Santa Cruz-Watsonville Inquiry-Based Learning in Environmental Sciences
An NSF GK-12 Project

What Can We Learn from Seabird Barf?

Seabirds & Marine Debris

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Field-tested with: 9th grade Integrated Science & Marine Biology students, Watsonville High School, Watsonville, CA (Fall, 2011)

Concepts: Ocean pollution, plastic debris in ocean, food chain/web, marine debris, human impacts on environment

Skills: observing, classifying/sorting, measuring, analyzing

Module Type: Short inquiry in groups and whole class

Duration: 1 45-minute class period and 1 2-hour class period

Key materials:
- albatross boluses
- probes
- tweezers
- magnifying glasses
- rulers
- triple-beam balances or digital scales
- cups for sorting
- LCD projector
- document camera
- calculators
- copies of class datasheets

Science Education Standards:

National: Science As Inquiry; Life Science; Science in Personal & Social Perspectives

California: Biology-Life Sciences: 6. Ecology; Investigation and Experimentation

Overview: Albatross boluses provide a record of what the seabirds fed on, which often includes plastic marine debris. In this project, each class builds a research question, hypothesis, procedures, and datasheet before dissecting albatross boluses from the Northwestern Hawaiian Islands and analyzing their results statistically and graphically. This project is framed by discussion of how marine debris impacts marine organisms and how humans can reduce their use and waste of plastics.

This project is an opportunity for students to:
- gain an understanding of how humans impact organisms & ecosystems even in remote places.
- learn about how scientists determine what animals eat.
- develop a research question and methods to answer their question.
- analyze the results of their investigation using basic statistics (e.g., mean, bar graph).

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For more information, see: http://scwibles.ucsc.edu

Background for Teachers

Seabirds that feed on the surface of the ocean (dippers and scavengers), such as Black-footed Albatrosses and Laysan Albatrosses, often mistake **plastic** pieces as food and feed plastics to their chicks. Some seabirds can rid themselves of these plastic pieces and other indigestible material by regurgitating (Ryan 1990). However, albatross chicks wait to regurgitate a compact mass of indigestible material - a **bolus** - just before **fledging** (leaving the nest and going to sea). By studying boluses, we can learn about seabird diets and human impacts on open ocean ecosystems far from land.

Seabirds can be used as ecological indicators of large marine ecosystems because they can range over huge expanses of ocean, but return to land in order to breed. Diet studies can highlight shifts in prey types and changes in abundance and distribution of prey. Seabirds can also be used to quantify changes in threats caused by increased human use of coastal and open-ocean ecosystems (e.g., plastic pollution).

Seabird Conservation Ecology

Albatross populations are very sensitive to changes in adult survival because they have low reproductive rates, low natural annual mortality, long life spans, and delayed sexual maturity.

According to the U.S. Fish and Wildlife Service, only the short-tailed albatross is endangered (FWS decided black-footed albatross are not endangered in October 2011). However, the International Union of Concerned Scientists (IUCN) has all three species on their Red List: Laysan albatrosses are "near threatened", blackfooted albatrosses are "endangered", short-tailed albatrosses are "vulnerable".

Probably the biggest threat to all species of albatrosses is longline fishing. Longline fishing vessels set lines up to 60 miles long and may use up to 30,000 baited hooks on each set to catch tuna, swordfish, cod, halibut, and other fish. Albatrosses and other seabirds grab the bait as the longlines are being set, get caught on the hook, and are dragged under the surface and drowned. Thousands of albatrosses and other seabirds are killed this way every year. They're considered "bycatch" because seabirds are not the target of the fishery. Fortunately, long-lining fisheries are increasingly using streamer lines and other techniques to reduce seabird mortality.

They are also poisoned by lead-polluted soils around the breeding colonies at Midway (causing droop-wing syndrome) and are killed by introduced mammals (particularly in the Main Hawaiian Islands where there are small colonies on Kauai and Oahu). They were also killed in huge numbers for their eggs and feathers in the 1800s.

Seabird Biology

Both Laysan Albatrosses (*Phoebastria immutabilis*) and Black-Footed Albatrosses (*Phoebastria albatrus*) range throughout the whole North Pacific in non-breeding months (July – November), but tend to stay closer to their breeding colony when they are incubating eggs and feeding chicks (Figure 1a and 1b; Young et al. 2009). Both species maintain large nesting colonies at Midway Atoll in the Northwestern Hawaiian Islands, which is almost halfway between North America and Asia. Over 70% of the world's Laysan albatrosses (Figure 1) nest at Midway, with over 450,000 nesting pairs in 2008 (www.fws.gov/midway). Over 25,000 nesting pairs of Black-Footed Albatrosses at Midway form the world's second largest breeding colony of this species.

