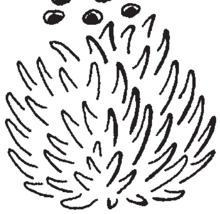



Marine Unit 1

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 *'Aina Ko'olau*)
- Ten to twenty knots
- Produced by air circulating clockwise around an area of high pressure centered northeast of Hawai'i
- 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 Hawai'i 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 *ʻAina 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 Hawaiʻi*, 3rd ed., University of Hawaiʻi Press, 1998, pp. 82-86.

Teacher Version

From Nuku Hiva to Hawaiʻi: Charting a Course

Task #1: Check the Weather

Safest month or months for *Hōkūleʻa* 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

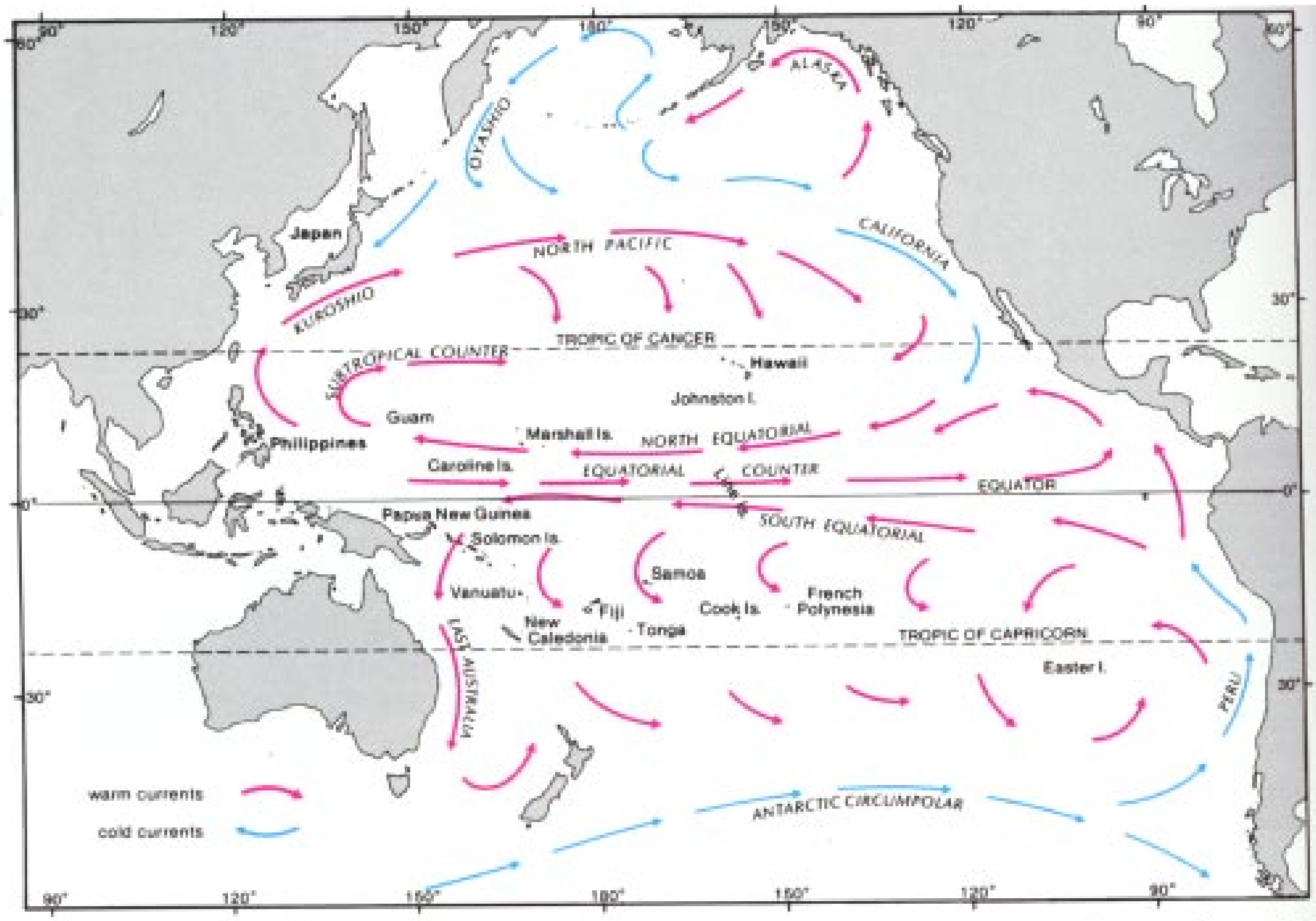
Total distance to be traveled: 405.3 miles

