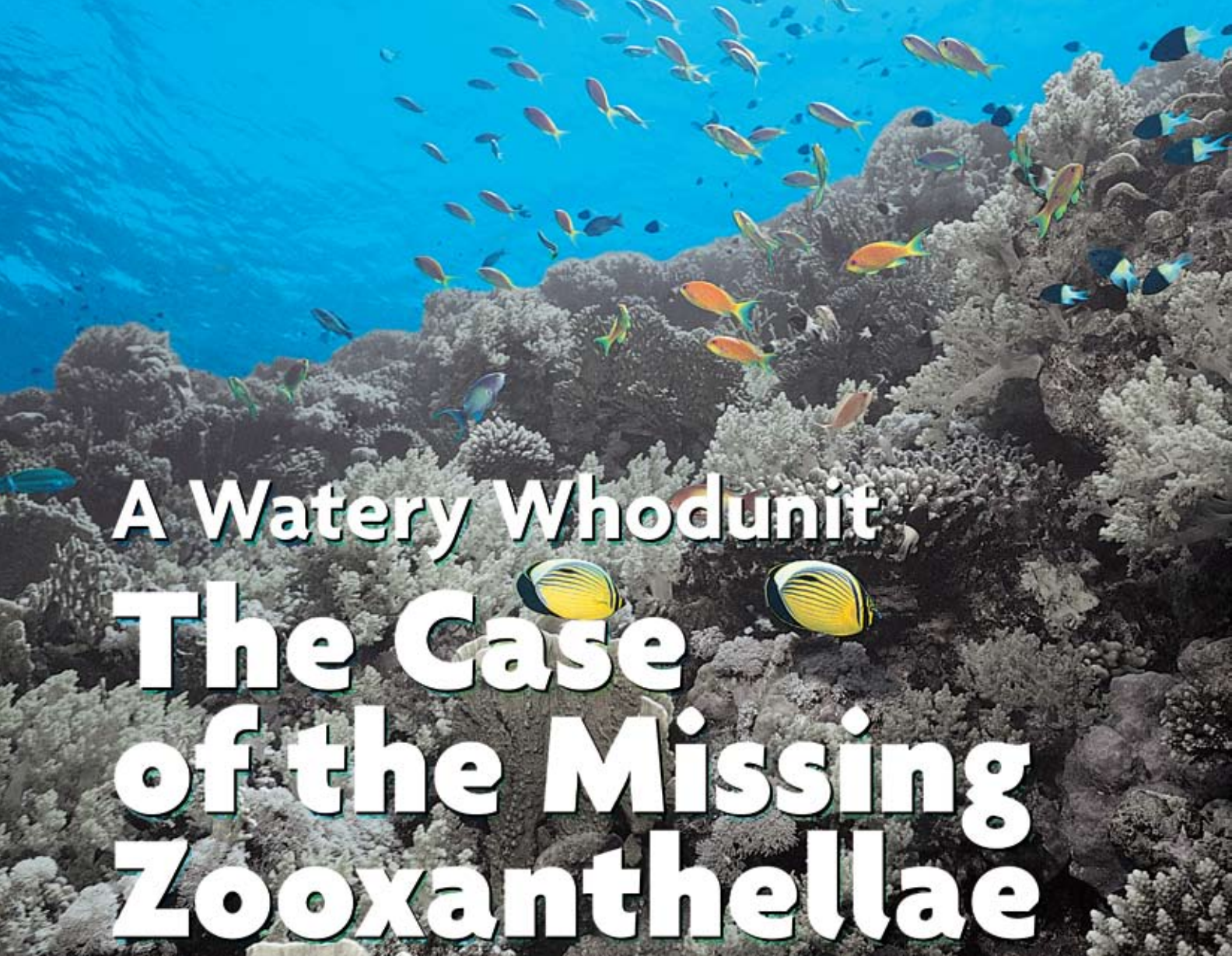


A Watery Whodunit
The Case of the Missing Zooxanthellae

by Kimberley A. Thomas, Barbara C. Bruno, Kate Achilles, and Sarah B. Sherman

Popular marine-life documentaries and animated films have captured the imaginations of millions of children and adults alike. Many people have been inspired to find Nemo or tell their own *Shark Tale*, but when it comes to understanding coral-reef biology and threats to reef health, the information is often bewildering and the conservation messages unclear. What exactly is coral bleaching? Why is it so important that coral-reef ecosystems be preserved?