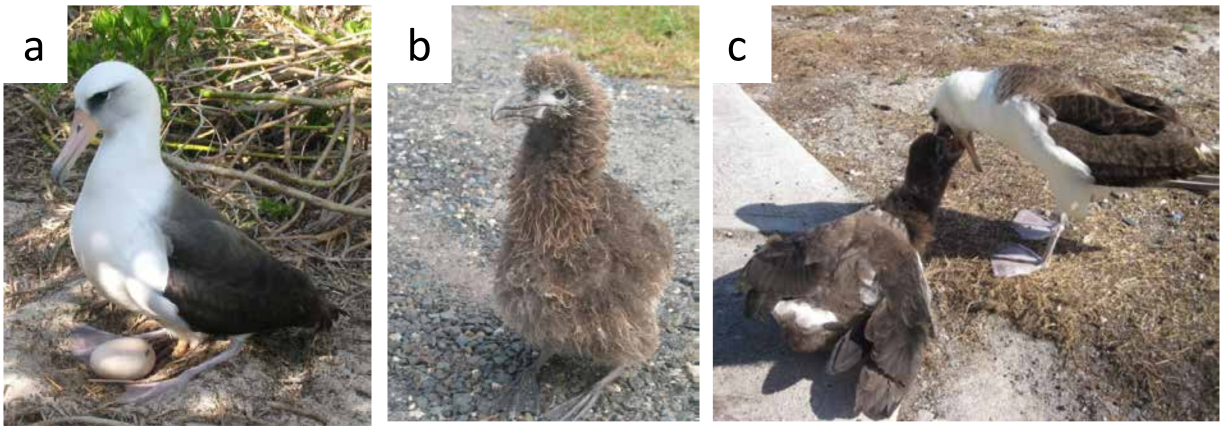

Figure 1: Laysan albatross adult and egg (a), chick (b), and adult feeding chick (c).

Both species feed on anything at the surface of the ocean. Black-Footed Albatrosses feed during the day on flying fish eggs, as well as squid and crustaceans. Laysan albatrosses, whose retinas contain more rhodopsin providing better night vision, feed at night on squid, fish, crustaceans and flying fish eggs. Both species feed their chicks by regurgitating food into the chick's mouth (Figure 1c). The chitinous beaks of squid and other indigestible items fed to chicks (e.g., plastic and fishing line) are retained in chicks' stomachs until the chicks regurgitate a compacted mass, the bolus, just before fledging (Figure 2a and 2c).

Unfortunately, if chicks consume too many plastic items before they are able to regurgitate them, they become more vulnerable to starvation and dehydration, which are the major causes of death (Figure 2b). Although one study showed that ingesting plastic did not directly increase mortality (Sievert and Sileo 1993), another study did show that albatross chicks that died "naturally" (of starvation and dehydration without obvious injury) had more plastic in their guts and lower body masses and fat indices than chicks killed by vehicle collisions (Auman et al. 1997). Another study showed that albatross chicks at Kure Atoll (most northwestern reef in Hawaiian Archipelago) had much more plastic in their boluses than chicks from Oahu, corresponding to satellite tags showing that Kure adult albatrosses foraged much more in the Western Garbage Patch (Figure 3 below) during the breeding season than Oahu adults (Young et al. 2009).

Figure 2: Albatross (a) bolus, (b) decomposing chick with gut of plastic, a common sight at Midway during the summer fledging season, and (c) dissected bolus from http://hilo.hawaii.edu/affiliates/prism/documents/BolusUnit.pdf

Marine Debris: Impacts, Sources, Movement, and What You Can Do
Paraphrased from NOAA Marine Debris 101

Plastic and other **marine debris** can have major impacts in several ways on marine habitats and organisms: wildlife ingestion and entanglement, habitat damage, transport of exotic species, ghostfishing, aesthetic eyesore, vessel damage/navigational hazard, and a variety of economic impacts and human health and safety risks (NOAA Marine Debris 101, EPA Marine Debris Impacts).