Total number of days for this segment: 3.1 days

Heading: W

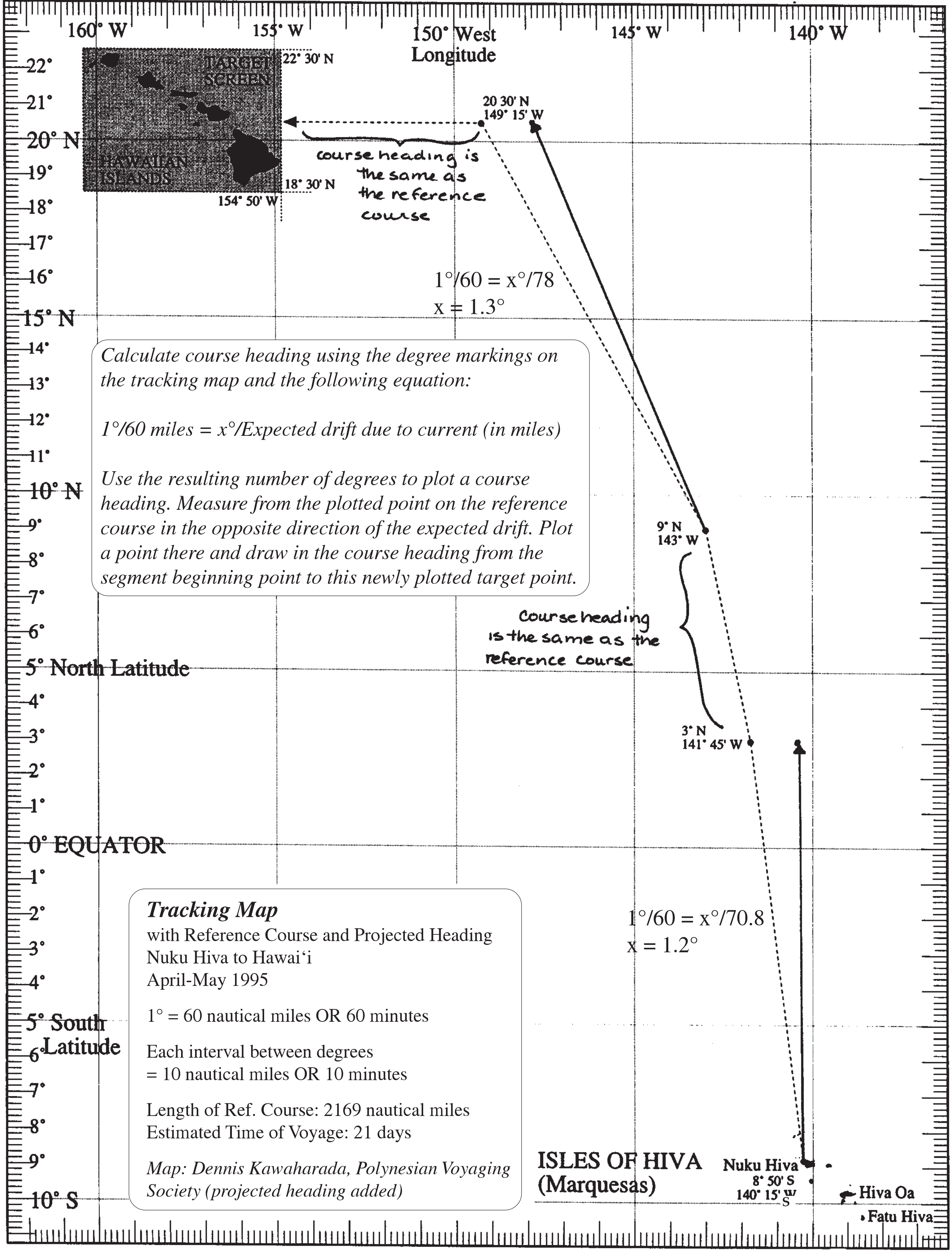
Determine the actual heading with current factored in and draw it on the reference course map. See “Reference Course and Course Heading Map” (p. 13) acetate for answer.