Reef-building corals are a diverse group of invertebrate animals that host zooxanthellae (single-celled symbiotic algae) and secrete a calcium carbonate skeleton, simultaneously providing food and shelter for other marine organisms. As a result of these combined services, coral reefs are some of the most diverse ecosystems on the planet, hosting more than one-quarter of all known fish species (Parry et al. 2007).

The value of such biodiversity is also evident on shore. More than one billion people rely on reef-associated organisms for protein, and each year billions of dollars are generated globally through ecotourism (NOAA 2010). The rich diversity of reef ecosystems is proving to be a valuable source of medicinal compounds such as antibiotics, painkillers, and anti-cancer agents (NOAA 2010). The coarse surfaces and large, complex shapes of reefs protect coastlines against erosion and property damage by

dissipating and absorbing waves (United Nations Atlas of the Oceans). Culturally, reefs and related marine life form the basis of spiritual and religious values, provide a sense of place and cultural identity, and are subjects of traditional ecological knowledge (WRI 2009). For all of these reasons, it is essential that we protect coral reefs.

Unfortunately, protecting coral reefs is an increasingly elusive goal. In addition to natural causes of death such as predation (e.g., by parrotfish and sea slugs); bacterial, fungal, and viral disease (e.g., black-band and white pox); and competition for resources (e.g., space, light), coral reefs face numerous direct and indirect threats from human activities. Corals sustain physical damage from destructive fishing practices such as cyanide fishing and blast fishing, or simply from carelessness, including tourists who drop anchors or walk on reefs. However, the most insidious threats are those that result in coral bleaching, whereby corals lose their pigmentation due to the displacement or death of zooxanthellae. Zooxanthellae produce up to 98% of a coral's diet, and the prolonged absence of zooxanthellae during a bleaching event makes corals vulnerable to disease and starvation (Nova: Science in the News 2003).

Although reef-building corals have been flourishing for over 500 million years (Pratt et al. 2001), most species have stringent water temperature (23–29°C) and clarity requirements that make them vulnerable to environmental change (CoRIS 2010). Until the 1980s, only one coral-bleaching event had ever been recorded (Goreau 1964). Since then, more than 70 coral-bleaching events have resulted in mass coral mortalities, with the greatest losses (50%–90%) occurring in the Caribbean Sea and Indian Ocean (Buddemeier, Kleypas, and Aronson 2004).

Global warming can induce thermal stress and bleaching in corals, such as the mass bleaching events in Australia's Great Barrier Reef in 1998 and 2002 (Hennessy et al. 2007) and in the "Coral Triangle" of Southeast Asia in 2010 (ARC Centre for Excellence 2010). But there are many other contributing factors to coral bleaching. For example, land-use practices such as agriculture and mining can enhance erosion and increase soil transport to the ocean, particularly during storm events. Suspended sediments can stimulate coral bleaching by interfering with light transmittance and impeding photosynthesis (CoRIS 2010). Excess phytoplankton (e.g., caused by nutrient runoff into the oceans) can have similar effects. In 2008, an algal bloom in the Gulf of Oman robbed the water of light and oxygen, precipitating the death of 95% of the coral reef within three weeks (Bauman et al. 2010).

Increasing awareness about the causes and dynamics of coral bleaching is a critical first step in mitigating this global environmental problem. In this fun murder mystery activity, students learn about coral reefs and the environmental threats they face through role-playing and a mock DNA forensics investigation. This activity is designed for students in grades 5 through 8, but can also work well with younger participants with

FIGURE 1 List of murder mystery characters

Character	Organism/threat	Role	Scene*
Sharkey	Shark	Police commissioner	1, 2, 3, 5
Deputy Moray	Zebra moray eel	Police deputy	1, 2
Pinchy	Crab	Witness	1
Dr. Simba	Lionfish	Witness	1
Pearl	Necklace sea star	Witness	1
Perky	Clownfish	Witness	1
Industrial Plant	Industrial pollution	Suspect	2
Glowball Warming	Global warming	Suspect	2
Seddi Mentation	Sedimentation	Suspect	2
All-gal Bloom	Algae	Suspect	2
Dr. Moo	Cowfish	Crime-scene scientist	3
Bacon	Hogfish	Crime-scene scientist	3
Skippy	Sea hare	Crime-scene scientist	3
Rocky	Raccoon butterflyfish	Juror	5
Tony	Tiger cowry	Juror	5
Scout	Seahorse	Juror	5

*Scenes in which characters have speaking lines. Scene 4 is the murder mystery investigation, and no one has lines during this scene.

advanced reading skills. It is aligned with the National Science Education Standards (NRC 1996) and the Essential Principles of Ocean Literacy (NGS and NOAA 2006). The complete lesson, which includes a narrated PowerPoint presentation, a pre- and post-survey, and the murder mystery skit, requires two class periods to complete. If you wish to only do the murder mystery skit (without costumes), one class period is sufficient.

