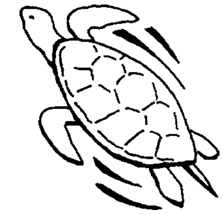


Activity #1

Anchialine Pond Detective Story

● ● ● Class Period One *Anchialine Pond Detective Story*

Materials & Setup

- "The Anchialine Pond Detective Story" acetates (master, pp. 11-19)
- Overhead projector and screen

For each student or group of three to four students

- Student Page "The Anchialine Pond Detective Worksheet" (pp. 20-25)

For each student

- Student Page "Hypothetically Speaking" (pp. 26-28)

Instructions

1) Divide the class into groups of three to four students, or have students work individually. Hand out the Student Page "The Anchialine Pond Detective Worksheet."

2) There are eight acetates.
   - Acetate #1 introduces anchialine ponds and the activity.
   - Acetates #2-6 each pose a mystery for students to resolve to by developing hypotheses. Most include the question, a photo, and a series of observations.
   - Acetate #7 is an "Information Interlude" that provides students with background for the next "mystery" acetate.
   - Acetate #8 is another "mystery" acetate that includes a question, a photo, and a series of observations.

   Use the acetates as a "script" for this activity. Go through the acetates, one by one, giving student groups time to come up with a hypothesis for each question and write it on their worksheets. You may incorporate class discussion into this activity by asking students to discuss their ideas openly with each other before recording their hypotheses. Before moving on to the next acetate, review the correct answer using the responses and additional information provided in the teacher background for "The Anchialine Pond Detective Story" (pp. 7-10).

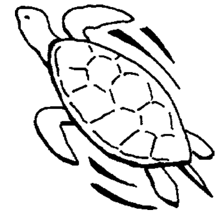
3) Hand out the Student Page "Hypothetically Speaking" as homework.

Journal Ideas

- Do you think it's important to protect the anchialine pools on Maui? Why or why not?
- Write a short story about the adventures of a traveling shrimp.

Assessment Tools

- Participation in group work
- Student Page "The Anchialine Pond Detective Worksheet"
- Student Page "Hypothetically Speaking"
- Journal entries



Teacher Background

The Anchialine Pond Detective Story

Background on Anchialine Ponds

The southwest coastline of Maui, dominated by rough *ʻaʻā* flows, is dotted here and there by anchialine ponds. These ponds are found between Cape Kīnau and Cape Hanamanioa. Anchialine ponds exist elsewhere on the Hawaiian Islands, as well.

Anchialine ponds are pools containing brackish or salt water but that have no surface connection with the ocean. Water levels in these ponds fluctuate with the tides, offering evidence that the pools maintain subsurface connections with the ocean through tiny openings in the porous lava substrate. In some anchialine ponds, the water is almost fresh, which indicates the mixing of ocean water with fresh ground water.

Ocean water enters the pools through underground fissures in the lava rock. The fresh water comes from direct rainwater and from groundwater that filters down from mountain slopes underground. This fresh water can be reached by digging wells along the shoreline, and it also seeps into lava tubes at sea level, the ponds, and into the ocean.

Fresh ground water forms a cold freshwater lens floating on top of the warmer ocean water because fresh water is less dense than salt water. Normally one might expect the warm water to be closer to the surface, but the difference in density makes the temperature reversal happen. In deeper ponds, this layering tends to stay in place. In shallow ponds under windy conditions, the layers get disturbed.

Common plants in anchialine ponds include marine algae (seaweeds), cyanobacteria (blue-green algae), and native widgeon grass (*Ruppia maritima*). Along pond edges, non-native pickleweed (*Batis maritima*), *makaloa* (*Cyperus laevigetus*), and *ʻākulikuli* (*Sesuvium portulacastram*) are sometimes found. Close to the ocean, anchialine pond fauna includes damselflies, eels, crustaceans, mollusks, worms, the Hawaiian flagtail or *āholehole*, mullets, and gobies. In ponds that are further inland, fish and marine algae are not typically found. In these ponds, the fauna is dominated by shrimp, most commonly *Metabetaeus lohena* and the endemic *ʻōpae ʻula* (*Halocaridina rubra*).

