll practice estimating percent cover using different techniques.

1) Estimate the percentage of the area inside the box covered by black without doing measurements.





2) Estimate the percentage of the area inside the box covered by black (no measuring).

3) Go back to the figures used in #1 and #2 above. *For each figure*, make a new estimate of percent cover using the following method:
   a) Draw a four -by-four grid that divides the box into 16 sections of equal size. Estimate percent cover in each of these sections, writing your estimates in or next to each cell of the grid.
   b) Average these estimates to come up with a total percent cover estimate.

   Figure #1 percent black cover estimate:

   Figure #2 percent black cover estimate:

4) Pick three numbers between one and 16. Write them down here.

Now, go back to the figures used in #1 and #2 above. Your grids divide the box into 16 equal sections. Using the following numbering scheme, select the percent coverage for the sections that correspond to the numbers you selected above.

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

Write the corresponding percent cover estimates below and average them:

	Figure 1	Figure 2
Section number ____	_______ percent cover	_______ percent cover
Section number ____	_______ percent cover	_______ percent cover
Section number ____	_______ percent cover	_______ percent cover

Average percent cover (include your calculations)

Get the Point

When researchers analyze photographs of coral reefs, they may use a method in which they generate a number of points that they overlay onto the photograph. The easiest way to generate these points is to use special computer software designed for this purpose. They then record the type of cover that lies directly underneath each point. Researchers then "extrapolate" or predict percent cover of various corals for the entire reef based on this sample. Comparing changes in coverage over time can help researchers track the growth of corals, damage to corals, and how well different species of coral are doing relative to each other.

In this exercise, you'll work with a partner to determine the percent coral cover in a photograph using two different methods. Each of you will use a different method, and then you will compare findings.

1) You take one of the two photo assignment sheets, and your partner takes the other. Follow the directions on your sheet, and when you are finished, compare your findings with your partner's findings below.

2) Fill in the following table with your findings.

	Percent Coral Cover	Percent Other Cover
Grid method		
Random method		

3) Do you think that one method was more accurate than the other? Why or why not?

4) How would you test to see whether one method was more accurate than the other?

5) How could you make both of these methods more accurate?

6) How do you think this kind of analysis could help scientists studying coral reefs? Why?

Photo Assignment Sheet #1: Grid Method

1) Draw a five-by-five grid over this photo that divides it into 25 equal sections. Number the intersection points on this grid from one to 16, and write the numbers near each intersection.

2) For each intersection point, record what lies under it on the photo: coral or something else.

1.

2.

3.

4.

5.

6.

7.

8.

9.

10.

11.

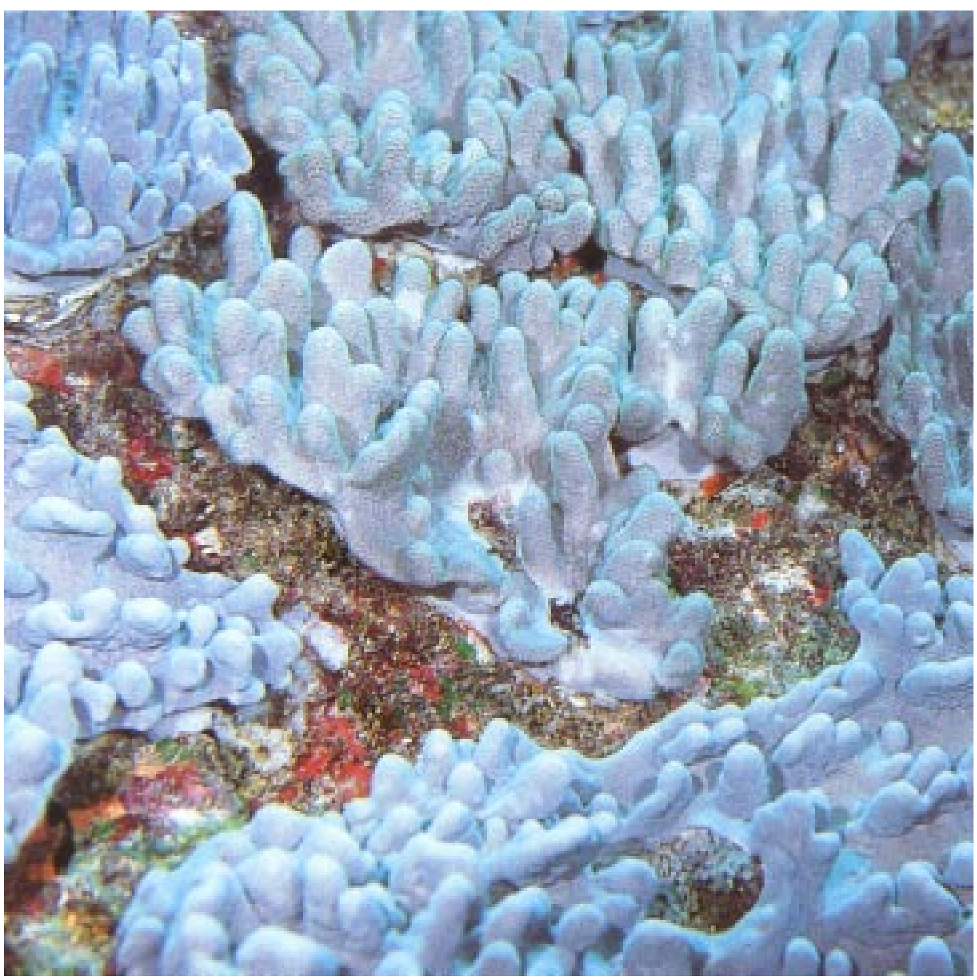
12.

13.

14.

15.

16.



Leather Coral (Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing)*

Photo Assignment Sheet #2: Random Method

1) Close your eyes and use your pen to mark dots on the photograph, as randomly as you can. Continue making dots until you have 16 of them on the photograph itself. Number these points from one to 16, and write the numbers on the photograph.

2) For each intersection point, record what lies under it on the photo: coral or something else.

1.

2.

3.

4.

5.

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7.

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9.

10.

11.

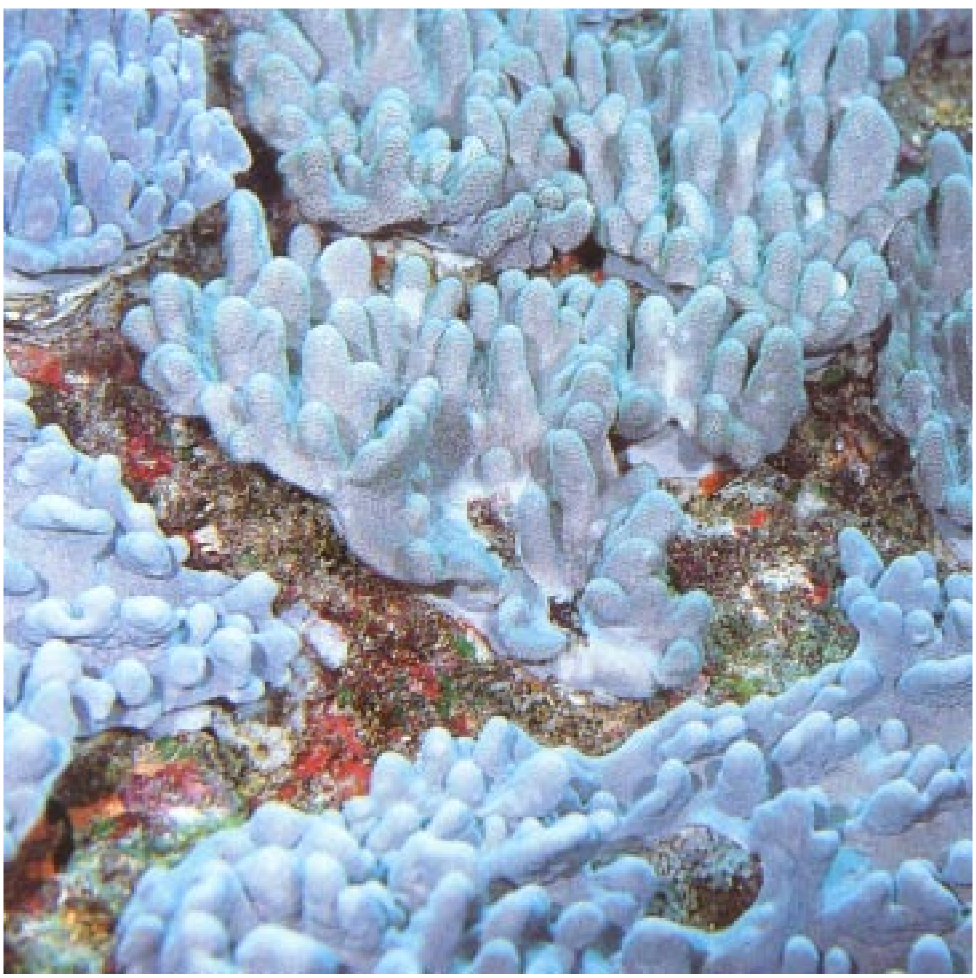
12.

13.

14.

15.

16.



Leather Coral (Photo: John P. Hoover, Hawai'i's Sea Creatures, *Mutual Publishing)*

Activity #2

Protecting Coral Reefs

● ● ● In Advance *Student Assignment*

- Assign the Student Page “Keeping an Eye on Coral Reefs” (pp. 22-25) as homework. This homework assignment includes Internet research on coral reef problems and protection.

● ● ● Class Period One *Protecting Coral Reefs*

Materials & Setup

For each student

- Student Page “Keeping an Eye on Coral Reefs” (pp. 24-27)

Instructions

1) Lead a class discussion that focuses on the ideas students generated through their Internet research. The discussion should cover:
    - How monitoring is being used to document the health of coral reefs,
    - What is being done in other parts of the world to protect coral reefs from specific threats,
    - What is being done on Maui and in other parts of Hawai‘i to protect coral reefs,
    - What students think should be done to protect Maui coral reefs,
    - What students could do to help protect Maui coral reefs,
    - How people’s actions on land and in the water affect coral reefs, and
    - What other information students might need to make informed decisions about Maui coral reef protection.

Journal Ideas

- Have you ever been snorkeling, swimming, or diving near coral reefs? If so, what was it like? If not, what do you think it would be like?
- Why are Maui coral reefs important to you?
- How do you think you and your family affect Maui coral reefs in your daily lives? (This question could be used before and after the unit to see if student views change based on what they learn.)
- What are the most important things one person can do to help protect Maui coral reefs?
- In *Kumulipo*, the Hawaiian creation chant, the coral polyp is considered to be the first living organism created and the origin of all life. How do you think ancient Hawaiians treated coral reefs based on this belief? What would be the same and what would be different today if people acted in this way?

Assessment Tools

- Two-page Internet research report
- Participation in class discussion
- Journal entries

Keeping an Eye on Coral Reefs

Coral reefs are found throughout the tropical oceans of the world. Coral reef ecosystems are among the most diverse in the world. According to the National Ocean Service, coral reefs are the second most productive biological system in the world after tropical rain forests. That means that, acre for acre, they produce the second greatest amount of "biomass," measured as the weight of all living organisms.