- Like seabirds, fishes (Davison and Asch 2011), turtles, and mammals ingest plastic because they mistake plastic for food or ingest plastic accidentally as they ingest (eat) food, which may lead to loss of nutrition, internal injury, intestinal blockage, starvation, and even death. For example, plastic shopping bags may look like jellyfish to hungry sea turtles (Sheavly and Register 2007).
- Many marine animals become entangled in marine debris every year, although the number is not currently estimated, which can lead to injury, illness, suffocation, starvation, and even death.
- Debris can abrade, scour, break, smother, and destroy fragile habitats such as seagrass meadows and coral reefs (Sheavly and Register 2007).
- Marine debris often carries a variety of organisms, such as barnacles, bryozoans, and algae, that may be exotic and even invasive (Gregory 2007).
- In a process called ghost fishing, an abandoned fishing net will continue to catch and

kill ocean life for many years and further stress overwhelmed fisheries. Solutions include using fishing gear with biodegradable parts, educating fishermen to reduce lost gear, and retrieving lost fishing gear.
- Plastic debris also accumulates hydrophobic pollutants in the ocean, such as PCBs, which may magnify up the food chain and even impact humans eating marine organisms and large predators such as orcas (Rios et al. 2007).

Sources of marine debris include:
- Land-based: littering, dumping, and poor waste management practices; storm water discharges; extreme natural events (e.g., tsunamis and hurricanes)
- Ocean-based: fishing vessels; stationary platforms; cargo ships and other vessels.