The hypogeal (which means associated with or living below the surface of the earth) shrimp species found in Maui anchialine ponds have been identified in similar habitats on a relatively small number of islands spread around the world, from Hawaiʻi to the western Indian Ocean. Trying to account for this "disjunct distribution pattern" has occupied scientists since the early 1960s. In 1983, Hawaiian marine scientist John A. Maciolek proposed a new hypothesis that students will consider during this activity.

Solving the Mysteries

Use the following notes to help students "solve" the anchialine pond mysteries presented on the "The Anchialine Pond Detective Story" acetates.

Mystery #1: The water in the ponds is both fresh water and salt water. Where does this water come from?

There are fissures in the rock that allow ocean water to enter the pools from underground. The freshwater component is both rainwater and groundwater. Groundwater comes from rain that falls on the mountain slopes, then seeps underground and slowly flows down Haleakalā. This fresh water can be reached by digging wells along the shoreline, and it also seeps into lava tubes at sea level, the ponds, and into the ocean.

In the anchialine ponds, it forms a cold freshwater lens floating on top of the warmer ocean water because fresh water is less dense than salt water. Normally one might expect the warm water to be closer to the surface, but the difference in density makes the temperature reversal happen.

Mystery #2: What makes the water turn red each spring at Wai‘ānapanapa?

‘Ōpae ‘ula—the red shrimp—gather in the spring, turning the rocks and pool red. According to Hawaiian tradition, this is a sign of forgiveness or the casting out of an evil spirit.

Mystery #3: You often see small, red shrimp in the ponds. If all the water goes out of the ponds at low tide, the shrimp disappear. Where do they go?

The shrimp live in the underground water, in cracks and fissures in the rock.

Mystery #4: The same species of shrimp that live in the Maui ponds also live in similar ponds on the Kona coast of Hawai‘i and holes in the ancient (and dry) coral reef that is now the ‘Ewa plain of O‘ahu. How did the shrimp travel between the islands?

Ocean currents transporting planktonic larval stages of shrimp probably account for the dispersal.

Mystery #5: The larvae reach the shorelines of the other islands. How do they get into the ponds?

Shrimp may find the ponds by following the trail of the fresh water that seeps into the ocean through cracks. (However, this has not been established, so other well-reasoned answers could be correct.)

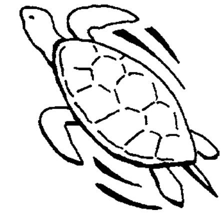
Information Interlude

Have students turn to pages 3-5 of the student page (pp. 21-23) that contains the map of worldwide dispersal of shrimp species, and the distribution table. Discuss these maps, highlighting the fact that certain of these shrimp species are found in widely separated geographic areas.

Mystery #6: Theories about isolation and speciation hold that shrimp species that live thousands of miles apart should have evolved into separate species. What can explain the fact that populations of the same shrimp species are found thousands of miles apart?

There is no answer to this question that has been proven correct. Encourage students to explain their hypotheses and their reasoning. As part of their homework (or for the remainder of the class) have students consider John Maciolek’s hypothesis to explain this phenomenon (on the first page of the Student Page “Hypothetically Speaking”).

The following section of this teacher background piece provides more information on John Maciolek’s hypothesis which may help you explain it better to students. The reading is technical and may be difficult to understand for some classes. You may use it to lead in to the homework assignment (Student Page “Hypothetically Speaking) or you choose to hold a brief in-class discussion following the homework assignment and use some of this information as background.



Explaining Disjunct Shrimp Populations

Excerpted from John A. Maciolek, "Distribution and Biology of Indo-Pacific Insular Hypogeal Shrimps," Bulletin of Marine Science*, 1983, Vol. 33, No. 3, pp. 606-618.*

Four hypotheses explaining disjunct distributions of hypogeal [shrimp] were discussed by Smith and Williams (1981). With reference to the "extremely disjunctive" distribution of *Antecaridina lauensis,* they rejected three of them: parallel evolution (i.e., from a common ubiquitous ancestor), transport by man, and persistence as relicts. They maintained that "Passive oceanic dispersal remains the only plausible explanation for the present distribution of *A. lauensis* . . . ." Dispersal as larvae or post larvae seems most likely, but adult migration is a possibility because of the known salinity tolerances and unusual longevity of the species.