Map of Pacific Ocean Currents

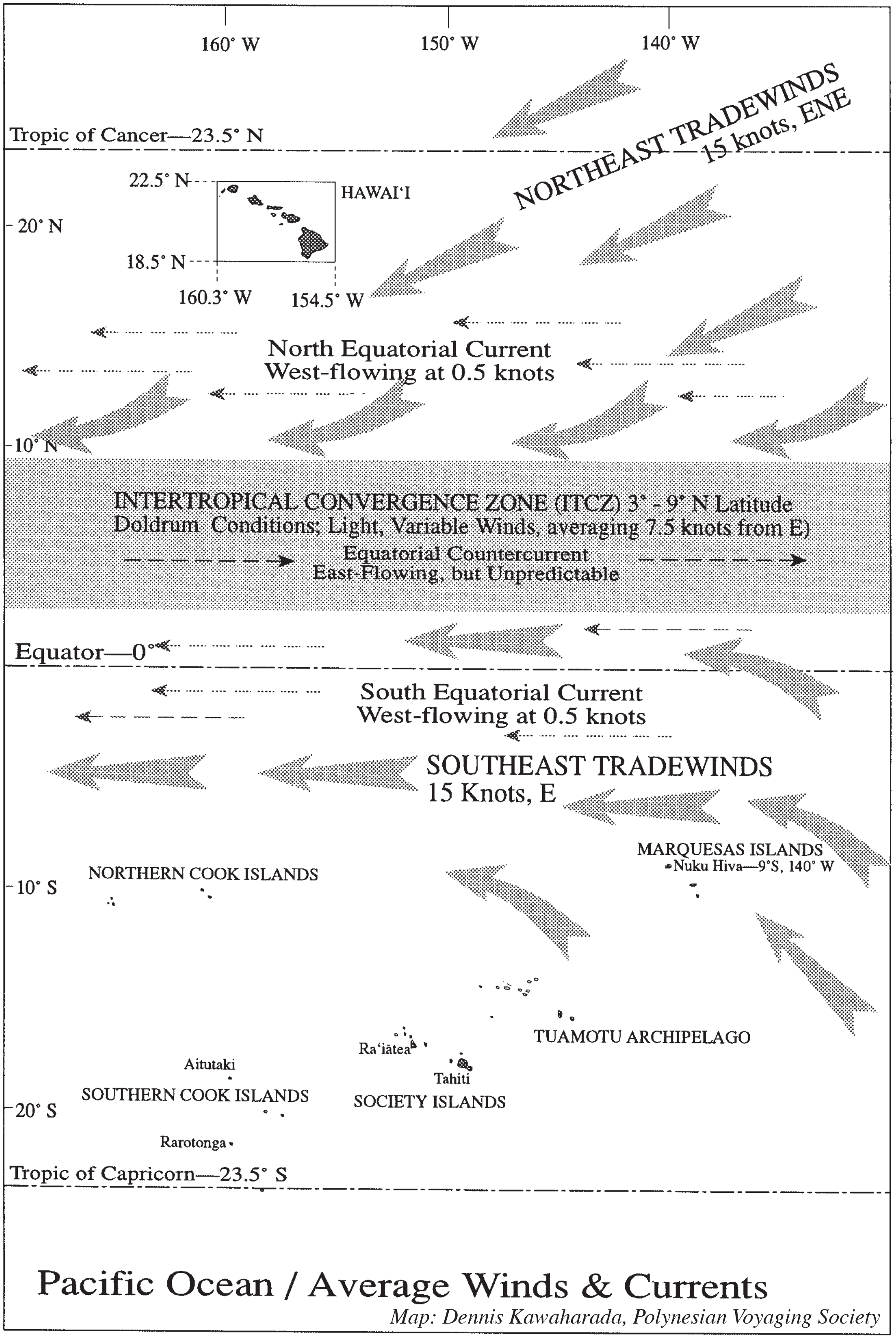


Map: Ann Fielding and Ed Robinson, An Underwater Guide to Hawai'i, *University of Hawai'i Press, Honolulu, 1987.*

Reference Course and Course Heading Map



Map of Currents Between Nuku Hiva and Hawai'i



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.

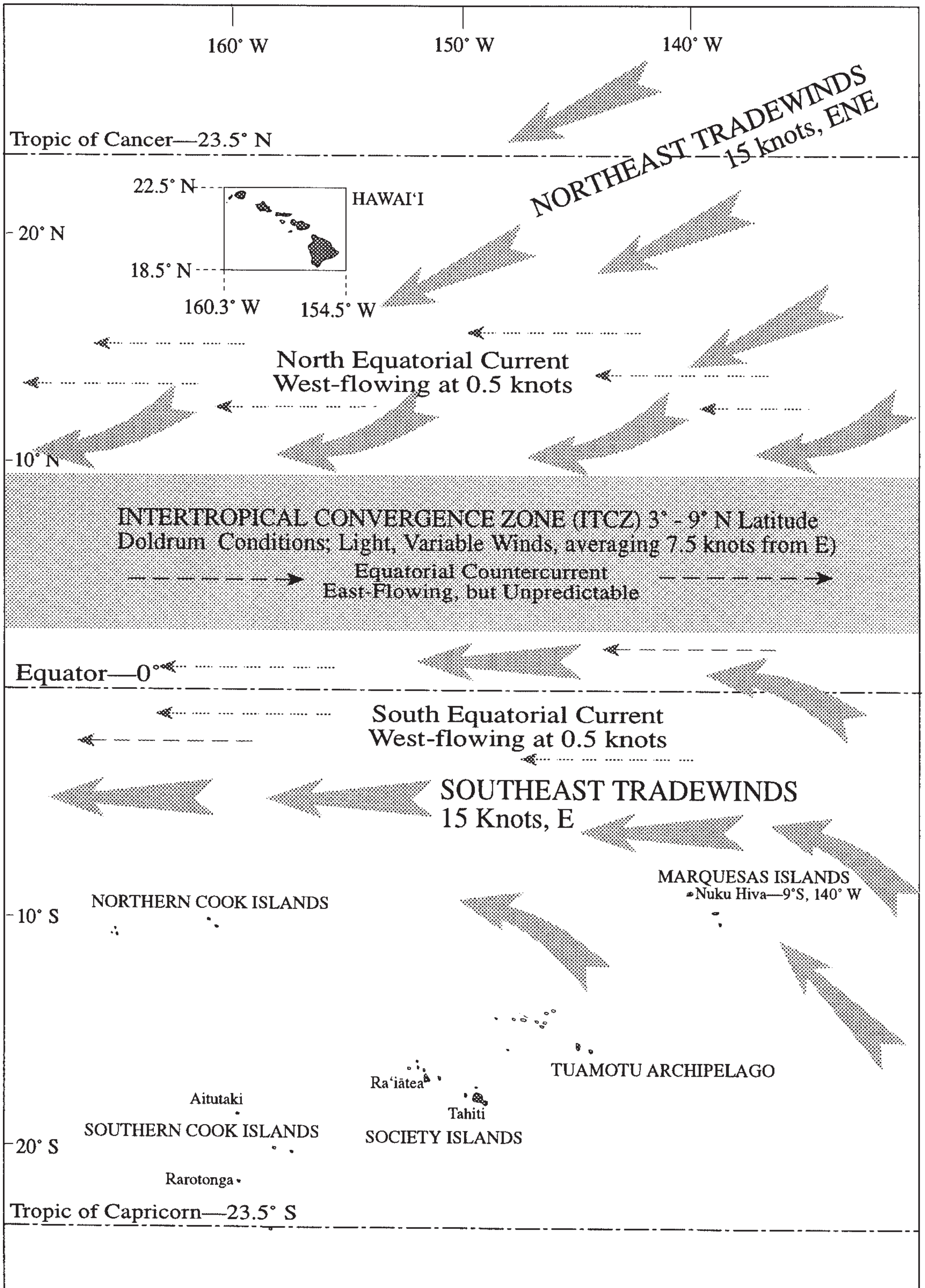
In this zone equatorial countercurrent flows eastward, between the two west-flowing equatorial currents. This countercurrent is formed as the water pushed west by the trade winds flows back east parallel to the equator. Like other conditions in this zone, the countercurrent is sporadic and shifting.