Note to teachers: Students may ask you whether the white coral that washes up on beaches is a result of coral bleaching. Some may be, but there is no single cause for the presence of white corals on shores. In some cases, tropical storms rip up healthy reef and deposit corals onto beaches where they then turn white. Alternatively, coral may first bleach or die from disease and then be dislodged from the substrate and wash up onto a beach.

The Case of the Missing Zooxanthellae

Overview

The Case of the Missing Zooxanthellae is a murder mystery activity organized into five scenes. In the story, Seymour is a coral who has suffered a premature demise because his zooxanthellae disappeared and he starved to death. In scene 1, the police commissioner (the teacher) and a deputy hold a meeting where witnesses report unusual behavior or events. In their accounts, the witnesses implicate four suspects in the abduction of Seymour's zooxanthellae: global warming, industrial pollution, an algal bloom, and sedimentation (characters called Glowball Warming, Industrial Plant, All-gal Bloom, and Seddi Mentation). In scene 2, the four suspects are interviewed and all provide alibis. In scene 3, crime-scene scientists explain what DNA is and collect mock DNA samples from each suspect. In scene 4, students conduct an

FIGURE 2 **Materials list (per class)**

All materials are inexpensive (less than a few dollars) and re-usable with multiple classes (none are consumable).

Materials to make suspect DNA samples (Figure 3) and **DNA evidence** (Figure 4)
- Thick string or yarn (approx. 30 feet)
- Scissors
- Colored beads, called pony beads, with a hole in the center (so they can be strung), available at any toy or craft store, with the following color distribution: red (96); green (72); yellow (123); and blue (87)

Crime-scene materials
- Plastic decorative aquarium coral (2 or 3 pieces), available at any pet store
- Bleached piece of coral, available as "decorative coral," not "live coral," online and at pet stores (the coral is Seymour, the victim in the case)
- Orange cones (4), available at any sports store (or they can be made of orange paper)
- Crime-scene tape ("Police: Do Not Cross" or similar text), available at home improvement stores or toy stores

Sites
- Whiteboard
- Phone
- Printer

Clues
- Dry-erase marker
- Prepaid phone card
- Printer cartridge (any kind)
- Key
- Beads or marbles (any amount) in a small box or cage to serve as abducted zooxanthellae
- Four tags or labels (write the word *CLUE* on these)

Props
- Plastic forceps (3)—distribute one to each crime-scene scientist
- Small resealable bags (3)—give one bag to each crime-scene scientist; they will use them to collect DNA samples from each suspect
- Key rings (3) with one key on each ring—distribute to Glowball Warming, Industrial Plant, and Seddi Mentation
- Key ring (1) with no key on it—give to All-gal Bloom

Other materials
- Signs or mailboxes (4), labeled *Glowball Warming*, *All-gal Bloom*, *Industrial Plant*, and *Seddi Mentation*—these serve as indicators of the suspects' residences

investigation to search for DNA evidence and clues to identify the guilty party. Finally, in scene 5, three jurors summarize the investigation and deliver their verdict. All scenes can be conducted in the classroom. If the teacher prefers, scenes 4 and 5 can be conducted outdoors. This activity is designed for one teacher and a minimum of 15 students (Figure 1). Additional students can participate in the murder mystery investigation; they just won't have speaking lines.

Advance preparation

Allow at least two hours to prepare for this lesson. First, gather the necessary materials (Figure 2). String the beads to make three exact replicates of each suspect's DNA sample (Figure 3) and three replicates of each piece of DNA evidence (Figure 4). Second, preview the narrated PowerPoint presentation (*http://cmore.soest.hawaii.edu/education/teachers/science_kits/marine_mystery_kit.htm*) and read through the script (Figure 5) to get a general sense of how the activity works. Third, set up the crime scene (Figure 6).