Six other members of the insular hypogeal shrimp group treated here [see the Student Page "Anchialine Pond Detective Worksheet" for details] have such disrupt distributions. The most extreme hiatus is that between populations of *Calliasmata pholidota* in the central Pacific and the northern Red Sea. It is also plausible to explain many of these scattered populations as the result of passive oceanic dispersal. This concept is supported by the occurrences of populations of several species on nearby islands that are separated by deep water. For example, five species occur on the adjacent islands of Maui and Hawai'i. Although their populations are not disjunct in a relative sense, the separation indicates the shrimps' abilities to migrate across an interval (50 km) of deep (>2000 m) ocean that has never had a shallow or emergent bridge.

Passive oceanic dispersal does not itself explain extreme separation of populations, nor whether any observed disjunction represents more than a single migration resulting in successful colonization. The phenotypic uniformity of species in separated populations implies either a one-time migration, recently or with complete cessation of evolution, or at least occasional interchange from repetitive migrations. Genetic mixing, which seems more likely, would require yet undetected populations at closer distances. The continuing discovery of hypogeal shrimps in new locations reduces the degree of disjunction for some species. But there remain vast areas of ocean, having currents adverse to passive dispersal and without island "steps," which would ultimately defy complete elimination of apparent disjunction. The obvious question is, do these shrimps require island—emergent land—as a habitat feature? If not, a given species could be more [widespread] in the Indo-Pacific, and oceanic dispersal would apply more universally as an explanation of all insular hypogeal shrimp distributions.

Thus far, these hypogeal shrimps have been reported only from on or within emergent land, and much emphasis has been given to their occurrence in exposed pools. Data presented earlier indicated that the essential habitat requirement for the shrimps as a group is seawater in rock interstices, and not its surface exposure in pools. Emergent land offers one unique contribution in some situations—the dilution of seawater with fresh groundwater. That these shrimps do not require such mixohalinity [low salinity levels] is shown by five of the species (*Antecaridina lauensis, Caliasmata pholidota, Halocaridina rubra, Ligur uveae,* and *Periclimenes pholeter*) that are known to have sustaining populations in continually euhaline (30% salinity and higher) water. No factors are evident that would prohibit these shrimps from inhabiting submerged rock that had the necessary interstitial cavities. Such habitat would be very difficult . . . to sample.

Accordingly, I submit that most if not all of these hypogeal shrimps could have widespread and probably longstanding populations in submerged as well as emergent rock of the tropical Indo-Pacific.

The following evidence is offered in further support of this hypothesis: (1) The common appearance of these shrimps in modern artificial exposures of groundwater (wells, quarries, and a bomb crater), as well as in very recent lava fields, more likely has resulted from localized movement of existing subterranean populations than by new migration from a distant and unspecified locality. (2) Most reported habitat localities are low islands that were probably inundated by high sea levels during the Pleistocene. It is more reasonable to assume that many or most populations existed there during submergence than that they all represent recent (post-emergence) migrations—a situation that would also raise the question of the whereabouts of Pleistocene refugia. (3) More direct substantiation is in unpublished information recently communicated to me by Dr. A. H. Banner of the University of Hawaii, and by Dr. D. Devaney and Ms. A. Fielding of the Bishop Museum. Dr. Banner's information concerns the discovery of *Metabetaeus* in limestone rubble from the reef flat of Ambon Bay and from the outer reef face near Tulear, Madagascar [locations indicated by question marks on the map in the student page]. Ambon material consisted of a single specimen of *M. lohena*, which, although not signifying an established population, does suggest the occurrence of one in the reef structure. The Tulear material consisted of five specimens obtained by an airlift pump from a depth of about 7 m. Unfortunately, [no specimen could be identified] to species. If this is either of the two established species of the genus, the finding would create a distribution nearly as disjunct as that of *Calliasmata pholidota*.