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

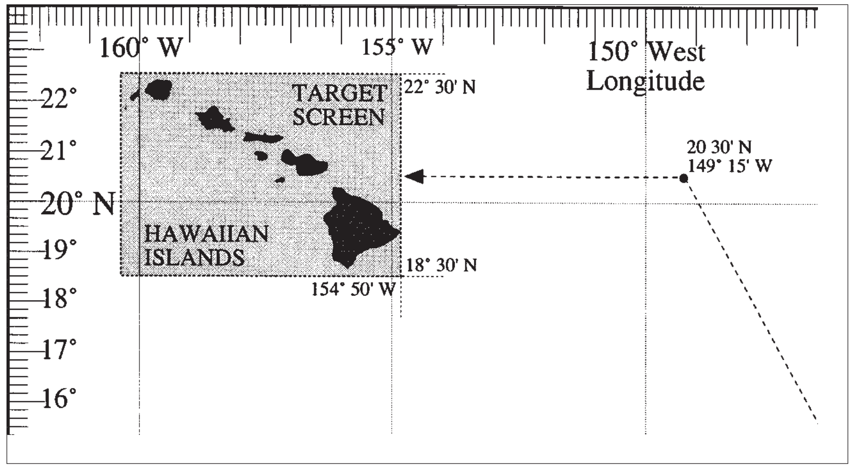
As you navigate through these major current and wind zones, you aim *Hōkūle'a* to the windward side of the Hawaiian Islands. That way, you



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

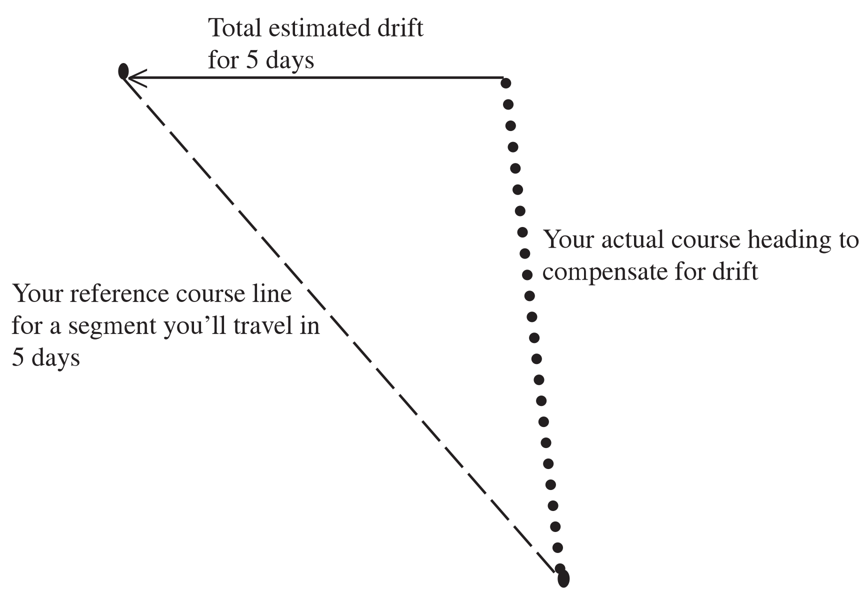
- The sailing plan is broken up into segments corresponding to each of the different wind and current zones you'll cross during the voyage:

  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:

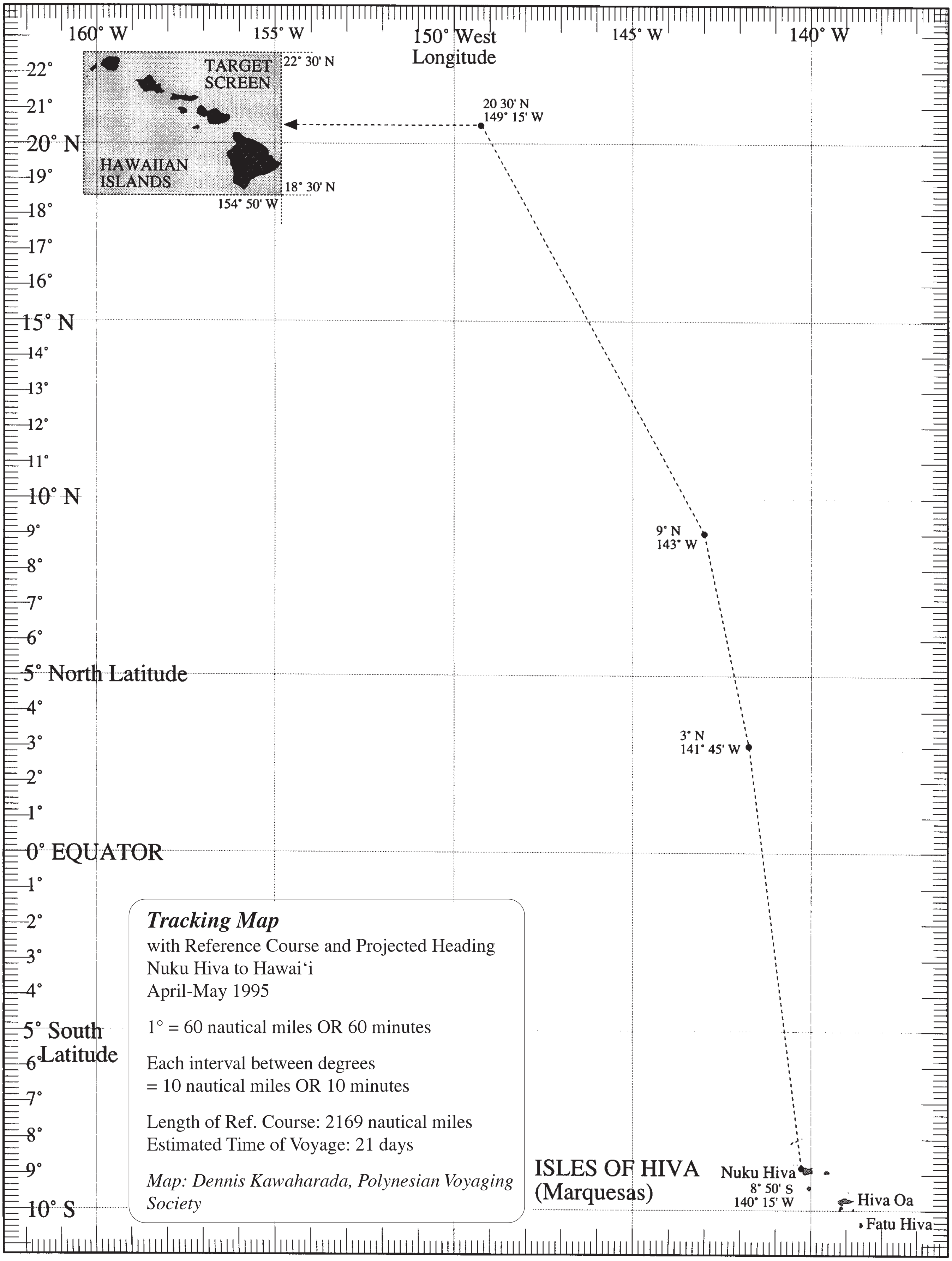
Expected actual performance of the canoe (add speed based on wind and current together):

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).


160° W
155° W
150° West Longitude
145° W
140° W
TARGET SCREEN
22° 30' N
HAWAIIAN ISLANDS
18° 30' N
154° 50' W
20 30' N
149° 15' W
9° N
143° W
3° N
141° 45' W
22°
21°
20° N
19°
18°
17°
16°
15° N
14°
13°
12°
11°
10° N
9°
8°
7°
6°
5° North Latitude
4°
3°
2°
1°
0° EQUATOR
1°
2°
3°
4°
5° South Latitude
6°
7°
8°
9°
10° S
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
ISLES OF HIVA (Marquesas)
Nuku Hiva
8° 50' S
140° 15' W
Hiva Oa
Fatu Hiva

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 Hawai‘i, 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 Hawai‘i, *University of Hawai‘i 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

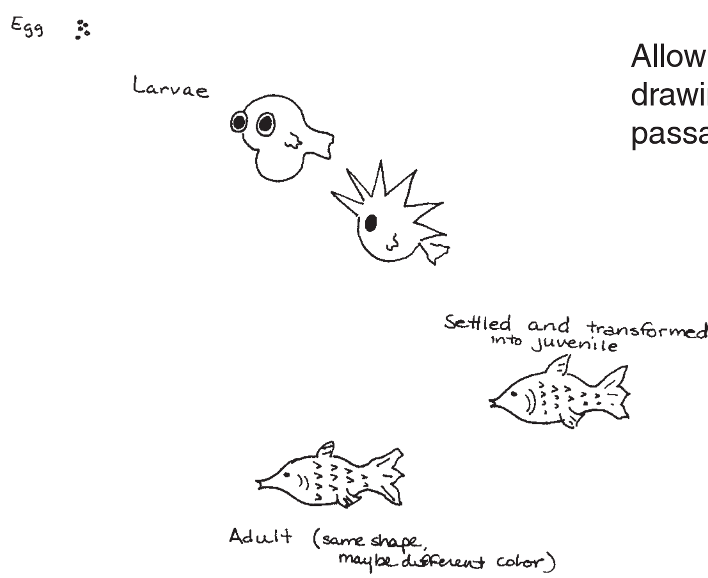
Marine Life on the Move

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.