Threats to Coral Reefs

In many parts of the world, coral reefs are severely degraded and threatened by human activities. Scientific monitoring of coral reefs has helped to establish that globally, the most damage to reefs is caused by:

Marine Pollution

Much of the pollution in the ocean started out on land. Construction in coastal areas as well as development, logging, or mining along streams that run to the sea can cause soil to erode and get washed into the ocean. In this process of "sedimentation," dirt, silt, and sand can cloud the water or settle directly on reefs, reducing available light and smothering the polyps, making it difficult for coral to thrive. Fertilizers and sewage also make their way into the ocean from land. The nitrogen and phosphorus in this runoff are nutrients that encourage rapid algae growth. Algae overgrowth can choke coral polyps by cutting off their supply of light and oxygen.

And as coastal areas become more built-up and urbanized, there is more paved-over area and less open area to absorb rains. This water may run off into the ocean, carrying with it pollutants such as oil and grease, metals such as mercury and lead, chemicals, and pesticide residues from lawns and landscaping. Trash dumped into or near the water can also kill coral reef animals, getting lodged in animals' stomachs or strangling them.

Fuel leaks from boats, dumping of wastewater holding tanks and bilges, and occasional large oil spills can also damage local coral reefs and interfere with coral reproduction.

Unsound Fishing Practices

People catching fish can harm the reef environment in many ways. In some parts of the world, fishermen desperate to catch fish use explosives, which kill all of the marine life in the surrounding area (making it easier to collect) and reduce nearby coral to rubble. In other places, people use cyanide, chlorine bleach, and other poisons to stun and capture valuable reef fish for the aquarium fish market and for sale in live fish restaurants and markets. The poisons affect not only the fish but also coral "polyps" (the flower-shaped, mature stage of corals) and other marine life in the area.

Overfishing is another concern. In areas where fishing pressure is high, fishermen may change their methods to catch smaller, younger fish that would once have been allowed to get older and reproduce more often. Or they may target new species of fish when the traditional ones become rare.

When people take too many fish from a reef, it can upset the balance of the natural community. For example, overfishing of fish species that eat algae that naturally grows on corals can allow the algae to grow so much that they smother the corals.

Collecting Coral for Trade

Corals are popular as decorations, jewelry, and medicinal supplements. In some parts of the world, they are also collected for use as construction material. Alive, they are sold for use in salt-water aquariums. Taking live corals damages reef communities, especially when collection is concentrated in one area.

Direct Physical Damage

Divers, snorkelers, and recreational boaters can damage reefs by touching them, walking on them, or dropping anchor. Reefs are sometimes dredged or dynamited to make way for coastal construction or to improve access to a harbor. Large seagoing vessels sometimes run aground, damaging large sections of reef.

There are also natural causes of damage to coral reefs, including hurricanes and typhoons, which can break up reefs with powerful waves, and cause heavy rains which increase runoff and sedimentation. Another common threat to corals is the crown-of-thorns starfish (*Acanthaster planci*). It is a large starfish that feeds on corals, and in some parts of the Pacific, large booms in crown-of-thorns populations have caused serious effects on coral reefs. *Acanthaster planci* breakouts have been linked to regions of increased development and "eutrophication" or low oxygen conditions caused by algae overgrowth.

Hawaiian Coral Reefs

Around the world, there is growing concern over reef health. The International Coral Reef Initiative is a new international effort that aims to reverse the trends that have damaged about ten percent of the world's coral reefs beyond recovery. The initiative, which began in 1994, now includes more than 90 member countries.

In Hawai‘i there is also concern about the health of our coral reefs. An initial assessment and the results of coral reef monitoring suggest that Hawaiian coral reefs are generally in better shape than reefs in many other parts of the world. Still, people are putting pressure on Hawaiian coral reefs, and the extent of our impact is not always known. One long-term study of coral reefs along the Maui coastline found that, between 1994 and 1998, coral cover declined at the northern sites, which are heavily used by people. In contrast, the more lightly used southern sites remained relatively stable.

In a series of meetings held during 1997 and 1998, scientists and resource managers identified four major problems facing Hawaiian coral reefs:

- Over-fishing,
- Sedimentation,
- Eutrophication, and
- Algal outbreaks.

Developing better research methods, tracking changes in coral reef systems, studying the effects of human-caused impacts such as those listed above, and basing management decisions on that information are all reasons that growing effort is being put toward assessing and monitoring the health of Hawaiian coral reefs.

The Hawai‘i Coral Reef Assessment and Monitoring Program (CRAMP) was begun in 1998 to help make the most of the effort that is being put into studying and monitoring coral reefs. CRAMP is developing and applying standard scientific techniques that will allow the results of many different studies of Hawaiian coral reefs to be compared.

Some monitoring programs rely on volunteer effort. Reef Check, for example, is a worldwide program for gathering basic information about coral reefs. Reef Check volunteers receive training that prepares them to do underwater surveys looking at fish, invertebrates, and coral cover. Reef Check has created special Hawai‘i data sheets because of the unique species that are found here.

Another volunteer monitoring program is conducted by the Reef Environmental Education Foundation (REEF). Through REEF, divers and snorkelers can participate in fish surveys as part of their regular diving activities. REEF has produced a waterproof color identification card for Hawaiian fishes and a special REEF survey form for Hawai‘i. (Websites listed on the following pages provide more information about these volunteer opportunities.)

Protecting Coral Reefs — Internet Research

People around the world are concerned about the health of coral reefs and what people can do to protect these important natural systems. We can learn a lot from what is happening in other parts of the world as we work to protect our coral reefs around Maui and the other Hawaiian Islands.

Your Assignment

1) Select one of the threats to coral reefs listed on the preceding pages.

2) Formulate a question about this threat to guide your Internet research and write it in the space below. Your question may have to do with how this threat is affecting specific coral reefs around the world, actions that people and organizations are taking to protect coral reefs from this threat, government policies designed to minimize this threat, how monitoring is being used to document this threat or the effect of protective actions, or another topic of your choosing.

3) Use the Internet to research your question and write a two-page report based on your research. As a reference, provide the URLs where you got the information on which your report is based.

Website Ideas

Hawai'i Coral Reef Assessment and Monitoring Program at <cramp.wcc.hawaii.edu>.

Reef Environmental Education Foundation at <www.reef.org>.

Reef Check at <www.reefcheck.org>.

Coral Reef Alliance at <www.coralreefalliance.org>.

Coral Reef Ecology website at <www.uvi.edu/coral.reefer>.

U.S. Environmental Protection Agency, Office of Water, "Coral Reefs and Your Coastal Watershed" at <www.epa.gov/owow/oceans/factsheets/fact4.html>.

Key Word Ideas

- Coral reef
- Coral reef ecology
- Coral bleaching
- Coral diseases
- Coral reef threats
- Coral reef monitoring
- Marine protected areas
- Mooring balls

Marine Unit 5

Marine Management

Overview

Since the time of the early Hawaiians, people have been making rules governing the use of the ocean and marine life. Some of these are designed to protect species that are threatened by human actions or that are important to humans but declining in numbers. This unit introduces students to some efforts underway to provide scientific data for use in reef and fishery management. They also learn about some of the ways in which people attempt to protect and restore populations of endangered marine species and design a study to provide more information about changes in fish abundance in the ‘Āhihi-Kīna‘u Natural Area Reserve.

Length of Entire Unit

Three class periods plus optional in-class time for work on study design (Activity #3) and research projects and presentations (Activity #4)

Unit Focus Questions

1) What are some distinguishing biological and behavioral characteristics of Hawaiian reef animals that are gathered or fished for by people?

2) What are the potential impacts of collecting aquarium fish from Hawaiian reefs?

3) How do scientists conduct studies to monitor and assess these types of impacts?

4) What are some approaches to protecting Hawaiian marine species?

Unit at a Glance

Activity #1
“Weren’t There More of Us?” Game

Students play a game to learn about Hawaiian reef animals and regulations intended to protect them.

Length
One class period

Prerequisite Activity
None

Objectives
- Identify Hawaiian reef animals that are valued by humans, distinguishing features of their biology and natural history, and how they are protected under Hawai‘i state regulations.

DOE Grades 9-12 Science Standards and Benchmarks
RELATING THE NATURE OF SCIENCE TO TECHNOLOGY: 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.

Activity #2
Impacts of Aquarium Fish Collecting on Coral Reefs

Students read a study on the impact of aquarium fish collecting and interpret data from that study.

Length
One class period, preceded by homework

Prerequisite Activity
None

Objectives
- Describe concerns about collecting fish from Hawaiian coral reefs for the aquarium fish trade.
- Interpret data produced by a study on the impact of aquarium fish collecting.
- Identify key elements of the design of the aquarium fish-collecting study.

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.

LIVING THE VALUES, ATTITUDES, AND COMMITMENTS OF SCIENCE: 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.

Activity #3
Design a Monitoring Study

Using research design principles learned from the aquarium fish-collecting study, students design their own marine-monitoring study.

Length
One class period, preceded by homework

Prerequisite Activity
Activity #2 “Impacts of Aquarium Fish Collecting on Coral Reefs”

Objectives
- Design a study to monitor the effectiveness of a specific marine protected area.

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. (Activity meets the design component of this benchmark.)

Activity #4
Marine-Management Research Projects

Students undertake research projects on marine-management topics of their choosing.

Length
Research time, with optional in-class presentations

Prerequisite Activity
None

Objectives
- Develop a research report on a topic related to marine management on Maui and across the state.

DOE Grades 9-12 Science Standards and Benchmarks
LIVING THE VALUES, ATTITUDES, AND COMMITMENTS OF SCIENCE: Students apply the values, attitudes, and commitments characteristic of an inquiring mind.
- SELF-DIRECTED: Use research techniques and a variety of resources to complete a report on a project of one’s choice.

Enrichment Ideas

- Obtain copies of current Hawai‘i state fishing regulations and find out whether fishing regulations have changed for any of the species in the “Weren’t There More of Us?” game. Fishing regulations are available from the Hawai‘i Department of Land and Natural Resources, Division of Aquatic Resources.

- Download and print descriptions of threatened and endangered Hawaiian marine animals from the U.S. Fish and Wildlife Service website at <pacificislands.fws.gov>. (These marine animals include the Hawaiian monk seal, green sea turtle, and hawksbill sea turtle.) Students work in small groups to develop a short presentation on threatened and endangered marine species in Hawai‘i. As a starting point, identify patterns and similarities among these threatened and endangered species: the similarities could be habitat, threats, distribution, conservation efforts, etc. Students can draw parts of their presentations on a map of the Hawaiian Islands, if they wish.

- Create a report that summarizes the key findings of the aquarium collection impact study in a popularly accessible, educational format. Students may include photos, graphs, and other graphics to augment the text of the report and make it visually appealing.

- Research whether there has been additional research done on the impacts of aquarium fish collecting on Hawaiian coral reef communities since Brian Tissot and Leon Hallacher completed their study in September 1999.

- Research what Fish Replenishment Areas and Regional Fishery Management Areas are under Hawai‘i state law. The Department of Land and Natural Resources Division of Aquatic Resources is a good starting point for this research. Find out whether and where these protected areas exist on Maui. If none exist, research whether any have been proposed and why they have not been created.

- Research the traditional Hawaiian *kapu* system that was used to govern when and where fishing was allowed. Compare to today’s approach to managing fisheries.

Resources for Further Reading and Research

Earth Trust, online curriculum about Hawai‘i endangered species at <www.earthtrust.org/wlcurric/index.html>.

Coral Reef Network provides information about marine protected areas in Hawai‘i at <www.coralreefnetwork.com>.