Information from the Bishop Museum concerns collections and sightings of *Ligur uveae* by scuba divers at several littoral marine locations in the central Pacific. Specimens cataloged in the Museum were collected in 1979 from a cave about 100 m offshore and 8 m deep at Oahu Island, and in 1981 from similar submerged caves at Maui and Hawai‘i. *L. uveae* was seen by knowledgeable divers in the same type of habitat at Lanai, Kahoolawe, and Hawai‘i, and also Kwajalein and Enewetak Atolls, Marshall Islands. The shrimp was found in the farthest recesses of the caves where it occurred on rock surfaces in groups of 10 or more. Individuals were not disturbed by close approach nor artificial light, and they had the night-time coloration described by Wear and Holthuis (1997). These occurrences suggest that *L. uveae* may well have a widespread distribution in the tropical marine littoral zone.

This broadened habitat hypothesis allows that the shrimps could occur in the groundwaters of many isolated and archipelagic islands where they have not yet been found, in shallow reefs and seamounts, and possibly in suitable rock of continental shelves. Distributions would be limited by a thermal minimum, as discussed earlier . . . [and] distributional limits become restricted with increasing depth [in the Pacific, that would occur at approximately 100 m]. Below this depth, 20°C water disappears rapidly; at 150 m, it separates into relatively small hemispheric masses separated by cool (15°C) water between 5° and 10°N latitude.

Literature Cited

- Smith, M. J. and W. D. Williams. 1981. The occurrence of *Antecaridina lauensis* (Edmonson) (Crustacea, Decapoda, Atyidae) in the Solomon Islands—intriguing biogeographical problem. Hydrobiologia 85: 49-58.
- Wear, R. G. and L. B. Holthuis. 1977. A new record for the anchialine shrimp *Ligur uveae* (Borradaile 1899) (Decapoda, Hippolytidae) in the Philippines with notes on its morphology, behavior, and ecology. Zool. Meded. 51: 125-140.

The Anchialine Pond Detective Story

Acetate #1

What are Anchialine Ponds?

Here and there in the rough *ʻaʻā* flows that dominate the southwest coastline of Maui between Cape Kīnaʻu and Cape Hanamanioa, lies a scattering of anchialine ponds. Anchialine ponds are brackish or saltwater pools, a unique habitat found on Maui, Oʻahu, and Hawaiʻi, as well as on other islands and coastal areas in tropical regions around the world.

Anchialine ponds are simple natural systems in which the balance is easily disturbed. For example, people sometimes disrupt the system by dumping aquarium fish in the ponds. The fish eat all the red shrimp, which normally feed on algae. With the shrimp essentially removed from the system, the algae can take over the pond.

Anchialine ponds at ʻĀhihi-Kīnaʻu
(Photo: Forest Starr and Kim Martz)

Mysteries to Solve

Anchialine ponds in Hawaiʻi are home to several species of tiny shrimp, some of which are found nowhere else in the world and others which have been found in anchialine ponds thousands of miles away.

You will be asked to solve six mysteries linked to these tiny shrimp. You will develop hypotheses to explain these mysteries based on observations made by scientists who have studied these unique ponds and their tiny inhabitants for many years.

Mystery #1

The water in the ponds is both fresh water and salt water. Where does this water come from?

Anchialine pool at Kanaio
(Photo: Philip Thomas)

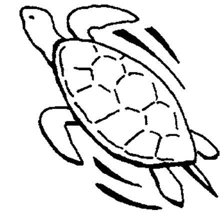
Observation #1 — If you taste the water, it is slightly salty but not as salty as the ocean.

Observation #2 — While the ponds in the photos are near the coast, they are far enough from the ocean that waves do not break into them.

Observation #3 — The water in the ponds rises and falls with the tides along the shoreline.

Observation #4 — If you swim along the lava rock shoreline, you will swim through water that is very blurry and colder than the surrounding ocean water.

Observation #5 — Hawaiians living along the lava shorelines from Cape Kīnaʻu, Kanaio and south to Kahikinui were able to dig wells along the coast or explore coastal lava tubes and find water that was slightly salty but good enough to drink. This was the only source of water for many people living along this coastline.



Acetate #3

Mystery #2
What makes the water turn red each spring at Waiʻānapanapa?