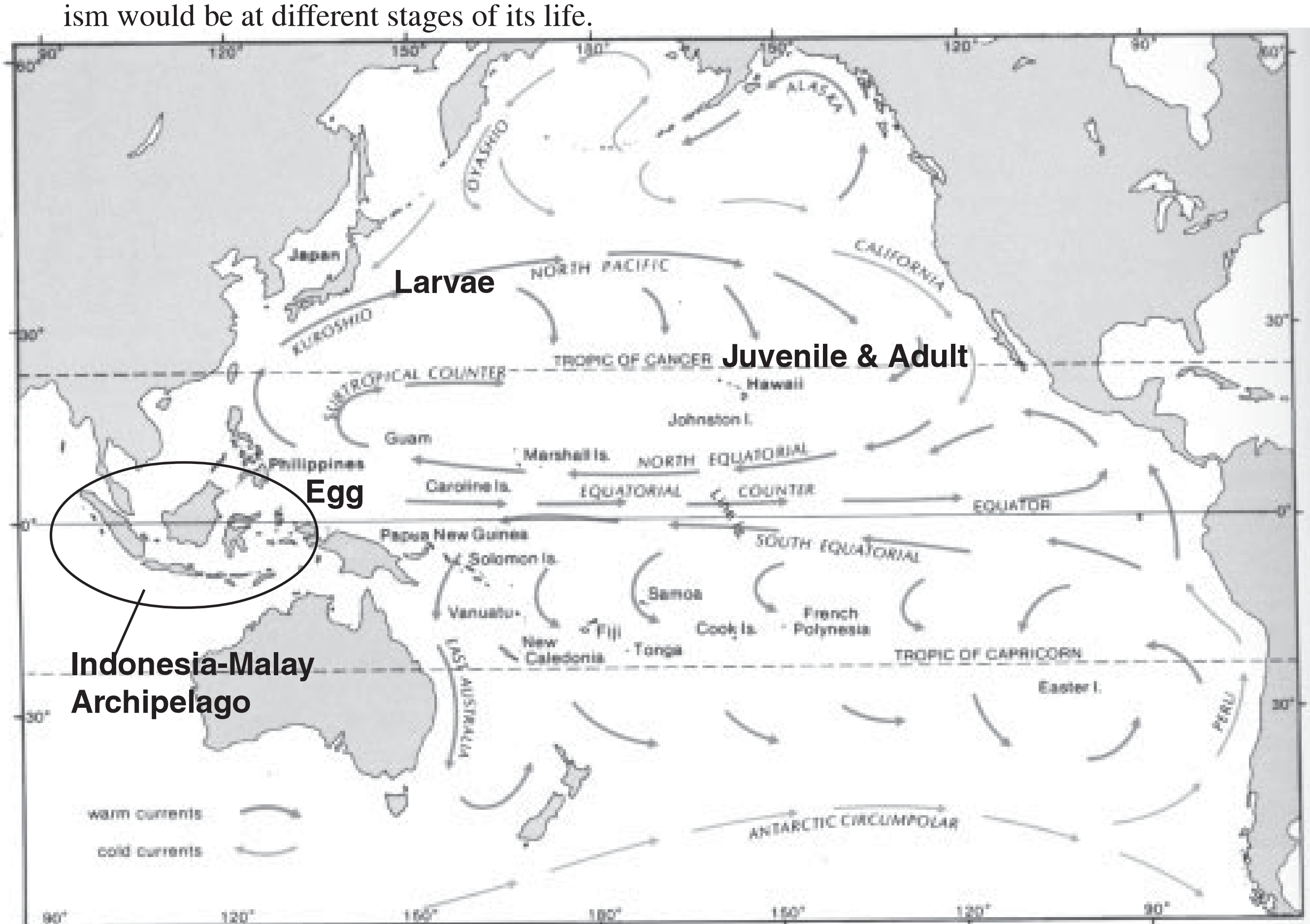
— Robert F. Myers, *Micronesian Reef Fishes: A Guide for Divers and Aquarists* 3rd ed., Sea Challengers, 1999, pp. 19-20.

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 Hawaiʻi. 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 Hawaiʻi, *University of Hawaiʻi 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 Hawaiʻi are found only in Hawaiʻi 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.