You are now ready to set up your murder mystery investigation sites. Assuming your classroom has a printer, phone, and whiteboard, your sites will be those shown in Figure 7. Put a label or tag on the dry-erase marker, phone card, printer cartridge, key, and cage of the abducted zooxanthellae to clearly identify these objects as clues. Figure 7 is your guide for hiding clues and DNA samples: At or near each site, hide the clue and DNA samples listed on the same row as the site. For example, hide the dry-erase marker and three copies of the first DNA sample at the crime scene, hide the phone card and three copies of the second DNA sample near the whiteboard, etc. The idea is that the DNA evidence may acquit a suspect, and each clue leads students to the next site: The dry erase marker found at the crime scene (site 1) leads students to the whiteboard (site 2); the phone card found there leads students to the phone (site 3), etc.

Note: If your classroom does not have any of the sites named in Figure 7, simply modify the site and the corresponding clue. For example, if your classroom has a chalkboard instead of a whiteboard, replace the dry-erase marker with a piece of chalk.

Finally, photocopy the script (Figure 5) as follows: Make five copies of scene 1 (for the four witnesses and Deputy Moray); make five copies of scene 2 (for the four suspects and Deputy Moray); make three copies of scene 3 (for the three crime-scene scientists); make four copies of scene 5 (for the three jurors and Glowball Warming); and make a copy of the entire script for yourself (the police commissioner). For younger students, it is helpful to highlight the line(s) for each of their characters.

Preparing students

Begin the lesson with a presurvey (Figure 8), followed by a discussion to introduce students to coral biology and four major causes of coral bleaching: climate

FIGURE 3 Suspect DNA key

FIGURE 4 DNA evidence key

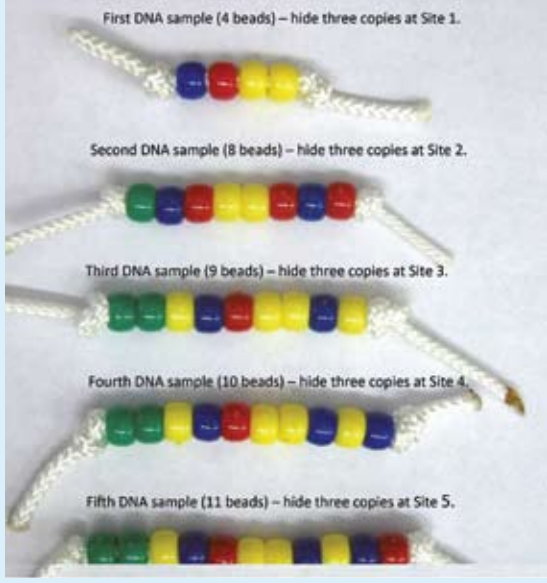


FIGURE 5 Marine mystery script *(notes to teachers are provided in italics)*

Scene 1: Interviewing witnesses

Police Commissioner Sharkey and Deputy Moray begin at the front of the classroom.

Sharkey: Good evening, I am Police Commissioner Sharkey, and this is Deputy Moray. I have invited you all here tonight to share the news of a tragic loss in our community. Mr. Seymour Coral was found dead in his garden early this morning. His zooxanthellae [zoh-zan-thell-lay] are also missing. We have not yet concluded whether they are still alive. I know that this is a terrible shock, but I need your help to find and collect evidence.

Deputy Moray: We have a handful of witnesses who saw our wanted poster and have courageously come here to report information. Please state your name and position and what you saw or heard. Let's start with the crab.

The four witnesses (Pinchy the crab, Dr. Simba the lionfish, Pearl the sea star, and Perky the clownfish) stand up or go to the front of the classroom to say their lines. The witnesses will share information that implicates different suspects.

Pinchy the crab: Hi, my name is Pinchy, and I'm the local gardener. Last week, while I was trimming my seaweed, I smelled weird chemicals coming out of Industrial Plant. They looked kind of greasy and shiny. I think they may have been toxic.

Deputy Moray: Hmmm…that's rather strange. We'll certainly need to follow up on that. What does the lionfish have to share?

Dr. Simba the lionfish: Hello, my name is Dr. Simba, and I was the victim's doctor. Last month, he complained of fevers and low blood sugar. As you know, this often happens when ocean temperatures rise, and I recently saw Glowball Warming turning up the thermostat on the reef. But when I followed up the next week, Seymour seemed fine so I didn't think anything of it.

Deputy Moray: That seems reasonable. And what did the sea star see?

Pearl the sea star: My name is Pearl, and I am, well I was [*gasp*, *sob*], Seymour's neighbor. He was such a friendly coral head.

Deputy Moray [*sympathetically*]: Yes, yes. Please continue.

Pearl: Well, I saw Seymour fighting with Seddi Mentation a few days ago. Seddi was trying to smother Seymour and wouldn't leave him alone. Now I feel like I should have done something!