Popoalaea, a Hawaiian chiefess from the Hāna area above Waiʻanapanapa, was married to a powerful and arrogant warrior chief named Kakae. Kakae became jealous of her affection for her brother, Piʻilani, and threatened to kill the chiefess. Popoalaea fled for her life, along with her faithful companion, Manona.

At the last minute, Manona picked up a small *kāhili*. This feathered standard was a symbol of royalty. They fled toward the sea, travelling in lava tubes and under cover until they reached the ocean at Papaloa, near Hāna.

Popoalaea and Manona found a deep cavern in which they hid during the day, emerging only at night to look for food and a way to escape to another island. A pool of water filled the entrance to the cave, and to enter, the women had to dive into the pool and under a jutting ledge. The cavern opened into a low room where Popoalaea and Manona passed their days silently dangling their feet in the water. Manona would sometimes wave the *kāhili* slowly back and forth to distract her mistress's thoughts.

Waiʻānapanapa cave
(Photo: Carol Gentz)

Meanwhile Kakae searched madly for his wife. At the village of Honokalani, he heard strange tales of spirits wandering the shore at night. Nearby, he stopped to rest on the rocks just above a pool of water at the entrance to a cave. He noticed the perfect reflection of the cave roof in the still surface of the water. Suddenly he saw something move in the reflection, and recognized it as the *kāhili*.

Kakae and his men dove into the cavern and there killed both women by dashing them against the rocks, then throwing their bodies into the pool. To this day, the roof and sides of the cave are dark with the women's blood. On the nights of Kū, when the moon is in a certain stage, the waters of the pool are said to become red, and there is an eerie light in the cave.

In the spring—the time of year at which the tragedy took place—the stones are said to be a redder hue.

Adapted from Elspeth P. Sterling, Sites of Maui*, Bishop Museum Press, Honolulu, 1998, pp. 125-6.*

Acetate #4

Mystery #3

You often see small, red shrimp in the ponds. If all the water goes out of the ponds at low tide, the shrimp disappear. Where do they go?

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

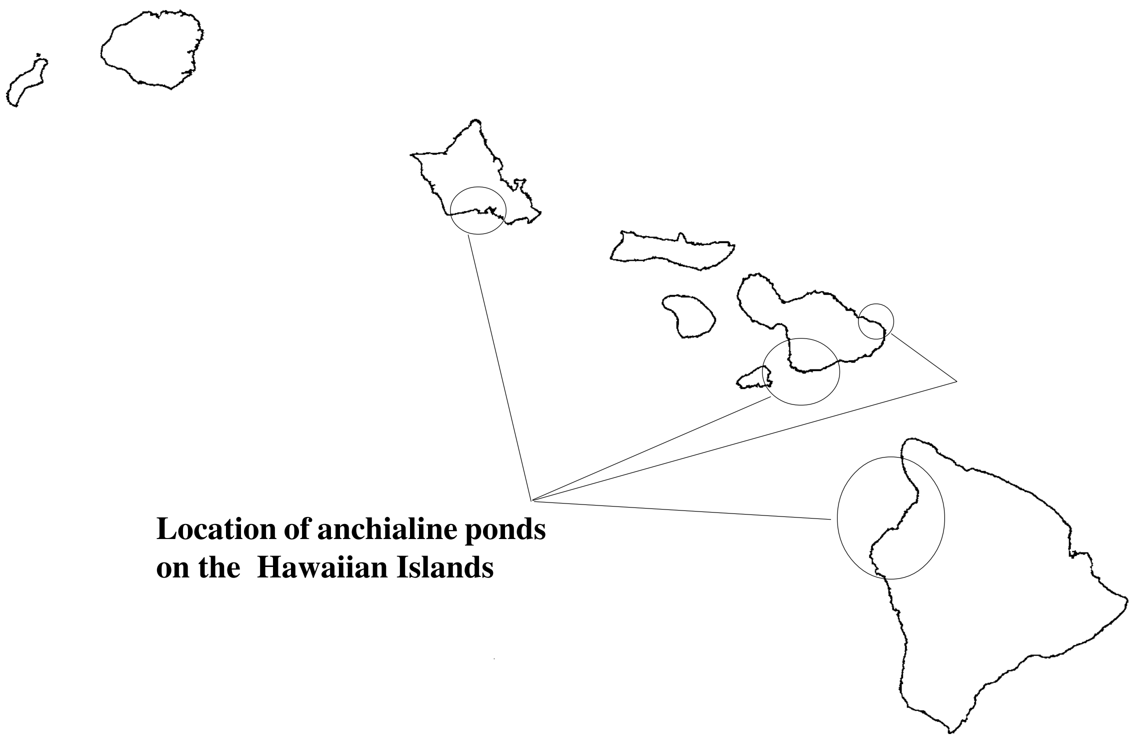
Observation #1: When the tide starts rising and the water level rises in the ponds, too, the shrimp enter the ponds.