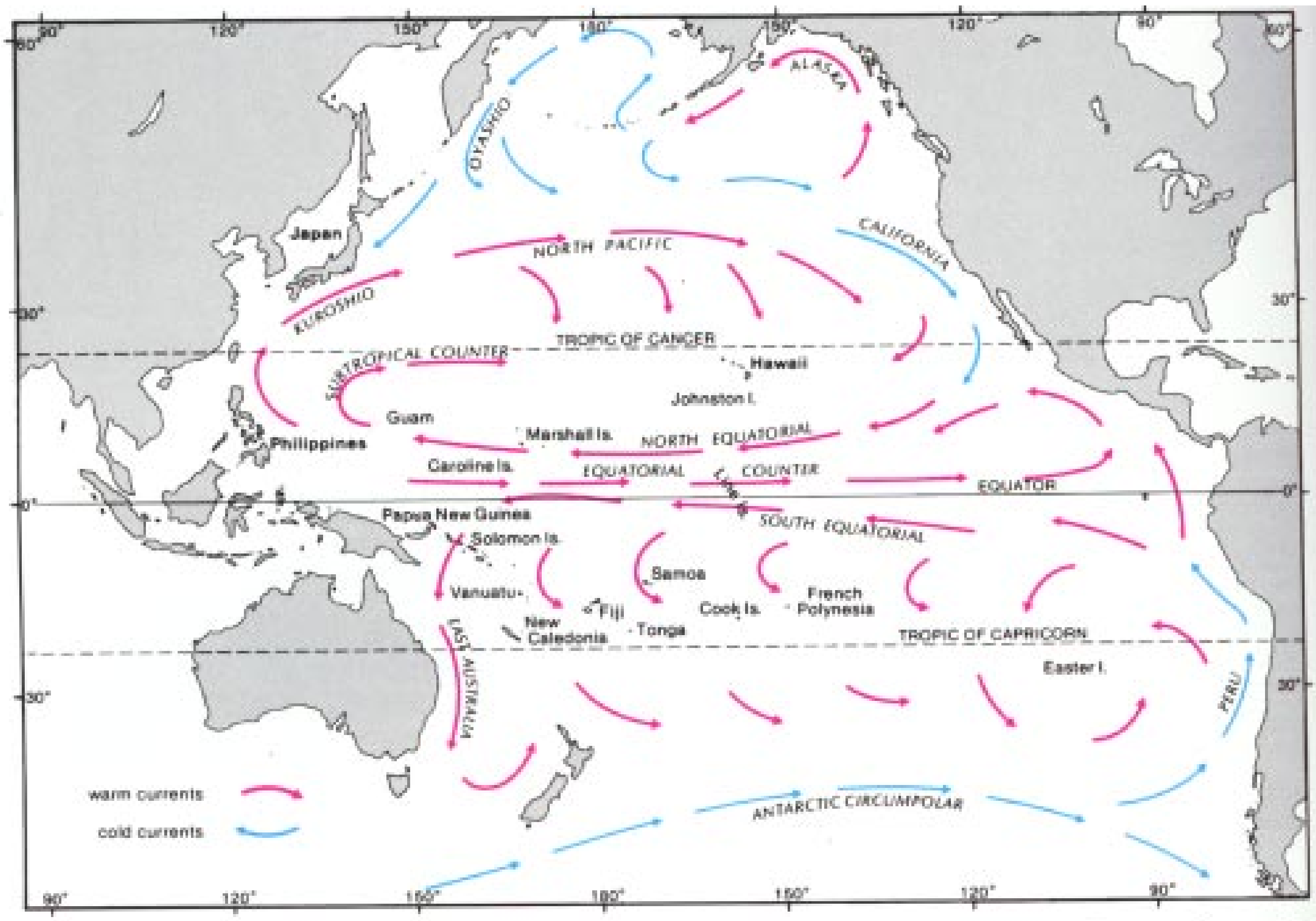
6) Name three factors that influence whether a coral species from Indonesia would be able to successfully colonize Hawaiian waters.

   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.

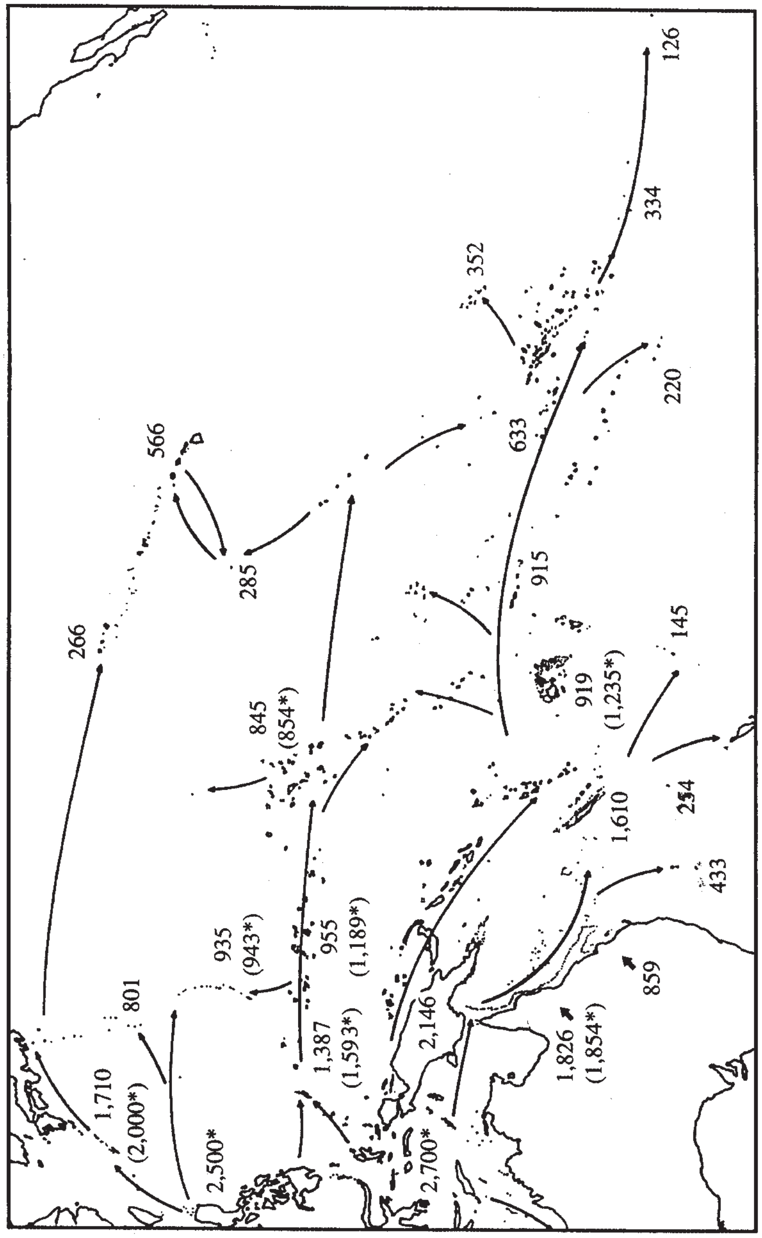
   Polynesian voyagers navigate in canoes that use sails and winds as well as ocean currents to power their travels. Unlike planktonic marine organisms, the voyagers navigate, guiding their own travels along a particular course.