Deputy Moray: Well, don't you worry about that now. Let's hear from our last witness, the clownfish.

Perky the clownfish: My name is Perky, and I deliver the mail. I was taking a package to Polly Polyp when I saw a cloud pass overhead. But this cloud hung around for a while. I then realized that it wasn't a cloud, it was All-gal Bloom casting a shadow on us. Brrr…All-gal Bloom gives me the shivers!

At this point, the police commissioner and Deputy Moray stop to recap the witnesses' information and have everyone identify the four suspects. The police commissioner uses the written prompts in the following lines to encourage the discussion.

Sharkey: All right, let's review and have the suspects come up to the front. Who did Pinchy think was responsible? Who did Dr. Simba suggest was guilty? That's right, and what did Pearl witness? And finally, who did Perky say she [or he] saw? OK, Deputy Moray, let's hear what our suspects have to say.

Scene 2: Interviewing suspects

Police Commissioner Sharkey and Deputy Moray will provide potential motives/methods and ask for alibis from the suspects in this scene. The four suspects (Industrial Plant, Glowball Warming, Seddi Mentation, and All-gal Bloom) will now stand up or go to the front of the classroom to read their lines.

Deputy Moray: Industrial Plant, let's start with you. Please explain why strange chemicals were coming off of you last week.

Industrial Plant: No problem. I care a lot about the environment, and I have very strict rules about my waste products. While they may not smell very good, all of my waste has been treated and breaks down naturally in the environment. I promise that these chemicals were not toxic.

Sharkey: Hmmm…that doesn't sound so bad, but depending on how our investigation goes, we might want to test those so-called safe chemicals anyway. And how about you, Glowball Warming? Dr. Simba said that Seymour was suffering from fevers and low blood sugar. You know that warming up the oceans can cause zooxanthellae to leave their coral home. This means the coral gets less food, and it slowly starves.

Glowball Warming: No way! Dr. Simba said that Seymour looked just fine after his first visit. Besides, Seymour's zooxanthellae are missing. So you have no one to ask about it. You've got no evidence against me!

Sharkey: I'm not so sure about your story, but why don't we hear from Seddi Mentation. Seddi, you can smother the reef with soil particles and were seen bullying Seymour. What do you have to say for yourself?

Seddi Mentation: I only really cause trouble when dirt gets washed off land during big storms, and there hasn't been any for weeks. I didn't do it!

Sharkey: That's true, hmmm. OK, what about All-gal Bloom? You can mu ltiply quickly and block out light that zooxanthellae need for photosynthesis. How do we know you didn't starve them of light and cause Seymour's death?

All-gal Bloom: The currents have been strong and washed me right off the reef. I didn't hang around long enough to cause that much trouble.

Shark: All of you have decent alibis, but let's review the facts.

Take a moment to review the facts of the case. This is a good opportunity for formative assessment. Question students to ensure they understand who the four suspects are and the real-life threats that they represent to coral reefs. This is also a good opportunity to review the importance of coral-reef ecosystems.

Deputy Moray: We now need our scientific team to sample your DNA before we release you.

Scene 3: Scientists collect DNA from suspects

Each of the three scientists (Dr. Moo the cowfish, Bacon the hogfish, and Skippy the sea hare) collects a DNA sample from each of the suspects, puts the sample in a resealable bag, and then goes to the front of the classroom.

Sharkey: Will the crime-scene scientists please introduce themselves and explain what they will be doing today?

Dr. Moo: Hello, everyone. I am Dr. Moo, and these are my assistants, Skippy and Bacon. We are collecting DNA, which is the microscopic genetic material found in every living thing.

Bacon: DNA is very delicate, so you have to be careful when handling it.

Skippy: Even though two individuals may be from the same species, some of their DNA is different enough to be able to tell them apart, just like a fingerprint.

Dr. Moo: But DNA is even better than a fingerprint, because it's found in many things: blood, saliva, bones, hair, and even fish scales!

Bacon: So if we find even a little bit of DNA at a crime scene, we can figure out who was responsible by matching it to a sample we collect from a suspect.

Skippy: I'll pass my samples around so that everyone can see that no two individuals have exactly the same DNA.

Wait for everyone to check out the samples.

Sharkey: OK, does everyone understand what DNA is?

This is another good opportunity for formative assessment. Question students to ensure they understand what DNA is (i.e., genetic material found in every living organism), that everyone's DNA is different, and that DNA can be used to identify who was at the crime scene if evidence such as hair or blood is left behind. Also be sure students understand that, in reality, only living organisms (not environmental threats) have DNA.