Hawai‘i Department of Land and Natural Resources Division of Aquatic Resources, “Hawai‘i Marine Life Conservation Districts” at <www.hawaii.gov/dlnr/dar/mlcd/index.html>.

Hawai‘i Department of Land and Natural Resources Division of Aquatic Resources, *Current Line* newsletter at <www.hawaii.gov/dlnr/dar/current_line.htm>.

Activity #1

Weren't There More of Us? Game

● ● ● Class Period One *Weren't There More of Us?*

Materials & Setup

- "Actual Size at First Reproduction" poster (included with this curriculum)
- "Reef Animal Photos" (master, pp. 18-24)
- One set of "Discussion Question Cards" (master, p. 25)

Per student group (Play with groups of four to eight students OR with an entire class of up to forty students.)

- One set of 40 "Weren't There More of Us?" game cards (master, pp. 9-13)
- "Weren't There More of Us?" Species List (one per student if playing with a single large group—master, p. 14)
- "Weren't There More of Us?" Instruction Card for small or large groups (one per student if playing with a single large group—master, pp. 15-16)
- Hawai'i fishing regulations flyers (included with this curriculum and available from the Hawai'i Department of Land and Natural Resources, Division of Aquatic Resources)

Instructions

1) Tell students they are going to play a game in which the objective is to work cooperatively to correctly match Hawaiian reef animals with exactly five corresponding characteristics and fishing regulations.

2) Play the game with a whole class of up to forty students or divide students into groups of four to eight. Groups will work independently, so they do not need to be of equal size. Hand out the game cards, species list, and appropriate instruction card.

3) Review game instructions with students.

4) Before starting the game, show pictures of all eight reef animals to students, and provide the name of each animal. You may choose to make the photos available for student viewing during the game or make the game more challenging by having student examine the photos only once at the beginning of the game. Do not give further information about the animals and their characteristics.

5) During the activity, do not give students any clues about the identity of the animals.

6) Conduct the game according to the appropriate game instructions for your group size.

7) After the game, divide the class into four groups and give each group one Discussion Question card. Give groups several minutes to come up with a response to the question and then lead a class discussion about the game using these discussion questions.

Notes

- "Sustainable yield" generally refers to taking animals at a time and in a way that enables the populations to maintain themselves over time.
- Examples of actions that could supplement government regulations protecting reef animals include education, enforcement, and setting up marine protected areas where animals can grow to reproductive maturity because they are not fished or hunted there.

Journal Ideas

- In traditional Hawaiian culture, fishermen offered their first catch to the gods. Do you do this or know anyone who does? Why is this practice significant?
- Do you think that people respect government regulations such as fishing limits and seasons? Why or why not?
- Hawaiians traditionally viewed the ocean as their icebox, taking only what they needed at the time and coming back for more when necessary. Do you think this view still influences people who fish in Hawaiian waters? Why or why not? If it has changed, what might have contributed to these changes?
- Do you think it is important that future generations be able to enjoy and use the reef animals that we do today? Why or why not?
- What do you think are the most effective ways to protect reef animals?

Assessment Tools

- Participation in the game
- Group reasoning ability and correct responses during the game
- Participation in group and class discussion
- Journal entries

Teacher Background

Weren't There More of Us? — Answer Key

Lau'īpala, Yellow tang (*Zebrasoma flavescens*)

- I live on shallow reefs around islands from Hawai'i to southern Japan but am abundant only in Hawai'i.
- I graze on *limu* (seaweed) on the rocks near the shore in calm areas.
- I am bright yellow in color.
- I am a popular aquarium fish, and more of me are collected and exported than any other fish in Hawai'i.
- I am not protected by Hawai'i fishing regulations.

Moi, Six-fingered threadfin (*Polydactylus sexfilis*)

- I am silvery with a deeply forked tail and live near the ocean bottom.
- The lower part of my pectoral fin is very unusual in that it has six separate slender rays that I use to probe for food on the ocean bottom.
- I eat shrimps, crabs, worms and other invertebrates that I search for on the ocean bottom.
- Because I have become scarce from overfishing, I am being grown in aquaculture facilities and restocked into coastal waters.
- The season for me is closed June through August. I can be taken once I reach seven inches in length, but I do not reproduce until I'm 11 inches long. You can only take 15 of me.

'Opihi, Limpet (*Cellana* spp.)

- I am shaped like a volcano.
- I live on surf-swept lava rocks and hang on tightly with my muscular foot.
- I creep slowly and eat algae on the surface of the rocks.
- My populations are decreasing because I am collected off the rocks when I am too small and haven't had a chance to reproduce.
- I can be collected all year long, but my shell has to be at least 1 1/4 inches wide.

He'e mauli, Day octopus (*Octopus cyanea*)

- I am very hard to see because I can change my skin texture and color to blend in with the reef.
- When frightened, I can jet away or squirt out black ink.
- I mainly eat crabs, which I pounce on with the web between my arms spread wide.
- I am strongly attracted to certain cowries which were used in old times as lures to catch me.
- I can be taken all year long but need to weigh at least one pound.

Ula, Spiny lobster (two species of *Panulirus*)

- I have ten legs and a hard outer shell with forward-pointing spines.
- I hide in caves and crevices and come out at night to feed.
- The meat in my tail is a highly prized food.
- Since I am easy to catch in traps or tangle nets, I am vulnerable to overfishing.
- I cannot be taken from May through August. You can keep me only if my tail is at least 2 3/4 inches wide. You cannot fish for me with a spear or take me if I am a female with eggs.

Uhu, also *Pālukaluka,* Redlip parrotfish (*Scarus rubroviolaceus*)

- I am a sand maker. I bite off pieces of dead coral, then grind it to sand in hard plates in my throat.
- If I am a female, I can change sex and color and become a beautiful blue male.
- I am an herbivore. My teeth are fused together to form a beak for scraping algae off rock and dead coral.
- I have large scales covering my body, which help protect me.
- I can be speared or sold once I reach one pound. I am 14 inches long when I first spawn.

Ulua aukea, Giant trevally (*Caranx ignobilis*)

- I am silvery with a deeply forked tail and swim in midwater.
- I feed on fishes that I chase down.
- I can be five feet long and weigh 145 pounds.
- I can reproduce once I reach 21 inches in length, but you can legally catch me when I'm only seven inches long.
- I am usually caught by polefishing from the shore between dusk and dawn.

Kūmū, Whitesaddle goatfish (*Parupeneus porphyreus*)

- I am pinkish red in color and stay near the bottom of the reef.
- I have two barbels or sensory "feelers" on my chin that I wiggle while probing the bottom for crabs, worms, and snails.
- I can be taken at seven inches but don't reproduce until I'm 11 inches long. You can fish for me all year long, and there is no limit to the number that can be taken.
- I am found only in Hawai‘i. In the old days I was used as an offering to the gods when a red fish was needed.
- I am one of the largest of my type of fish, reaching 16 inches in length.

Weren't There More of Us? cards (cut on dashed lines)

I live on shallow reefs around islands from Hawai'i to southern Japan but am abundant only in Hawai'i.	I am not protected by Hawai'i fishing regulations.
I graze on *limu* (seaweed) on the rocks near the shore in calm areas.	I am silvery with a deeply forked tail and live near the ocean bottom.
I am bright yellow in color.	The lower part of my pectoral fin is unusual in that it has six separate slender rays that I use to probe for food on the ocean bottom.
I am a popular aquarium fish, and more of me are collected and exported than any other fish in Hawai'i.	I eat shrimps, crabs, worms and other invertebrates that I search for on the ocean bottom.

Weren't There More of Us? cards (cut on dashed lines)

Because I have become scarce from over-fishing, I am being grown in aquaculture facilities and restocked into coastal waters.	**I am shaped like a volcano.**
The season for me is closed June through August. I can be taken once I reach seven inches in length, but I do not reproduce until I'm 11 inches long. You can only take 15 of me.	**I live on surf-swept lava rocks and hang on tightly with my muscular foot.**
I creep slowly and eat algae on the surface of the rocks.	**My populations are decreasing because I am collected off the rocks when I am too small and haven't had a chance to reproduce.**
I can be collected all year long, but my shell has to be at least 1 1/4 inches wide.	**I am very hard to see because I can change my skin texture and color to blend in with the reef.**

Weren't There More of Us? cards (cut on dashed lines)

When frightened, I can jet away or squirt out black ink.	**I have ten legs and a hard outer shell with forward-pointing spines.**
I mainly eat crabs, which I pounce on with the web between my arms spread wide.	**I hide in caves and crevices and come out at night to feed.**
I am strongly attracted to certain cowries which were used in old times as lures to catch me.	**The meat in my tail is a highly prized food.**
I can be taken all year long but need to weigh at least one pound.	**Since I am easy to catch in traps or tangle nets, I am vulnerable to overfishing.**

Weren't There More of Us? cards (cut on dashed lines)

I cannot be taken from May through August. You can keep me only if my tail is at least 2 3/4 inches wide. You cannot fish for me with a spear or take me if I am a female with eggs.

I am a sand maker. I bite off pieces of dead coral, then grind it to sand in hard plates in my throat.

If I am a female, I can change sex and color and become a beautiful blue male.

I am an herbivore. My teeth are fused together to form a beak for scraping algae off rock and dead coral.

I have large scales covering my body, which help protect me.

I can be speared or sold once I reach one pound. I am 14 inches long when I first spawn.

I am silvery with a deeply forked tail and swim in midwater.

I feed on fishes that I chase down.

Weren't There More of Us? cards (cut on dashed lines)

I can be five feet long and weigh 145 pounds.

I can reproduce once I reach 21 inches in length, but you can legally catch me when I'm only seven inches long.

I am usually caught by polefishing from the shore between dusk and dawn.

I am pinkish red in color and stay near the bottom of the reef.

I have two barbels or sensory "feelers" on my chin that I wiggle while probing the bottom for crabs, worms, and snails.

I can be taken at seven inches but don't reproduce until I'm 11 inches long. You can fish for me all year long, and there is no limit to the number that can be taken.

I am found only in Hawai'i. In the old days I was used as an offering to the gods when a red fish was needed.

I am one of the largest of my type of fishes, reaching 16 inches in length.

Weren't There More of Us?

Species List

1. *Lau'īpala*, Yellow tang *(Zebrasoma flavescens)*
2. *Moi*, Six-fingered threadfin *(Polydactylus sexfilis)*
3. *'Opihi,* Limpet *(Cellana* spp.*)*
4. *He'e mauli*, Day octopus *(Octopus cyanea)*
5. *Ula*, Spiny lobster *(*two species of *Panulirus)*
6. *Uhu,* also *Pālukaluka,* Redlip parrotfish *(Scarus rubroviolaceus)*
7. *Ulua aukea*, Giant trevally *(Caranx ignobilis)*
8. *Kūmū*, Whitesaddle goatfish *(Parupeneus porphyreus)*

Weren't There More of Us?

Species List

1. *Lau'īpala*, Yellow tang *(Zebrasoma flavescens)*
2. *Moi*, Six-fingered threadfin *(Polydactylus sexfilis)*
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8. *Kūmū*, Whitesaddle goatfish *(Parupeneus porphyreus)*

Weren‘t There More of Us?

Game Instructions for Teams of Four to Eight Students

Object

Work cooperatively to match Hawaiian reef animals with exactly five corresponding characteristics and fishing regulations—the first team to make all the correct matches wins.