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

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#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

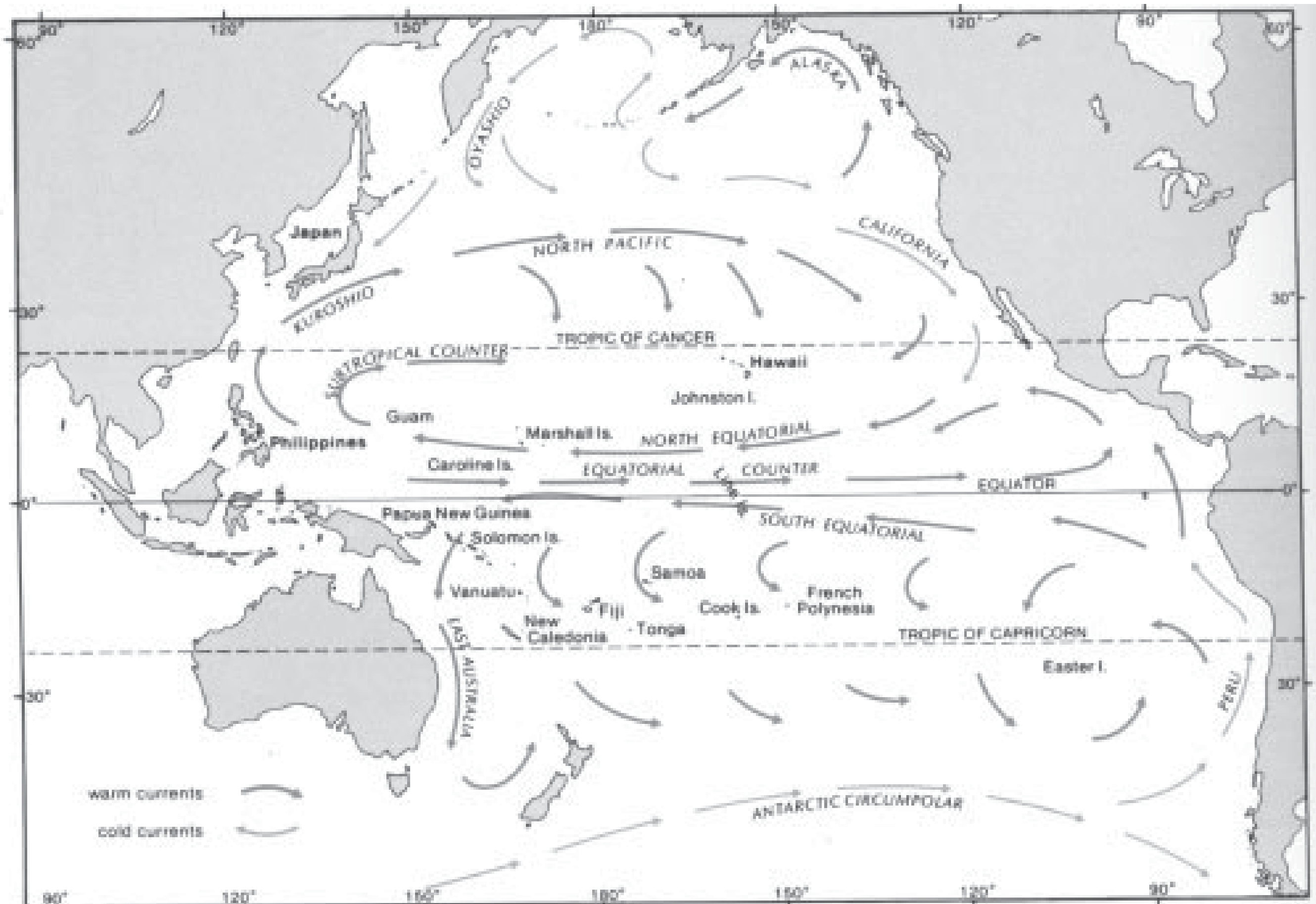
Reproduction among reef fishes is highly varied and often quite complex. The vast majority of fishes lay eggs. The birth of fully developed young is extremely rare among bony fishes and common only among cartilagenous fishes [fishes such as sharks and rays whose skeletons are largely composed of cartilage 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
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4) Do ocean currents favor the dispersal of marine life from the South Pacific to Hawai‘i? 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 Hawai‘i?

   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 Hawai‘i.