Sharkey: All right, everyone, it's time to start the investigation. Let's begin at the crime scene. DNA is very fragile and can break apart easily. Therefore, let's try to find at least three pieces of DNA at the crime scene.

Scene 4: Search for clues

Everyone leaves their scripts aside. The scientists need to bring their resealable bags of suspect DNA samples with them. After the investigation is completed, continue with Scene 5.

Scene 5: Court hearing and verdict

The jurors and Glowball Warming stand at the front of the classroom. Police Commissioner Sharkey distributes Scene 5 scripts to Glowball Warming and the three jurors.

Sharkey: Will the jury please take a few moments to discuss the case and report the verdict?

Rocky the butterflyfish: With four different suspects and many pieces of information from witnesses, it was difficult to figure out who was responsible.

Tony the tiger cowry: But then we found Glowball Warming's DNA at All-gal Bloom's house with the missing zooxanthellae, and it became clear who did it.

Scout the seahorse: Therefore, we have decided that Glowball Warming was responsible for driving the zooxanthellae away from Seymour, which resulted in his death!

Rocky: "Police Commissioner Sharkey, lock him [or her] up!"

Glowball Warming: "This isn't fair! Those darn zooxanthellae were stealing my greenhouse gases!"

FIGURE 6 Crime scene

change; sedimentation; algal blooms; and industrial pollution (Figure 9). These four environmental threats are the suspects in the murder mystery investigation. If you wish, you can share the narrated PowerPoint presentation with your students. Assign roles to your students (Figure 1) and distribute scripts. Exception: Do not distribute the scene 5 scripts until the beginning of scene 5, because these scripts reveal the guilty party. The role of Deputy Moray has the greatest number of lines, so assign this role to a student who is comfortable reading aloud. Either as homework or during class time, have students practice their lines and design a simple costume for themselves. Some ideas for costumes are provided in Figure 10. Ask students to bring their costumes to the next class period.

Solving the mystery

The second class period is the murder mystery activity. First, distribute the materials (see Figure 2). The instructor (the police commissioner) will facilitate a community meeting to gather information from witnesses and suspects and explain to students how genetic evidence is used in criminal investigations. Students will read their scripts through the end of scene 3, and then begin the search for clues.

The investigation (scene 4) will start at the crime scene. The bleached white coral is the late Seymour Coral. Tell your students that there are three pieces of DNA evidence and a clue hidden at the crime scene (as well as all subsequent locations), and that they should keep searching until they have found all four items. Once all four items have been found, students break up into three groups, one for each piece of DNA, to analyze the DNA evidence and determine which suspect, if any, can be acquitted; each group should include a scientist (who has samples of each suspect's DNA) and a piece of DNA evidence. Then they use the clue to figure out where to go next. To maximize participation, stipulate that each student may find only one clue or strand of DNA evidence, and that everyone has to move as a group to the next site. The hunt for clues and DNA analysis should require little teacher involvement. The teacher should use Figure 7 as a guide throughout the investigation.

Once students have found the key, instruct the suspects to pull out their key chains. The only suspect missing a key is All-gal Bloom. At this point, most will suspect that All-gal Bloom is guilty. The group should go to All-gal Bloom's house, where they will find the

FIGURE 7 Structure of the murder-mystery investigation

Murder-mystery investigation site	Evidence* (3 copies of each)	Clues	Any suspect acquitted?
1. Crime scene	1st DNA evidence	Dry-erase marker	No
2. Whiteboard	2nd DNA evidence	Phone card	Yes (Industrial Plant)
3. Phone	3rd DNA evidence	Printer cartridge	No
4. Printer	4th DNA evidence	Key	Yes (Seddi Mentation)
5. All-gal Bloom's house	5th DNA evidence	Cage of zooxanthellae	Yes (All-gal Bloom)

*See Figure 4 for DNA evidence key.