How to Play

1) Choose a dealer who gives one card to each player.

2) Play begins with the player to the right of the dealer and proceeds in a counter-clockwise direction.

3) The first player reads the information on his or her card aloud.

4) The entire group discusses which of the animals on the Species List the characteristic belongs to. The player with the card becomes that animal's "keeper." Consult the fishing regulations flyer and "Size at First Reproduction" poster for help when you need it.

5) The second player reads the information on her or his card.

6) After group discussion, the group may decide that the second animal is the same as the first animal. If so, the card is given to the first "keeper." If the second animal is different than the first, the second player keeps the card and becomes the "keeper" of the second animal.

7) Continue until all the first round cards have been read and assigned to a keeper.

8) Continue dealing rounds of cards and assigning them to animals, as before.

9) After the second round, there may be some players without animals to "keep" and some with more than one animal. When that happens, a player without an animal to keep should "adopt" one from a player who is keeping more than one animal, so each player has an animal to keep. If there are fewer than eight players, some will have more than one animal.

10) When all the cards have been assigned, keepers should have exactly five fact cards for each animal. If some animals have more than five cards, you must determine which cards have been incorrectly assigned. Some features may overlap slightly, so your team will need to discuss the possibilities and look for clues to the correct match.

11) When you think you have the correct matches, ask your instructor to check your team's work.

Weren't There More of Us?

Game Instructions for Groups Up to Forty Students

Object

Work cooperatively to match Hawaiian reef animals with exactly five corresponding characteristics and fishing regulations

How to Play

1) Pass out all the cards. Some players may have more than one.

2) Players read the information on their card(s) and try to determine the identity of the animals.

3) When players think they know what their animal(s) is, they call out the name. For example, a person with the card that says, "I have a lush fur coat," calls out, "Monk seal!"

4) Other players listen to the names being called out and try to fit the information on their cards into one of the animal groups. They give their cards to the first person who called out the name of a particular animal. That person is designated the "keeper," and the other students join him or her to find the other correct matches for that animal.

5) When all the cards have been added to a set, keepers should have exactly five fact cards for each animal. If some animals have more than five cards, players must get together to determine which cards have been incorrectly assigned. Some features overlap slightly, so you will need to discuss the possibilities and look for clues to the correct match.

6) Consult the fishing regulations flyer and "Size at First Reproduction" poster for help as needed.

7) At the end of the game, ask your instructor to check the sets to determine if they are correct.

Lau'īpala, Yellow tang (*Zebrasoma flavescens*)

Photo: John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Moi, Six-fingered threadfin (*Polydactylus sexfilis*)

Photo: John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

'Opihi, Limpet (*Cellana* spp.)

Cellana exarata *pictured (Photo: Ann Fielding)*

He'e mauli, Day octopus (*Octopus cyanea*)

Photo: David R. Schrichte in John P. Hoover,
Hawai'i's Sea Creatures, *Mutual Publishing*

Ula, Spiny lobster (two species of *Panulirus*)

Panulirus marginatus *pictured*
(Photo: John P. Hoover, Hawai‘i’s Sea Creatures, *Mutual Publishing)*

Uhu, also *Pālukaluka,* Redlip parrotfish (*Scarus rubroviolaceus)*

Photo: Bruce Carlson

Ulua aukea, Giant trevally (*Caranx ignobilis*)

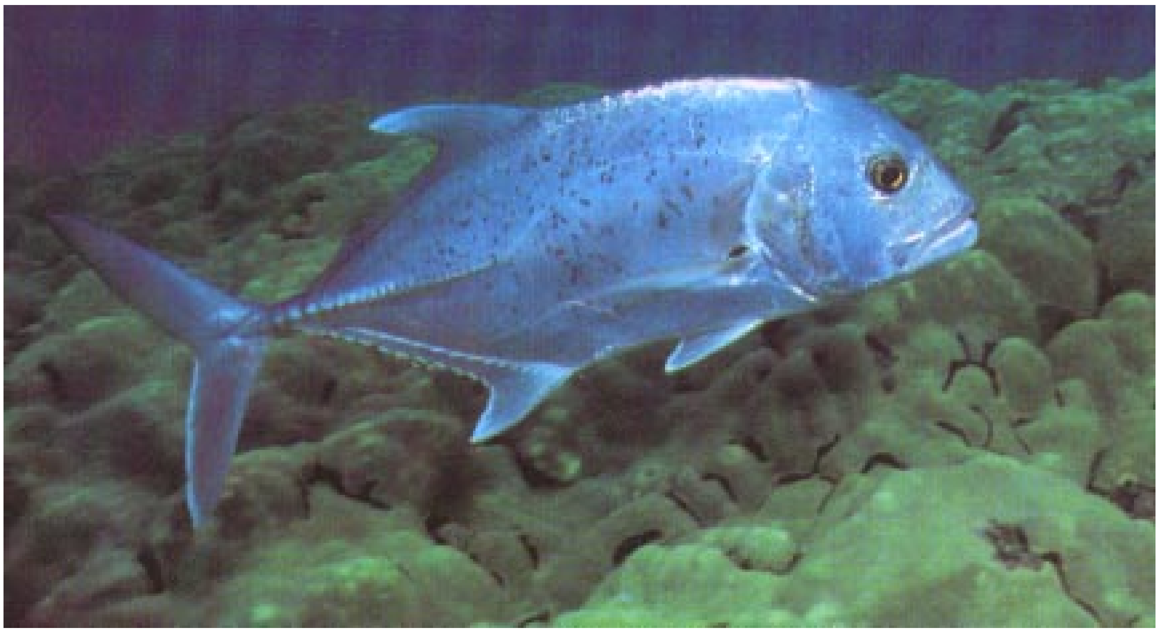

Photo: David R. Schrichte in John P. Hoover,
Hawaii's Fishes, *Mutual Publishing*

Kūmū, Whitesaddle goatfish (*Parupeneus porphyreus*)

Photo: John P. Hoover, Hawaii's Fishes, *Mutual Publishing*

Discussion Question Cards

Cut apart on dashed lines

Most of the reef animals in the game are protected by regulations such as closed seasons, size limits, and limits on numbers of animals that can be taken. But, as you learned, the size limits on some species allow people to take animals that have not been able to reproduce yet. Does this seem smart to you? Why or why not?

What do you think the best way is to protect populations of reef animals? Explain your answer.

What do you think the term “sustainable yield” means when it comes to catching or collecting reef animals?

The government regulates the taking of reef animals that have been determined to be at risk for overfishing/harvesting. Do you think fishing/hunting regulations are effective tools for protecting reef animals? Do you think they can work by themselves?

Activity #2

Impacts of Aquarium Fish Collecting on Coral Reefs

● ● ● In Advance *Student Assignment*

- As homework, assign the Student Pages "Impacts of Aquarium Fish Collectors on Coral Reef Fishes in Kona, Hawai'i" (pp. 34-41) and "Questions About the Reading" (pp. 42-45).

● ● ● Class Period One *Discussing Study Designs*

Materials & Setup

For each student

- Student Page "Impacts of Aquarium Fish Collectors on Coral Reef Fishes in Kona, Hawai'i" (pp. 34-41)
- Student Page "Questions About the Reading" (pp. 42-45)

Instructions

1) Beginning with student questions and responses to the homework assignment, hold a class discussion about the study, its design, conclusions, and implications for managing coral reef fisheries.

2) For advanced classes, move from the general discussion to a more detailed discussion of experimental design. For guidance and background, use "Impacts of Aquarium Collectors on Coral Reef Fishes in Kona, Hawai'i" (complete original report in appendix) and "Notes for Class Discussion on 'Impacts of Aquarium Collectors on Coral Reef Fishes'" (pp. 28-29).
   The class discussion should get into the details of experimental design at an appropriate depth for the level of students. Students should be prepared for this discussion based on their reading and answering the homework questions.

3) Wrap up the discussion by focusing on the final homework question, how students would go about learning whether aquarium collecting is a current problem on Maui and what they would do to prevent it from becoming a problem in the future.

Journal Ideas

- If you were in charge of regulating aquarium fish collecting, what would you do based on reading the Tissot and Hallacher study?
- Do you think that people should be allowed to collect native Hawaiian fish for the aquarium trade? Why or why not?

Assessment Tools

- Student Page "Questions About the Reading" (teacher version, pp. 30-33)
- Participation in class discussion
- Journal entries

Teacher Background

Notes for Class Discussion on "Impacts of Aquarium Collectors on Coral Reef Fishes"

To make the main points of this paper easier for students to grasp, several parts of the study and discussion were left out of the simplified student version of the paper. Depending upon the level of student and the nature of the course you are teaching, you will want to go into details of the study that will help students understand experimental design.

Below are the main elements of the paper, along with page references to the full version of the paper (see appendix). First, make sure that students understand the results of the study as presented in the student version. Then, with the time remaining, go into the elements of experimental design, emphasizing the first three sections of the paper.

1) Introduction/statement of the problem (pp. 4-5)
   The context for this study is the growing global and Hawai'i-based trade in marine aquarium fishes collected from the wild. The authors identified a lack of conclusive studies documenting the magnitude of impacts on natural populations.

2) Scope/purpose of the study (p. 4)
   This study had two main purposes. Only the first is covered in the student version of the paper:
   a) Obtain quantitative estimates of the impact of aquarium collectors on reef fishes;
   b) Evaluate evidence for destructive harvesting methods and changes in the reef community associated with reductions in herbivory (predation on plants).

3) Methods (pp. 5-7)
   a) The authors explain their experimental design (a paired control-impact design) and its major assumptions. The student version of the paper deals very little with the assumptions of the design and how they were tested/addressed. The main assumptions and how they were tested and addressed in the study and report are:

Assumption

Prior to the onset of aquarium harvesting, there was no difference in abundance of aquarium fishes between the control and impact sites. (The study was begun after the impacts had begun.)

How addressed, tested

- Paired control and impact sites were geographically close together (p. 10).
- The survey was conducted on corals, macroalgae, and the general substratum of each transect. Analysis showed remarkable similarity between the paired control-impact sites (pp. 8, 10).
- The survey included ecologically similar species not targeted by aquarium collectors. A prediction of this assumption is that non-collected species should not differ between control and impact sites. This prediction was supported by study data (pp. 6, 8-10).

Assumption	How addressed, tested
All differences between the control and impact sites are due to aquarium fish collecting and not other factors, such as fishing.	• Impact sites were largely inaccessible from shore, minimizing shore-based recreational fishing (p. 10). • There was no significant control-impact variation in abundance of a nontarget species (not collected for aquariums) subject to commercial and recreational fishing (p. 10). • Introduced piscivorous (fish-eating) fishes that may cause significant mortality among aquarium species were rare at the study sites (pp. 10-11).

b) The authors also describe their research sites, methods, personnel, and timing of the surveys, as well as steps they took to minimize bias (pp. 6-7). Much of this detail has been left out of the student version of the paper.

c) Methods of analysis are described (p. 7). Only the basic calculation of percent change in abundance is described in the student version of the paper. The analysis for statistical significance is not described in the student version, nor were the factors included (impact, location, and impact-location).

4) Results (pp. 6-9)
In the student version of the paper, this section is condensed and combined with the discussion section, primarily because so many of the results had to do with analyses not covered in the student paper.