Observation #2: If you dig a well along the shoreline, you are likely to have some of these shrimp in your well.

Observation #3: So far, the shrimp found in the ponds in Hawai'i have not been seen in the ocean. But they are small, so it could be the case that they simply have not been discovered in the ocean yet. Most do not exceed 3.0 cm (1.2 in) in body length.

Mystery #4

The same species of shrimp that live in the Maui ponds also live in similar ponds on the Kona coast of Hawaiʻi and holes in the ancient (and dry) coral reef that is now the ʻEwa plain of Oʻahu. How did the shrimp travel between the islands?

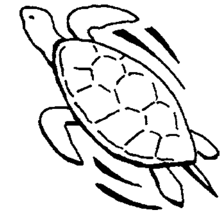


Observation #1	These shrimp can live in a wide range of salinity levels but need some saltiness in the water.
Observation #2	Maui and the Big Island have a deep-water channel between them, and even when the sea level was lower during the last ice age about 12,000 years ago, there was still a deep channel.
Observaton #3	In their larval stages, reef fish and corals disperse to other places as part of the "plankton" (tiny organisms that float freely through the ocean).

Mystery #5

The larvae reach the shorelines of the other islands. How do they get into the ponds?

Anchialine ponds at Cape Hanamanioa
(Photo: Forest Starr and Kim Martz)



Acetate #7

Information Interlude

Anchialine ponds are found in coastal areas throughout the tropics. As you can see from the maps in "The Anchialine Pond Detective Story Worksheet," certain species are found in ponds separated sometimes by thousands of miles of ocean.

Find these examples on the shrimp distribution maps:

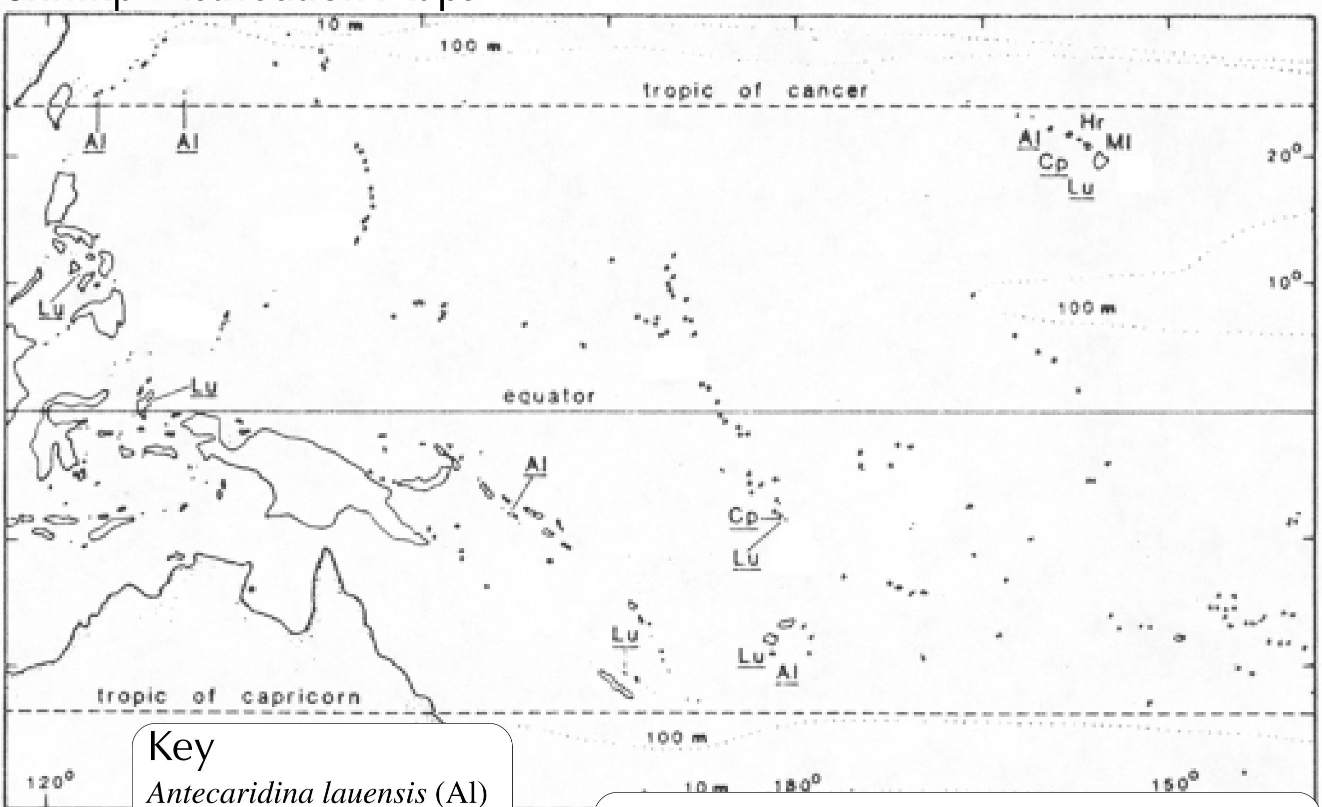
Cp = *Calliasmata pholidota*
Found in ponds on Hawaiian Islands, Ellice Islands, and the north end of the Red Sea