FIGURE 8 **Pre- and postsurvey for student assessment *(sample answers provided in italics)***

1. What is DNA? *DNA is a molecule that provides the genetic instructions for the development and functioning of all living organisms.*

2. How can DNA be used to solve crimes? *Scientists can compare DNA evidence [from samples such as hair or blood] found at a crime scene with samples of suspects' DNA. Everyone's DNA is different, so only one person's DNA will exactly match the evidence, and this person is the guilty suspect.*

3. Many corals contain tiny plantlike cells inside their tissues. How do these plantlike cells help the coral? *These tiny plantlike cells (called zooxanthellae) produce food for the coral.*

4. What is coral bleaching? *Corals are typically brightly colored, due to the brightly colored zooxanthellae inside their tissues. Coral bleaching is the process by which corals lose their pigmentation due to the displacement or death of zooxanthellae.*

5. Due to human activities (such as driving cars), the Earth and its oceans are getting warmer. Describe one harmful effect of a warmer ocean. *Corals can only live in a narrow range of temperatures. When ocean temperatures rise above ~29°C, corals are not able to survive.*

6. What is an algal bloom? *An algal bloom is an unusually large number of tiny marine algae. Algal blooms are usually caused by an increase in nutrients (such as nitrogen and phosphorus) entering the water.*

7. Explain how sedimentation can cause—or contribute to—coral bleaching. *Corals grow best in clear, blue water so that their zooxanthellae can get plenty of sunlight to produce food. Soil and other particles suspended in the water reduce the amount of light reaching a coral, making it difficult for zooxanthellae to produce food. Eventually, the zooxanthellae may leave the coral or die, causing the coral to lose its coloring and become "bleached."*

8. Describe two benefits that humans get from coral reefs. *Answers will vary and may include one or more of the following: Humans get protein from fish and other reef organisms and benefit financially from ecotourism (NOAA 2010). Reef ecosystems also provide medicinal compounds such as antibiotics, painkillers, and anti-cancer agents (NOAA 2010). Reefs protect coastlines against erosion and property damage by dissipating and absorbing waves (United Nations Atlas of the Oceans). Reef ecosystems form the basis of spiritual and religious values, provide a sense of place and cultural identity, and are subjects of traditional ecological knowledge (WRI 2009).*

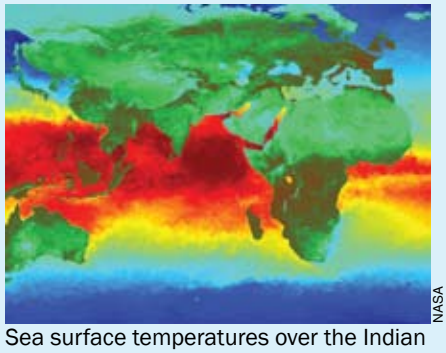
9. Describe two things that you or your family members can do to protect coral reefs. *Answers will vary and may include one or more of the following: Respect coral reefs by not walking on—or touching—them. Practice sustainable fishing methods and don't overfish reefs. Support legislation to establish marine conservation areas around coral reefs. In terms of the environmental hazards addressed in this activity:*
   a. *Don't waste energy—do your part to curb global warming.*
   b. *To minimize industrial pollution, support vendors that use sustainable practices. Look for eco-labels on your clothing and electronics.*
   c. *When hiking in coastal areas, stay on the trail: This will minimize erosion and sedimentation.*
   d. *Buy organic food and support sustainable agriculture to minimize harmful agricultural runoff into the oceans.*

10. Draw a picture of a coral-reef ecosystem. *Drawings will vary and may include coral polyps and zooxanthellae in healthy or diseased states. Students may also include fish, other marine life, boats, and the environmental hazards threatening coral reefs (such as sedimentation, algal blooms, industrial pollution, and global warming).*

FIGURE 9 Environmental suspects

1. Glowball Warming (global warming)

- Coral reefs can only live in waters between 23–29°C. Many corals have tiny plant-like cells called zooxanthellae that live in their tissues and provide food for the coral by photosynthesis.
- If water temperature increases, zooxanthellae are unable to produce food for the coral. When water temperature continues to rise, corals often lose their zooxanthellae through a process known as coral bleaching.
- If the coral does not acquire more zooxanthellae, the coral can starve and die.

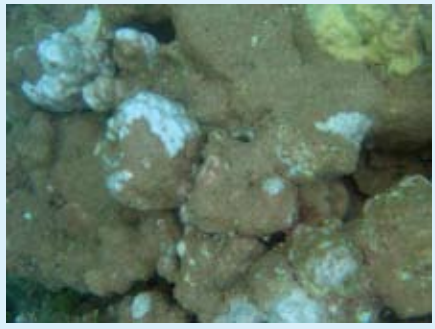


NASA

Sea surface temperatures over the Indian Ocean.