5) Discussion (pp. 9-13)
In this paper, the discussion of results has four sections:
-Evaluation of assumptions (see table above)
-Magnitude of impacts (eliminated from the student version)
-Indirect effects (eliminated from the student version)
-Implications for fishery management

6) Acknowledgments (p. 13)

7) References
References in the student version have been modified based on editing the original.

8) Tables and figures
Only some of the tables from the original paper are in the student version.

Teacher Version

Questions About the Reading

Answer the following questions. Attach additional sheets if necessary.

1) What was the purpose of the study?

   To examine the effects of aquarium collecting on reef fish populations in Hawaiʻi

2) Why did the researchers choose to survey both fish species that are commonly collected for the aquarium trade and those that are not?

   Each nontargeted fish species was chosen because its habitat and food type are similar to one or more targeted species. These nontarget species provided a base of comparison that helped researchers determine whether the changes in population were related to aquarium collecting.

3) Explain what the "impact" sites were and what the "control" sites were and why they are important in this study.

   The impact sites were areas with high levels of aquarium collecting. The control sites were adjacent to impact sites, in areas where aquarium collecting is prohibited. Researchers could estimate the magnitude of impact by comparing population density and changes in population density at sites where aquarium collecting occurs and where it does not.

4) The researchers were interested in determining how much difference there was between fish abundance at the control and impact sites. They determined the mean density of fish at each of the sites. Then they calculated a percent change in fish abundance for each species, and for each species at each of the two study sites.

A negative percent change indicates fewer fish at the impact relative to the control site, while a positive value indicates the opposite pattern.

Species	Mean overall percent change
Aquarium fishes	
Achilles tang (*Acanthurus achilles)*	-57.1
Potter's angelfish (*Centropyge potteri)*	-46.1
Multi-band butterflyfish (*Chaetodon multicinctus)*	-38.2
Ornate butterflyfish (*Chaetodon ornatissimus*)	-39.5
Four-spot butterflyfish (*Chaetodon quadrimaculatus)*	-41.6
Goldring surgeonfish (*Ctenochaetus strigosus*)	-14.7
Longnose butterflyfish (*Forcipiger* spp.)	-54.2
Orangespine unicornfish (*Naso lituratus*)	31.2
Moorish idol (*Zanclus cornutus*)	-46.5
Yellow tang (*Zebrasoma flavescens*)	-47.3
Non-Aquarium Species	
Brown surgeonfish (*Acanthurus nigrofuscus*)	27.3
Blueline surgeonfish *(Acanthurus nigroris)*	67.2
Convict surgeonfish or tang *(Acanthurus triostegus)*	-4.3
Oval butterflyfish *(Chaetodon lunulatus)*	-70.0
Arc-eye hawkfish *(Paracirrhites arcatus)*	-36.4
Blackside hawkfish *(Paracirrhites forsteri)*	58.4
Blue-eye damsel *(Plectroglyphidodon johnstonianus)*	-31.3
Pacific gregory *(Stegastes fasciolatus)*	326.0
Saddle wrasse *(Thalassoma duperrey)*	17.4

4a) Which three species show the greatest difference between the number of individuals at control sites and impact sites? For each species, identify whether this difference indicates that there are fewer individuals at the control sites or the impact sites.

Pacific gregory *(Stegastes fasciolatus)* — fewer at control sites

Oval butterflyfish *(Chaetodon lunulatus)* — fewer at impact sites

Blueline surgeonfish *(Acanthurus nigroris)* — fewer at control sites

4b) Which four species show the greatest negative mean percent change—indicating fewer individuals at the impact sites relative to the control sites? Discuss the possible significance of these results based on whether these species are collected for the aquarium trade or not.

Oval butterflyfish (*Chaetodon lunulatus*)
Achilles tang (*Acanthurus achilles*)
Longnose butterflyfish (*Forcipiger spp.*)
Yellow tang (*Zebrasoma flavescens*)

Three of the four species are targeted by aquarium collectors. This probably indicates that aquarium collection, which occurs at the impact sites and not the control sites, decreases fish populations.

5) What patterns do you notice when you compare the aquarium species with the non-aquarium species, looking at whether the percent change is negative or positive? What do these patterns suggest about the impact of aquarium collecting?

All but one of the aquarium species show a negative percent change, while the results are mixed among non-aquarium species (three negative and four positive). This result suggests that aquarium collecting decreases populations of target species and that other factors might also have come into play (because of the mixed results among the non-aquarium species).

6) The experimental design that the researchers selected for this study makes two major assumptions:
   a) The study began after aquarium fish collecting had already started in the impact areas. Therefore, the design assumes that the natural abundance of aquarium fishes at the control and impact sites were similar prior to the onset of aquarium collection.
   b) The design assumes that all differences between the paired control and impact sites were due to aquarium fish collecting and not other factors, such as fishing.

Choose one of these assumptions and think of a way that the researchers could — or did — build into the study a way to test whether the assumption seems valid.

There are many correct responses to this question, which should be evaluated based on student reasoning, as well as references back to the study:

a) One way the researchers controlled for the first assumption was to select control and impact sites that are close together, to lessen the likelihood of spatial variation. They also used a combination of nontarget species that were ecologically similar to target species, and other species that were indicators of particular habitats, as indicators of the ecological similarity of the control and impact sites.

Other ways of assessing the correctness of this assumption include comparing control and impact sites for factors such as species diversity and richness, and comparing the habitats by looking at coral and algae abundance and diversity, and non-living substratum composition.

b) One way to control for the second assumption is to select sites that are largely inaccessible from shore, to minimize the impact of shore-based recreational fishing. (The authors did this in the aquarium collecting study, but that may not be clear from the student background reading.)

Other ways of testing the assumption include looking at density variation in target and nontarget species that are subject to commercial and recreational fishing. If the density of nontarget species that are fished for does not vary between control and impact sites, this suggests that fishing impacts are not significant.

Another factor that could differentially affect reef fish populations could be the presence of predator fishes. Including predator fishes in the surveys would help determine whether this factor does influence reef fish populations.

7) Some people say that aquarium collecting is not a problem on Maui, while others believe that it is a problem in some areas or could quickly become one. Write one paragraph about what you would do to find out whether aquarium collecting is a threat to Maui reef animals. Write another paragraph about what you think should be done, if anything, to protect Maui reef fish populations from the impacts of collecting.

Well-reasoned responses are acceptable.

Impacts of Aquarium Collectors on Coral Reef Fishes in Kona, Hawai'i

This paper is condensed with authors' permission from a September 1999 report of the same name prepared for the State of Hawai'i Division of Aquatic Resources by Brian N. Tissot, Ph.D. (Washington State University — Vancouver) and Leon E. Hallacher, Ph.D. (University of Hawai'i – Hilo). This distillation of their paper focuses on the first goal of their study: to obtain "quantitative" or number-based estimates of the impact of aquarium collectors on reef fishes. It does not cover methods, data, or conclusions associated with the second goal of the study: to evaluate evidence for destructive fish harvesting methods and changes in the reef community associated with reductions in herbivory.

Introduction

Each year, some 350 million ornamental aquarium fish worth $963 million are sold around the world (Young, 1997). Although marine fishes account for only ten to 20 percent of the total, the harvest level for marine species grew rapidly in the1980s (Andrews, 1990). Over 99 percent of marine fishes sold in the aquarium trade are taken from the wild, unlike their freshwater counterparts, most of which are cultivated (Young, 1997). Almost all marine ornamentals are of tropical origin and many are harvested from coral reefs. Because aquarium fish collectors focus heavily on a few species and often capture large quantities of individuals of high value, the potential for overfishing is high (Wood, 1985).

Many studies have discussed the potential effects of the aquarium trade on marine fishes in Australia (Whitehead et al., 1986), Hawai'i (Taylor, 1978; Walsh, 1978; Randall, 1987), Indonesia (Wood, 1985), the Philippines (Albaladejo and Corpuz, 1981), Puerto Rico (Sadovy, 1992), and Sri Lanka (Edwards and Shepherd, 1992). But there are no conclusive studies documenting the magnitude of impacts on fish populations, despite repeated calls for such studies to help sustain the aquarium trade industry over the long term (Walsh, 1978; Wood, 1985; Young, 1997).

Most of the marine ornamentals originating from the U.S. are taken from Hawai'i waters. Hawai'i is known for its high-quality fishes and rare endemic fishes of high value (Wood, 1985). As early as the 1970s, concerns over the effects of aquarium collecting on reef fish populations in Hawai'i were being raised. (Taylor, 1978; Walsh, 1978). Aquarium fish collectors and recreational dive tour operators came into conflict over apparent declines in nearshore reef fishes (Taylor, 1978). This conflict continues up to the present (Grigg, 1997; Young, 1997; Clark and Gulko, 1999). Early concerns prompted the Hawai'i Division of Fish and Game [now the Division of Aquatic Resources] to require monthly collection reports of all permit holders starting in 1973 (Katekaru, 1978). These reports have been the primary basis for managing the aquarium industry in Hawai'i since then (Miyasaka, 1994, 1997).

Data from collection reports suggest that the size and value of the Hawai'i aquarium fish industry is growing. In 1973, 90,000 fishes with a total value of $50,000 were reported (Katekaru, 1978). In 1995, the annual harvest had risen to 422,823 fishes with a total value of $844,843 (Miyasaka, 1997).

Although a total of 103 fish species were collected statewide in 1995 (Division of Aquatic Resources [DAR], unpublished data), over 90 percent of the harvest is focused on 11 species. The yellow tang (*Zebrasoma flavescens*) accounted for 52 percent of the total harvest in 1995 (DAR, unpublished data; Miyasaka, 1997). Given the increasing rate of harvest focused on a small number of species, the potential for "overexploitation" is high, meaning the fishes are taken at such a rate that they cannot maintain their populations over the long term.

Materials and Methods

We used a "paired control-impact design" to estimate the impact of aquarium collectors on the "abundance" or relative numbers of reef fish in an area. The magnitude of the impact was estimated by comparing the difference between fish abundance at "impact" sites, where aquarium fish collecting was known to occur, relative to nearby "control" sites where collecting was prohibited.

We established four study sites that served as two control-impact pairs for the study (Figure 1). Impact sites were selected in areas where high levels of aquarium fish collecting was occurring (personal communications). Control sites were located in areas adjacent to impact sites, where aquarium fish collecting was prohibited.

The first pair of study sites were located at Honokōhau and Papawai on the island of Hawai'i. Papawai is a Fishery Management Area (FMA) where the collecting of aquarium fishes is prohibited (DLNR, 1996). It served as a control site. Honokōhau was frequented by aquarium collectors and served as an impact site. These paired sites will hereafter be referred to as the "Honokōhau" study area. The second pair of study sites were located at Red Hill North and South. Red Hill South is a FMA where the collecting of aquarium fishes is prohibited (DLNR, 1996), and which served as a control site. Red Hill North was frequented by aquarium collectors and served as an impact site. These paired sites will hereafter be referred to as the "Red Hill" study area.

At each study site four permanent 50-meter "transects" or lines were established at ten to 15 meter depths by installing stainless steel eyebolts at the beginning and end points of each. The abundances of fishes was estimated using a visual strip-transect search method (Sale and Douglas, 1981). In this method, a pair of divers swam side-by-side down either side of the transect line and count all fish seen within a corridor three meters wide and extending to the surface.