Al = *Antecaridina lauensis*
Found in ponds on Hawaiian Islands, Fiji Islands, Mozambique Channel Islands, Solomon Islands, at the south end of the Red Sea, and in Japan

According to widely accepted ideas about isolation and speciation, these widely separated populations should have diverged into separate species because of the limited pool of genetic material and specific local conditions. If these shrimp populations are as separate as they seem, scientists would expect to see more endemic shrimp species and fewer species that were scattered in anchialine ponds around the world.

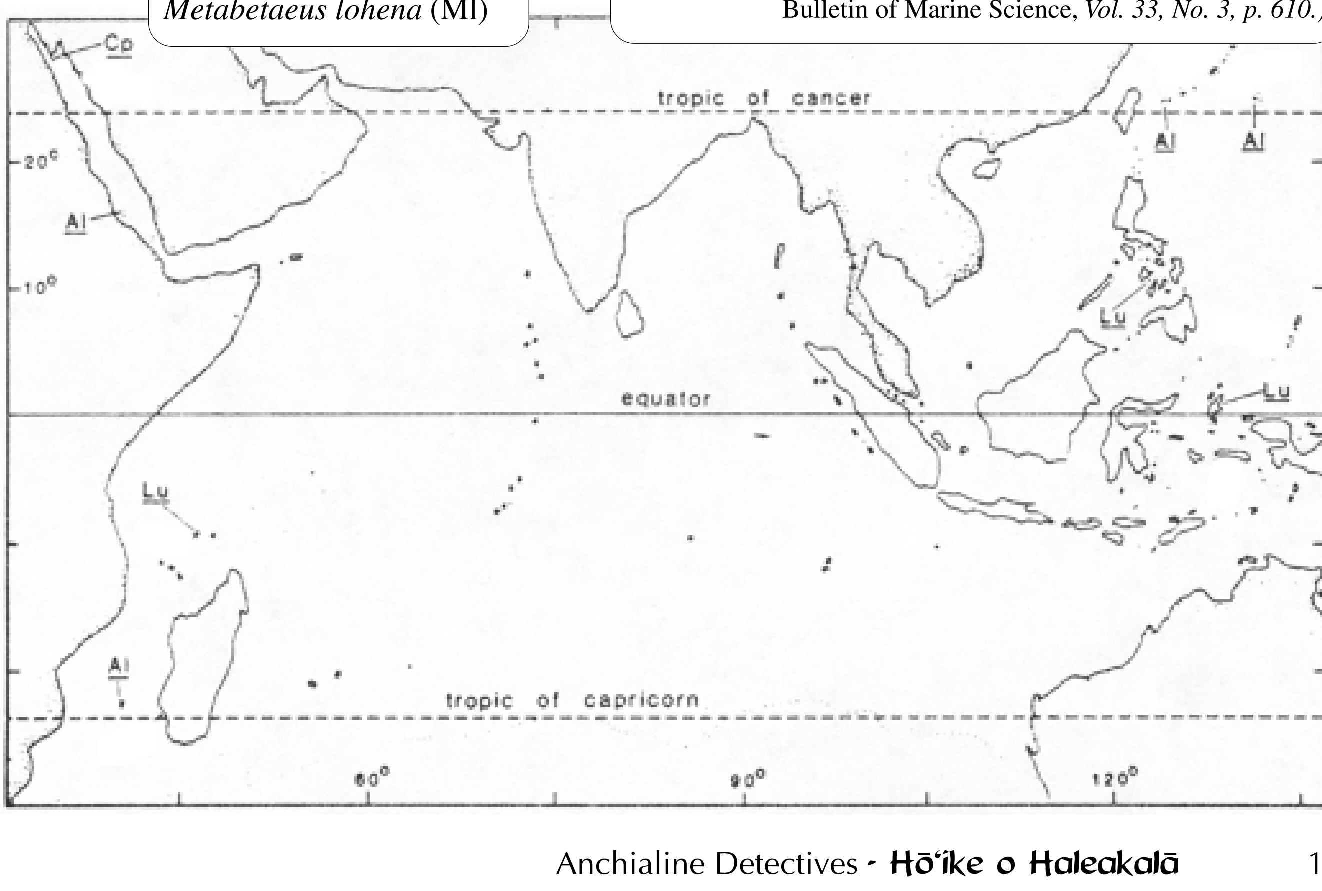
Acetate #8

Shrimp Distribution Maps



Key
Antecaridina lauensis (Al)
Calliasmata pholidota (Cp)
Halocaridina rubra (Hr)
Ligur uveae (Lu)
Metabetaeus lohena (Ml)

Distribution of insular hypogeal shrimps in the central and western Pacific Ocean (above) and western Pacific and Indian Oceans (below) (Adapted from John A. Maciolek, "Distribution and Biology of Indo-Pacific Insular Hypogeal Shrimps," Bulletin of Marine Science, *Vol. 33, No. 3, p. 610.)*



Mystery #6

Theories about isolation and speciation hold that shrimp species that live thousands of miles apart should have evolved into separate species. What can explain the fact that populations of the same shrimp species are found thousands of miles apart?

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

Observation #1	The shrimp *Antecaridina lauensis* (Al), *Halocaridina rubra* (Hr), and *Metabetaeus lohena* (Ml) can live up to 5 years in aquariums. They live longer than other types of small shrimp.
Observation #2.	All of the small, red shrimp found in the anchialine ponds can tolerate a wide variation in "salinity" (saltiness of the water), but they must have a little bit of seawater in the mix. They can live in pure ocean water.
Observation #3	All these shrimp need dark, underground crevices. While human beings have mostly seen them in the ponds, the shrimp probably do not need to come into ponds. While *Ligur uveae* (Lu) is found in ponds in other parts of the world, it has never been seen in a pond in Hawai'i. Here, it has been seen by divers only in underwater caves. While we tend to associate the shrimp with anchialine ponds, it is possible that they do not *need* to live in or on "emergent land" (land that comes out of the water, an island).
Observation #4	On islands where populations of the shrimp have been found in anchialine ponds, the shrimp sometimes show up in new holes in the ground such as a bomb crater, wells, and quarries, as well as in ponds in recent lava flows. This suggests that they have migrated through underground crevices to enter these new holes, so there is probably an extensive underground population.
Observation #5	Only two of the many species of small, red shrimp are endemic to an area. Since isolation generally results in the evolution of new species, this seems to indicate that larvae are passively floating in currents between these various areas. But in many places the currents don't go the right way!