2. Seddi Mentation (sedimentation)

- Mining, building, farming, and other human activities loosen soil (sediment).
- When it rains, loose soil can get washed off the land and carry nutrients and toxic chemicals into rivers and streams, and eventually into the ocean.
- Corals grow best in clear, blue water so that their zooxanthellae can get plenty of sunlight to produce food. Soil and other particles that are suspended in the water reduce the amount of light reaching a coral, making it difficult for zooxanthellae to produce food.
- As the sediment settles out of the water, it can bury corals or cause them to use a large amount of energy to keep clean.



DAVID BURDICK, NOAA

Sediment-smothered reef.

3. All-gal Bloom (algal bloom)

- The runoff from agricultural areas is rich in nutrients, such as nitrogen and phosphorus.
- These nutrients can cause tiny marine algae to grow into vast numbers, which is called an algal bloom.
- Similar to the process of sedimentation, these algal blooms can block sunlight and thus reduce coral growth.
- The change in ocean color (to red) in the photo to the right is due to a pigment produced by the algae.

MIRIAM GODFREY, NIWA

An algal bloom in New Zealand.

4. Industrial Plant (pollution)

- Industrial pollution includes the dumping of heavy metals and other toxins into the oceans and rivers, and the release of heated water from the cooling systems of power plants.
- Pollution affects a coral's ability to feed and reproduce (the toxins interfere with proper egg development).
- The pollution enters the coral through the polyps, and the heavy metals from the pollution can kill the animals. When the polyps are killed, no new coral layers can be produced.

NOAA

Industrial point-source pollution.

zooxanthellae being held captive. But wait! A fifth set of DNA evidence that matches Glowball Warming's DNA is found at All-gal Bloom's house, incriminating Glowball Warming. Glowball Warming was trying to frame All-gal Bloom for stealing the zooxanthellae, but forgot about DNA evidence!

We recommend ending with a student-led discussion on protecting coral reefs. What can they do as individuals or as a community to protect these vital ecosystems?

Assessment

Ongoing formative assessment occurs throughout the mystery (see Figure 5), and a pre-/postsurvey (Figure 8) is also provided to assess changes in students' understanding of basic coral biology, the importance of reef ecosystems, and causes of coral bleaching. This test can also help identify when misunderstandings occur.

Extensions

Coral reefs are complex, fascinating ecosystems that provide myriad opportunities for scientific, artistic, and literary lesson extensions. After being assigned their character roles, students may be given additional time to research their character and share with the rest of the class interesting facts about the organism or environmental threat they will portray. After conducting the murder mystery activity as written, students can prepare different DNA evidence samples for alternate endings, so that other classes can have different murder mystery experiences. They can even pair up with an elementary school class to act out their new version. We have found that middle school students like reading the scripts, whereas the younger students enjoy wearing the costumes.

There are numerous opportunities for teachers to tie in this activity to social studies. For example, students can research the world's major coral reefs, learn about the countries where they are found, and explore how reefs are perceived and used by different cultures.

Conclusion

Understanding coral reefs and the threats they face is an essential precondition to preserving them. Hence,

FIGURE 10 Costume ideas for characters

Sharkey the shark
(police commissioner)
- Shark hat

Deputy Moray the zebra moray eel
(deputy sheriff)
- Zebra mask

Pinchy the crab (witness 1)
- Crab hat

Dr. Simba the lionfish (witness 2)
- Lion mask
- Lab coat
- Stethoscope

Pearl the sea star (witness 3)
- Star headband

Perky the clownfish (witness 4)
- Rainbow clown wig
- Red clown nose

Industrial Plant
(suspect 1—industrial pollution)
- Yellow hard hat

Glowball Warming
(suspect 2—global warming)
- Black cape

Seddi Mentation
(suspect 3—sedimentation)
- Shirt with dirt on it

All-gal Bloom
(suspect 4—algal bloom)
- Green feather boa

Dr. Moo the cowfish
(scientist 1)
- Cow mask
- Lab coat

Bacon the hogfish
(scientist 2)
- Pig mask
- Lab coat

Skippy the sea hare
(scientist 3)
- Rabbit mask
- Lab coat

Rocky the raccoon butterflyfish
(juror 1)
- Raccoon mask

Tony the tiger cowry
(juror 2)
- Tiger mask

Scout the seahorse
(juror 3)
- Horse mask

we offer this activity to educate middle school students about coral biology and the problem of coral bleaching. In addition to stimulating dialogue about coral bleaching, we hope that this activity will inspire students to participate in marine conservation initiatives. This activity can be readily adapted to different target audiences and environments, and we encourage you to share your adaptations with the authors. ■

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