Surveys began at Honokōhau in March, and at Red Hill in September, of 1997 and ended at both sites in December 1998. All sites were sampled at

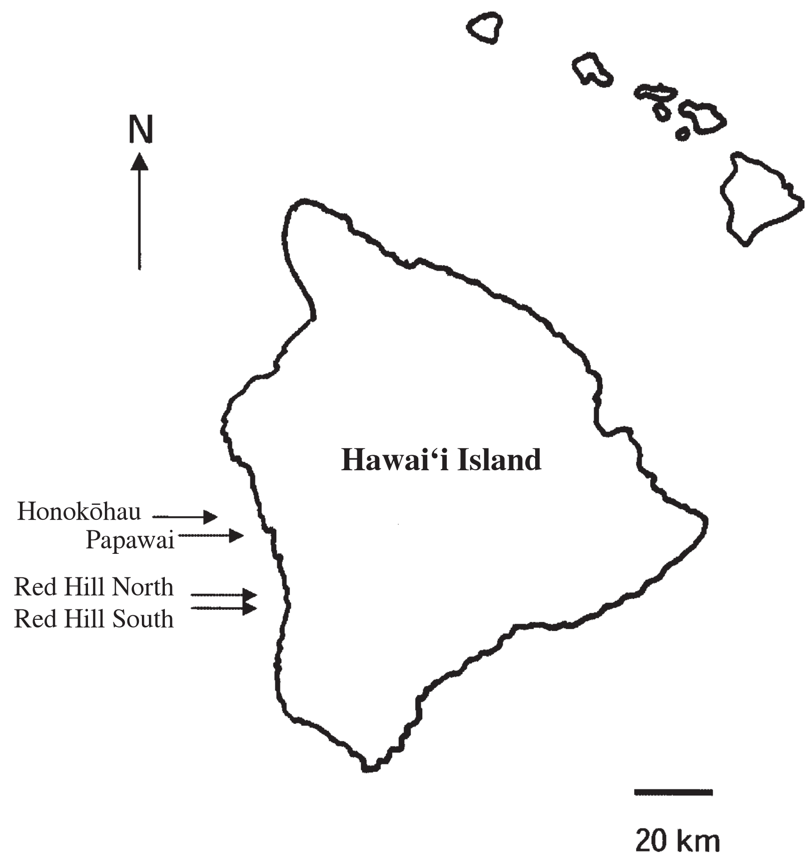

Figure 1. Map of study sites located on the island of Hawai'i

intervals of two to five months for a total of eight surveys at Honokōhau and five at Red Hill.

During each survey we estimated the abundance of 21 fish species (Table 1). Eleven aquarium fish species were selected based on reported high levels of collection. In addition, we also surveyed ten fish species not targeted by aquarium collectors. These species were selected to serve as indicators of specific habitats and food types and provide data to support the study's assumptions.

The divers used in this study were undergraduates who had completed a rigorous coral reef-monitoring course and were trained in species identification and survey techniques (Russell, 1997; Hallacher and Tissot, 1999). In order to minimize observer bias, the same diver-pairs were used at each control-impact study site during each survey. Divers did, however, vary among surveys. To minimize variation, all surveys were conducted in the middle of the day (generally from 9:00 a.m. to 3:00 p.m.) and both control and impact sites were surveyed either on the same day or on consecutive days.

Percent change in fish abundance was calculated as the difference between both control sites and both impact sites using the formula:

$$\text{Percent change} = [(D_{impact} - D_{control})/D_{control}] \times 100$$

Where D = density expressed as number of individuals per 100 square meters. Thus, a negative percent change indicates fewer fish at the impact relative to the control sites, while a positive value indicates the opposite pattern.

Results and Discussion

Of the 21 species surveyed, two species (Racoon butterflyfish, *Chaetodon lunula,* and Teardrop butterflyfish, *C. unimaculatus*) were too rare for analysis with one individual of each species observed during the entire study. These species were excluded from any further analysis.

Overall, there were numerous "significant" differences (which are unlikely to occur based on chance alone) in the abundance of aquarium fishes between control and impact sites but few differences in the abundance of non-aquarium species (Table 2).

The results of this study indicate that eight of the ten fishes targeted by aquarium collectors were significantly reduced in abundance in areas subjected to harvesting, relative to managed areas where collecting was prohibited. The magnitude of these declines ranged from 57 percent in Achilles tang *(Acanthurus achilles)* to 38 percent in Multi-band butterflyfish *(Chaetodon multicinctus)*. In contrast, only one of the nine "nontarget" species not typically collected for aquariums varied significantly between these areas, suggesting that aquarium collectors are having significant impacts on the abundance of targeted fishes in near-shore areas on the Kona coast of Hawai'i.

Evaluation of Assumptions

Part of the design of this study was to use a combination of nontargeted species that were ecologically similar to target species (those that are collected for the aquarium trade). This is one way to infer whether observed differences are due to the impact of aquarium collectors or due to other differences between the control and impact sites.

Overall, aquarium fishes exhibited significant differences between control and impact sites, while nontarget species did not. Table 3 details some of these comparisons.

The one exception to this pattern was the Arc-eye hawkfish (*Paracirrhites arcatus*), the only nontarget species that was significantly less abundant in impact relative to control areas. This species lives in close association with corals, primarily *Pocilliopora meandrina*, which although rare at all study sites, was less abundant at impact relative to control sites.

Implications for Fishery Management

This study indicates that aquarium collectors are having significant impacts on eight of the ten

(Continued on p. 40)

Table 1. List of fishes monitored during the study

Information on diet and trophic level is based on Randall (1985, 1996).

SPECIES	TROPHIC LEVEL	DIET
Aquarium fishes		
Achilles tang (*Acanthurus achilles*)	Herbivore	Filamentous algae
Potter's angelfish (*Centropyge potteri)***	Herbivore	Filamentous algae and detritus
Racoon butterflyfish (*Chaetodon lunula*)°	Carnivore	Small invertebrates
Multi-band butterflyfish (*Chaetodon multicinctus)***	Corallivore	Coral polyps
Ornate butterflyfish (*Chaetodon ornatissimus)*	Corallivore	Coral polyps
Four-spot butterflyfish (*Chaetodon quadrimaculatus*)	Corallivore	Coral polyps
Goldring surgeonfish (*Ctenochaetus strigosus*)	Detritivore	Detritus
Longnose butterflyfish (*Forcipiger* spp.)•	Carnivore	Small invertebrates
Orangespine unicornfish (*Naso lituratus*)	Herbivore	Macroalgae
Moorish idol (*Zanclus cornutus*)	Omnivore	Sponges and algae
Yellow tang (*Zebrasoma flavescens*)	Herbivore	Filamentous algae
Nonaquarium fishes		
Brown surgeonfish (*Acanthurus nigrofuscus*)	Herbivore	Filamentous algae
Blueline surgeonfish (*Acanthurus nigroris)* *	Herbivore	Filamentous algae
Convict tang (*Acanthurus triostegus*)	Herbivore	Filamentous algae
Teardrop butterflyfish (*Chaetodon unimaculatus*)°	Corallivore	Coral polyps
Oval butterflyfish (*Chaetodon lunulatus*)	Corallivore	Coral polyps
Arc-eye hawkfish (*Paracirrhites arcatus*)	Carnivore	Invertebrates and fishes
Blackside hawkfish (*Paracirrhites forsteri*)	Carnivore	Invertebrates and fishes
Blue-eye damsel (*Plectroglyphidodon johnstonianus*)	Corallivore	Coral polyps
Pacific gregory (*Stegastes fasciolatus*)	Herbivore	Filamentous algae and detritus
Saddle wrasse (*Thalassoma duperrey*)*	Carnivore	Invertebrates

* endemic to Hawai'i ° too rare to be included in the analysis
• two species of longnose butterflyfish were included in this category

Table 2. Mean density of aquarium and nonaquarium fishes at control and impact study sites pooled for the entire study

	Density (no. / 100 m²)			
	Honokōhau		Red Hill	
	Impact	Control	Impact	Control
Aquarium fishes				
Acanthurus achilles	0.23	0.69	0.40	0.92
Centropyge potteri	1.48	2.50	0.25	0.85
Chaetodon multicinctus	2.98	4.95	3.43	5.72
Chaetodon ornatissimus	0.25	0.59	0.57	1.37
Chaetodon quadrimaculatus	0.01	0.15	0.17	0.38
Ctenochaetus strigosus	24.10	35.60	32.10	28.70
Forcipiger spp.	1.27	3.24	0.75	1.33
Naso lituratus	1.58	1.25	0.92	1.72
Zanclus cornutus	0.34	0.89	0.28	0.65
Zebrasoma flavescens	9.72	19.80	14.30	24.40
Overall Density	42.00	69.7	53.20	66.00
Nonaquarium fishes				
Acanthurus nigrofuscus	12.10	11.30	23.90	17.60
Acanthurus nigroris	1.24	2.60	3.42	1.68
Acanthurus triostegus	0.16	0.32	0.17	0.13
Chaetodon lunulatus	0.26	0.11	0.00	0.00
Paracirrhites arcatus	1.28	1.56	0.87	3.68
Paracirrhites forsteri	0.42	0.17	0.15	0.60
Plectroglyphidodon johnstonianus	1.82	2.11	0.97	1.93
Stegastes fasciolatus	1.29	0.73	0.15	0.10
Thalassoma duperrey	3.91	3.22	3.30	3.65
Overall Density	22.50	22.20	32.90	29.40

Table 3: Comparisons in change in abundance among similar target and nontarget species

Species	Similar characteristics	Change in abundance
Nontarget Brown surgeonfish (*Acanthurus nigrofuscus*)	Generalized herbivores that feed on filamentous algae, occupy the same depth ranges and habitats, and exhibit similar patterns of spawning and larval recruitment (Randall, 1985; Walsh, 1987; Lobel, 1989)	No significant variation between impact and control sites
Target Yellow tang (*Zebrasoma flavescens*)		Forty-seven percent less abundant at impact sites than at control sites
Nontarget Oval butterflyfish (*Chaetodon lunulatus*) Blue-eye damsel (*Plectroglyphidodon johnstonianus*)	Feed on coral or live in close association with coral	No significant variation between impact and control sites
Target Multi-band butterflyfish (*Chaetodon multicinctus*) Ornate butterflyfish (*C. ornatissimus*) Four-spot butterflyfish (*C. quadrimaculatus*)		Significantly lower abundances at impact sites
Nontarget Blueline surgeonfish (*Acanthurus nigroris*) Convict surgeonfish (*A. triostegus*) Blackside hawkfish (*Paracirrhites forsteri*) Pacific gregory (*Stegastes fasciolatus*) Saddle wrasse (*Thalasoma duperrey*)	Generalized diets and distributions across the reef	No significant variation between impact and control sites
Target Achilles tang (*Acanthurus achilles*) Potter's angelfish (*Centropyge potteri*) Moorish idol (*Zanclus cornutus*)		Significantly lower abundances at impact sites

species examined. However, more specific information about location, catch and effort is essential to verify the results of this study. The current system of catch reporting in Hawai‘i is limited to monthly collecting reports, with the 235-kilometer (146-mile) coastline of west Hawai‘i divided into three large sections (Miyasaka, 1997). These reports are not compared to actual catches, so there is no quality assurance that the reports are accurate. Analysis of the current catch reports indicates that significant numbers of reports are not filed (DAR, personal communication). Routine monitoring of the collector’s catch report should be instituted to provide some level of quality assurance about the reported catch data.

The magnitude and extent of the impacts documented in this study clearly point to an increased need for management of these species in Hawai‘i. Responding to continued strong public outcry over the aquarium collecting issue, the Hawai‘i state legislature passed a bill in 1998 which focused on improving management of reef resources. The law established the West Hawai‘i Regional Fishery Management Area. It also set aside a minimum of 30 percent of the west Hawai‘i coastline as Fish Replenishment Areas (FRAs), protected areas where aquarium fish collecting is prohibited. Based largely on input from the West Hawai‘i Fishery Council, a community-based group of individuals, a network of nine FRAs has been proposed as a plan to manage the aquarium industry. Our current efforts are focused on monitoring these areas in order to evaluate the effectiveness of the proposed reserve network as a fishery management tool. Through monitoring of changes in abundance in the reserves relative to existing protected and impact areas (including the Honokōhau and Red Hill study sites), we will be able to test predictions derived from the results of this study.

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Questions About the Reading

Answer the following questions. Attach additional sheets if necessary.

1) What was the purpose of the study?

2) Why did the researchers choose to survey both fish species that are commonly collected for the aquarium trade and those that are not?

3) Explain what the “impact” sites were and what the “control” sites were and why they are important in this study, and to research in general.

4) The researchers wanted to determine how much difference there was between fish abundance at the control and impact sites. They determined the mean density of fish at each of the sites. Then they calculated a percent change in abundance for each species.

A negative percent change indicates fewer fish at the impact relative to the control site, while a positive value indicates the opposite pattern.

Species	Mean percent change for both study sites
Aquarium fishes	
Achilles tang (*Acanthurus achilles*)	-57.1
Potter's angelfish (*Centropyge potteri*)	-46.1
Multi-band butterflyfish (*Chaetodon multicinctus*)	-38.2
Ornate butterflyfish (*Chaetodon ornatissimus*)	39.5
Four-spot butterflyfish (*Chaetodon quadrimaculatus*)	-41.6
Goldring surgeonfish (*Ctenochaetus strigosus*)	14.7
Longnose butterflyfish (*Forcipiger* spp.)	-54.2
Orangestripe unicornfish (*Naso lituratus*)	31.2
Moorish idol (*Zanclus cornutus*)	-46.5
Yellow tang (*Zebrasoma flavescens*)	-47.3
Nonaquarium Species	
Brown surgeonfish (*Acanthurus nigrofuscus*)	27.3
Blueline surgeonfish (*Acanthurus nigroris*)	67.2
Convict tang (*Acanthurus triostegus*)	-4.3
Oval butterflyfish (*Chaetodon lunulatus*)	-70.0
Arc-eye hawkfish (*Paracirrhites arcatus*)	-36.4
Blackside hawkfish (*Paracirrhites forsteri*)	58.4
Blue-eye damsel (*Plectroglyphidodon johnstonianus*)	-31.3
Pacific gregory (*Stegastes fasciolatus*)	326.0
Saddle wrasse (*Thalassoma duperrey*)	17.4

4a) Which three species show the greatest difference between the number of individuals at control sites and impact sites? For each species, identify whether this difference indicates that there are fewer individuals at the control sites or the impact sites.

4b) Which four species show the greatest negative mean percent change—indicating fewer individuals at the impact sites relative to the control sites? Discuss the possible significance of these results based on whether these species are collected for the aquarium trade or not.

5) What patterns do you notice when you compare the aquarium species with the non-aquarium species, looking at whether the percent change is negative or positive? What do these patterns suggest about the impact of aquarium fish collecting?

6) The experimental design that the researchers selected for this study makes two major assumptions:
   a) The study began after aquarium fish collecting had already started in the impact areas. Therefore, the design assumes that the natural abundance of aquarium fishes at the control and impact sites were similar prior to the onset of aquarium collection.
   b) The design assumes that all differences between the paired control and impact sites were due to aquarium fish collecting and not other factors, such as sport fishing or pollution.

   Choose one of these assumptions and think of a way that the researchers could — or did — build into the study a way to test whether the assumption seems valid.

7) Some people say that aquarium collecting is not a problem on Maui, while others believe that it is a problem in some areas or could quickly become one. Write one paragraph about what you would do to find out whether aquarium collecting is a threat to Maui reef animals. Write another paragraph about what you think should be done, if anything, to protect Maui reef fish populations from the impacts of collecting. (If you played the “Weren’t There More of Us?” game, how did what you learned from that game influence your response to these questions?)

Activity #3

Design a Monitoring Study

● ● ● In Advance *Student Assignment*

- As homework, assign the Student Page "Design Your Own Monitoring Study" (pp. 48-52). You may want to give students several days to complete this assignment, allowing students ample time to complete their study designs. If you want students to research and footnote any parts of their design proposals (such as the project background), let them know this in advance.

● ● ● Class Period One *Discussing Study Designs*

Materials & Setup

For each student

- Student Page "Design Your Own Monitoring Study" (pp. 48-52)

Instructions

1) Divide the class into four or five small groups. Have students describe their study designs to other students in their group. Each group should select the best study design from the ones presented.

2) Bring the whole class back together and have the students whose study designs were selected by the groups present them to the whole class. Lead a discussion about the similarities and differences in the designs and how this kind of monitoring information could affect how natural areas are managed.

3) Have the class vote on the best study design of those selected by the groups. The class will present that study design to the Department of Land and Natural Resources (DLNR) on Maui. Select a small committee of students to write a cover letter describing what the class has learned during this unit and offering the study design as a suggested way for DLNR to monitor ʻĀhihi-Kīnaʻu Natural Area Reserve.

Journal Ideas

- Describe one point of similarity and one point of difference between your study design and the one Brian Tissot and Leon Hallacher did on the Big Island.
- How important do you think scientific research should be to government policy makers deciding how to protect Hawaiian marine areas and marine life? What else should they consider in making these decisions?

Assessment Tools

- Design for monitoring study: Evaluate these on the basis of completeness using the list of elements in the Student Page "Design Your Own Monitoring Study," scientific rigor, logic, and clarity of presentation.
- Journal entries

Design Your Own Monitoring Study

Natural Area Reserves (NARs) are among the most highly protected lands managed by the State of Hawai‘i. They protect the best of what is left of the unique biological and geological resources of Hawai‘i. The ‘Āhihi-Kīna‘u Natural Area Reserve is situated near the end of the road at Mākena on Maui, and is the only reserve in the Department of Land and Natural Resources (DLNR) system that includes a marine section as well as a land section. It is one of only two areas on Maui where fishing is restricted.

Within the reserve are the only three miles (4.8 kilometers) out of 120 total miles (193 kilometers) of Maui coastline that are totally protected, where no type of fishing, collecting of any marine life, or motorized vessel is allowed.

‘Āhihi-Kīna‘u Natural Area Reserve is an example of what is often called a “marine protected area” or MPA. MPAs are parts of the ocean that have legal restrictions on fishing, collecting, and other human activities that directly affect populations of fish and other marine life. There are many ways to manage marine protected areas. Some are closed to fishing or collecting altogether. Others have restrictions about the kind of gear that can be used. Still others limit fishing to certain species.

The basic ideas behind MPAs are that:

- MPAs may provide a refuge for fish, a protected area where they can exist in natural abundance without direct pressure from humans collecting or fishing for them.
- MPAs may provide a “source” area for fish and other marine life. Population levels may be higher inside MPAs than outside them. MPA supporters believe that populations in fishing grounds and other areas outside the MPAs will grow as larvae and fish “spill over” from the MPA.
- MPAs provide places to study recovery from prior fishing and/or collecting pressure.
- MPAs, like wilderness areas, may provide places to study intact natural communities, relatively undisturbed by human activities.

How Well Protected is ‘Āhihi-Kīna‘u?

The reserve is designed to be a marine protected area. The following activities are prohibited by law in the reserve:

a) To remove, injure, or kill any form of plant or animal,
b) To introduce any form of plant or animal life, or
c) To operate, anchor, or moor any motorized vessel.

However, reality is different than the law envisions. Although fishing and motorized vessels are prohibited in the reserve, illegal fishing still happens. The area is flanked on one side by La Pérouse Bay, where fishing is allowed, but the reserve is a prime spot for poachers anyway, many of whom enter the reserve in motorized vessels.

So, for researchers and natural resource managers, it is difficult to know just how well ‘Āhihi-Kīna‘u is working as a marine protected area. It is a challenge to interpret the results of monitoring and observations such as the following:

Image: Maui Recreation Map, *State of Hawai'i*

1) According to 1998 surveys, populations of some reef fish in the reserve have declined in variety and abundance, in comparison to surveys done in 1972, many years before the reserve was formed, and

2) '*Opihi* (limpets) are scarce along much of the coastline.

It is difficult to trace the causes of problems such as these because, although 'Āhihi-Kīna'u is supposed to be a protected area, people and illegal activities could be contributing. And that kind of illegal activity is not easy to monitor, especially along the reserve's rugged and remote lava coastline.

What's Really Going On Here?

Imagine that you are a scientist—perhaps Leon Hallacher or Brian Tissot—and the Department of Land and Natural Resources has asked you to help them monitor populations of fish in the reserve and determine the cause of the decrease in abundance of many fish species between a 1972 fish survey and one performed in 1998.

Some scientists believe that the decline in fish abundance and variety in the reserve is linked to the destruction of much of the finger coral habitat in powerful storms such as Hurricane 'Iniki (1992) and Iwa (1982). Others believe that illegal fishing has played an important role in decreasing fish abundance in the area.

Your job is to design a study to provide more information about:

1) Why the changes in abundance of many fish species has happened, and
2) Whether fish diversity and abundance seem to be recovering or declining since 1998.

As background, read the article from the DLNR-Division of Aquatic Resources newsletter, *Current Line* (April 1999) that follows. Then design a study that will provide information about the two goals listed above. As you design your study, don't forget you have access to a pool of willing and able university students who would love the chance to be part of this project. As in the Tissot and Hallacher study, they can help you collect data in the field.

Assignment

Write a study proposal including these seven elements:

1) Title

2) Name of investigator(s)

3) Brief project background

4) Purpose and objectives

Questions to ask yourself:

- Why are you doing this study?
- What do you plan to accomplish?

5) Hypothesis (or hypotheses)

- What results do you anticipate?
- What do you think caused changes in fish abundance?

6) Approach and methods

Questions to ask yourself:

- What is your basic experimental design?
- What kinds of areas do you want to study? (The Tissot/Hallacher study, for example, looked at "impact" areas and "control" areas, and defined what was meant by those terms and why they were included in the study.)
- How long should the study be?
- What is the geographic scope of the study?
- Will you look at particular species of fish or other marine life? Will you look at adults, juveniles, and/or larvae? Why?
- What assumptions are made in your research design? Do you need to add or do anything differently to gather evidence about the validity of these assumptions?

7) Dissemination of findings

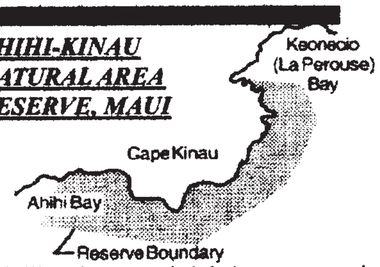
Questions to ask yourself:

- Who should receive the information generated by this study? Why?
- In what form should this information be disseminated?

From Hawai'i Division of Aquatic Resources, "Current Line" newsletter, April 1999.

INSHORE PROJECTS

AHIHI-KINAU NATURAL AREA RESERVE, MAUI



Ahihi-Kinau shore waters include the waters seaward of Cape Kinau a distance of 2000 to 3000 feet as shown above

The Ahihi-Kinau Natural Area Reserve (NAR), set on the last historic lava flow on Maui, was established in 1973. Ahihi-Kinau contains five natural communites including anchialine pools with a high diversity of rare Hawaiian shrimps (i.e. 'Ōpae'ula), a unique coastal lava tube community that provides habitat for native Hawaiian cave animals, and 900 acres of nearshore waters off Cape Kinau. NARs are different from Marine Life Conservation Districts (MLCDs) in that these areas are prime examples of relatively unmodified/unaltered native ecosystems which are set aside to protect "the best of what's left" of Hawaii's unique native environments. Therefore, fishing or taking of marine life is NOT ALLOWED.

Surveys done in 1972 by the Division of Fish and Game (now known as Division of Aquatic Resources) staff revealed dense growths of finger corals (Porites compressa) at 4 out of 6 survey sites along with a good diversity of fish species. In 1998 (26 years later), these same areas were again surveyed with some notable results. Fish populations in the remonitored areas appear to have decreased from 1364 fish per acre in 1972 to 962 fish per acre in 1998. The following tables give some examples on the differences between the numbers of specific fish seen in 1972 and 1998 at Ahihi-Kinau:

Fish that have increased or barely changed (<5%) in numbers per acre

Fish	*1972 Survey Numbers*	*1998 Survey Numbers*	*Diet*
C. strigosus (kole)	185	177	algae
C. vanderbilti (black-fin damsel)	72	98	zooplankton, copepods
A. nigofuscus (lavendar tang)	18	180	filamentous algae
P. multifasciatus (moana)	29	60	small crabs, fish, shrimp

Fish that have decreased (6% to 900%)) in numbers per acre

Fish	*1972 Survey Numbers*	*1998 Survey Numbers*	*Diet*
C. ovalis (blue damsel)	100	6	wide variety (shrimps, crustacean larvae, worms, fish eggs, etc.)
M. flavolineatus (white weke)	92	10	wide variety
A. abdominalis (mamo)	91	22	algae, zooplankton, crustaceans
D. albisella (aloiloi)	67	10	wide variety
M. vanicolensis (red weke)	67	22	echinoderms, worms, crustaceans
C. hanui (chocolate dip damsel)	64	24	"
T. duperrey (saddleback wrasse)	64	48	echinoderms, worms, crustaceans
Z. flavescens (yellow tang)	57	38	algae

As you can see, most of the fish appear to have decreased in numbers from 1972. DAR staff conducting the re-monitor surveys in 1998 did not observe the dense growths of finger corals as it was noted on 4 out of the 6 original survey sites in 1972. Instead of lush coral beds, the habitat in these areas now consist mostly of coral rubble. Since finger corals are very fragile, it is speculated that powerful storms like Hurricane Iniki (1992) and Hurricane Iwa (1982) caused the destruction of these vast coral beds within the last 26 years. The apparent loss of this finger coral habitat may explain the observed changes in fish populations.

Since the habitat now consists of coral rubble, this provides a lot of surface area for fine algal growth and other organic matter, which is an excellent food source for fishes such as the kole and lavendar tang. As a result, you can see from the previous tables that the numbers for these fish have either increased or remained relatively stable. This kind of coral rubble habitat may not have a wide variety of the larger invertebrates, but animals such as small shrimp, crabs, copepods, and other zooplankton can thrive providing a food source for fish like the black-fin damsel and moana, whose numbers have also increased. Most of the other fish whose numbers have decreased require a wider variety in diet than what can be found in coral rubble habitat. These fish probably moved into areas that are able to provide the right kind of diet for them, such as areas with richer coral growth. In addition to food, the more branching type corals provide shelter for juvenile fishes such as the yellow tang and aloiloi.

The mystery of Mother Nature is in Her continuing evolutionary ways, finding balance for all of Earth's natural resources. We can only monitor and observe these forever changing situations, as in the case of Ahihi-Kinau NAR. However, all is not lost in Ahihi-Kinau as wherever Mother Nature takes away, She always provides for someplace else. Additional surveys in 1998 along the shoreline of Ahihi-Kinau NAR revealed fish populations in quantities and diversity similar to many of the State's Marine Life Conservation Districts (MLCDs):

Comparison of Fish Counts in Ahihi-Kinau (inshore) to Other MLCDs in Terms of Numbers per Acre and Species Diversity

MLCD Location	*Date of Survey*	*Number of Fish per Acre*	*Number of Species Seen*
Honolua Bay, Maui	10/97	3764	76
Hanauma Bay, Oahu	5/97	3257	67
Ahihi-Kinau (inshore), Maui	**2/98**	**2839**	**83**
Manele-Hulo-poe, Lanai	10/97	2686	86
Molokini Shoals, Maui	10/97	2034	92

Top Ten Most Abundant Species Observed Along Shoreline Surveys of the Ahihi-Kinau NAR in 1998

Rank	*Fish Species*	*Number of Fish Per Acre*
1	C. strigosus (kole)	684
2	A. nigrofuscus (lavendar tang)	478
3	Z. flavescens (yellow tang)	282
4	C. vanderbilti (blackfin dam-sel)	194
5	A. achilles (achilles tang)	185
6	M. niger (humu ele ele)	121
7	T. duperrey (saddle-back wrasse)	41
8	Family Scari-dae (Uhu)	34
9	N. lituratus (clown tang)	30
10	A. sordidus (kupipi)	25

Although the resources are not what they were once described in the remonitored areas in Ahihi-Kinau, the shoreline fishery resources appear to have "weathered the storm". This is excellent news which means that areas like Ahihi-Kinau NAR can serve to provide the fishery stocks needed to spawn and restock other nearby areas.

Since fishing is not allowed within the boundaries of the Ahihi-Kinau NAR, you can clearly see that overfishing is not always the only factor that can contribute to declines in fish populations. Changes in habitat, such as those caused by natural disasters like hurricanes or man-made influences such as non-point source pollution and urban runoff, can also change the habitat causing fish populations to fluctuate. In the case of natural disasters, Mother Nature can always take care of Herself. The rest of us have to do our part to conserve and take care of our ocean resources by taking only what we need and limiting what we put into our ocean environment. You never know what may cause a fish or any other marine animal species to decline or increase.

Activity #4

Marine-Management Research Projects

Materials & Setup

- Student Page “Marine Management Research Projects—Suggested Topics” (pp. 54-56)

Instructions

1) Have students select a research topic related to marine management issues on Maui or around the state of Hawai‘i. They may use ideas from the Student Page “Marine Management Research Projects—Suggested Topics” or come up with their own.

2) Students should use a variety of sources to research their topics and develop a report using the media of their choosing.

Assessment Tools

- Student research reports

Marine-Management Research Projects -- Suggested Topics

There are many interesting research topics having to do with how people manage the marine environment and the species that live there. This background sheet suggests a handful of topics for which information is readily available.

Possible Research Topics

1) Marine Protected Areas

Protected areas are parts of the marine environment that have limits placed on how people can use them. In some marine protected areas (or refuges), fishing is not allowed at all. In others, fishing is limited to certain types of gear or certain species. Protected areas are designed to give marine plants and animals a break from human pressure. Research topics include the following:

- How and why are marine protected areas used in Hawai‘i? Where they have been used, have they been effective? Why or why not?

- How and why are marine protected areas used elsewhere in the world? Have they been effective? Why or why not?

- What do experts say about how to make marine protected areas effective?

- Under the traditional Hawaiian system governing fishing in the waters around the islands, certain areas were declared *kapu*, or forbidden, for periods of time to allow populations of marine life to recover from fishing pressure. These *kapu* areas were essentially marine protected areas. Research the traditional Hawaiian management system, as well as other islands where similar traditional systems are still used to manage coral reefs.

- What is the current status of Molokini Island and its surrounding waters? Is it a protected area of any variety? What regulations are in place to protect the surrounding coral reefs from damage by recreational boaters, snorkelers, and divers? What is being done to protect the coral reefs around Molokini?

2) Aquaculture

From the time of the ancient Hawaiians, people have been growing fish and other marine life for food. Along the coastlines of the islands, you can see the remnants of Hawaiian fishponds, some of which have been restored.Today, aquaculture operations raise fish for food and to restock fish into parts of the ocean that have been overfished. There is even experimentation with raising fish for the aquarium trade in aquaculture operations. Research topics include the following:

- How were fishponds constructed, used, and managed in early Hawaiian times? Which species were grown in these ponds? Which parts of Hawaiian society were fed by the marine life from these ponds? What is being done to restore fishponds on Maui or elsewhere in the Hawaiian Islands? Are there traditional fishponds in use today?

- What are some current examples of aquaculture on the Hawaiian Islands? Describe them as well as similarities and differences between modern aquaculture and how it was practiced by early Hawaiians.

- What are some of the potential benefits and problems associated with aquaculture? For example, what are the possible effects on water quality, wild fish populations, or human food supply?

3) Managing Marine Fishing

People use the abundant marine life here for many purposes. Some people fish for their own food, some fish commercially, and others make a living on sport-fishing charter boats. Making sure that there are enough fish and different kinds of fish to satisfy all of these uses is one job of government fishery managers. Research topics include the following:

- Which are the main species fished for commercially or for food or sport? Describe the species, their habitats, and how they are fished for. What is the status of populations of these fish in the waters around the Hawaiian Islands?

- Which kinds of food and sport fish were introduced on purpose? Why? What effect has their introduction had on native marine plants and animals?

- What is being done in Hawai‘i to increase populations of fish that are valuable for food or sport fishing? Which methods seem most effective? Least effective? Why? Research and explain other approaches you think might work well.

- What rights do native Hawaiian people have to fish and collect marine life for subsistence purposes? Describe some of the issues and concerns related to this topic, perhaps focusing on subsistence fishing that is allowed at ‘Āhihi-Kīna‘u Natural Area Reserve.

4) Protecting Threatened or Endangered Marine Species

Many marine species are protected by laws and regulations. Some of these rules are designed to protect species that are in danger of extinction. Others are designed to keep species from becoming endangered or threatened with extinction. Conservation efforts help protect many species, regardless of whether they are in danger of extinction. Research topics include the following:

- Pick a species or a type of plant or animal that you are interested in. What is the status of that species and what, if anything, is being done to protect it? (In general, there is more information available on species that are on the federal endangered species list than for species that are not endangered. Endangered Hawaiian marine species include hawksbill and green sea turtles, humpback whales, and Hawaiian monk seals.)

- What habitat conservation efforts are helping to protect endangered species and other species in the oceans around Maui and the other Hawaiian Islands? Research what is happening at the Hawaiian Islands Humpback Whale National Marine Sanctuary or the work of coral reef protection groups on Maui.

- What major laws and treaties are in place to protect endangered species? Research the Endangered Species Act, the Marine Mammal Protection Act, or the Convention on International Trade in Endangered Species of Wild Fauna and Flora. How do these laws help protect marine species found in Hawai‘i?

- What is the current status of U.S. Navy proposals to test and employ Low Frequency Active Sonar in waters around the Hawaiian Islands? What arguments are (or were) made for and against this proposal?