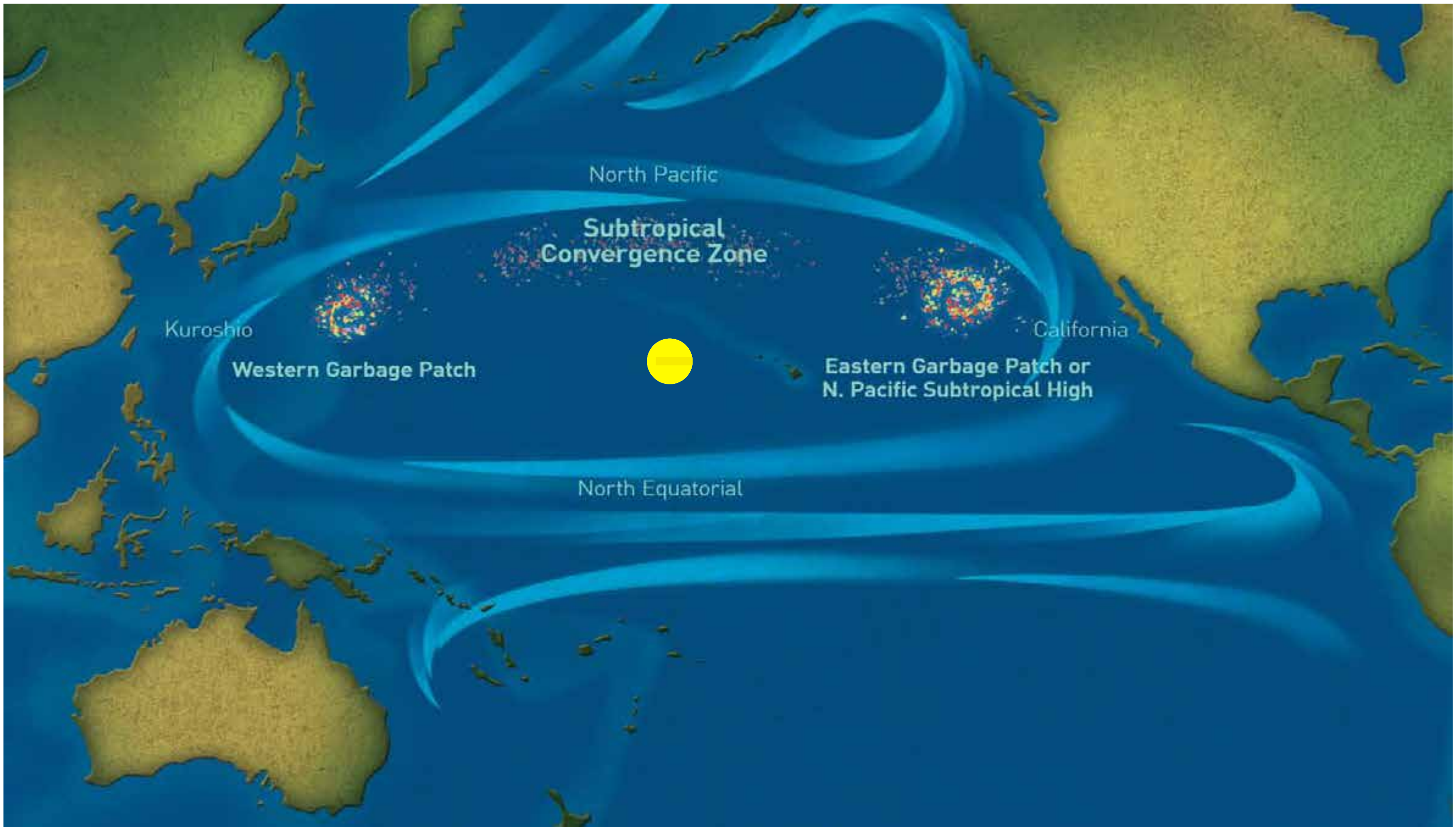

Figure 3: Map of 3 areas in Pacific Ocean where marine debris accumulates: Eastern Garbage Patch or North Pacific Subtropical High, North Pacific Subtropical Convergence Zone, and Western Garbage Patch. Yellow dot indicates Midway Atoll. (http://marinedebris.noaa.gov/info/patch.html)

Floating marine debris moves via ocean currents and atmospheric winds. Debris in the North Pacific Ocean often is transported clockwise by the North Pacific Subtropical Gyre.

Debris often accumulates in the center of the gyre in the North Pacific Subtropical High, often called the "Eastern Pacific Garbage Patch" by the media. This area is midway between Hawai'i and California. There is also a small gyre off Japan that is sometimes called the Western Pacific Garbage Patch. Debris also concentrates in the North Pacific Subtropical Convergence Zone, just north of the Hawaiian Archipelago. This is an area of high productivity, pelagic species feeding and migration, and marine debris concentration – and one of the reasons for marine debris accumulation in Hawaii (NOAA Marine Debris 101). Despite the misnomer "garbage patch," most of the debris in these areas are small bits of plastic that may not even be visible to the naked eye. Because the three Pacific "garbage patch" areas are constantly changing size and location, we can't measure their exact size or easily clean them up.

This module is a good opportunity to encourage students to help reduce the amount of marine debris that enters the ocean (NOAA Marine Debris 101):

- Encourage your school to sponsor or get involved in a local cleanup in your area.
- Reduce, reuse, recycle. Choose reusable items and use fewer disposable ones.
- Keep streets, sidewalks, parking lots and storm drains free of trash - they can empty into our waterways and oceans.
- At the beach, park or playground, dispose of all trash in the proper receptacles or take your trash home with you. Pick up any debris you see while out.
- Support legislation and other measures that help stem the marine debris problem.
- Serve as an example to others. Encourage your friends and family to help keep the beaches and oceans clean.

Glossary

Bolus = compact mass of indigestible material such as squid beaks and plastic regurgitated by albatrosses and other seabirds
Bycatch = nontarget organisms hauled from the ocean and discarded dead in fishery operations (oikonos.org)
Chitin = structural polysaccharide in arthropod (e.g., insects, crabs) exoskeletons, snail radulas, and squid beaks
Entanglement = process of organisms becoming tangled and trapped (often injured and killed) by fishing nets and other marine debris
Ghost fishing = process of an abandoned/discarded fishing net continuing to catch and kill marine life for many years
Ingestion = consumption of a substance by an organism usually through the mouth in animals (= eat)
Marine debris = any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes (NOAA Marine Debris 101)

Plastics = materials composed of repeating chainlike molecules called polymers and usually derived from fossil fuels; used to make many everyday objects because it is often strong, lightweight, flexible, and durable (Monterey Bay Aquarium Plastics in the Water Column)
Polychlorinated Biphenyl (PCBs) = part of broad family of manmade organic chemicals known as chlorinated hydrocarbons which were used in wide variety of industrial and manufacturing purposes between 1929 and 1979 and are demonstrated to cause cancer, as well as a variety of other adverse health effects on the immune system, reproductive system, nervous system, and endocrine system
Rhodopsin = a pigment in the eye retina enabling vision in low light conditions

Science Education Standards Addressed

This module addresses National Science Education Standards A. Science As Inquiry

(p.173-176); B. Life Sciences (p.181-187), F. Science in Personal and Social Perspectives (p.193-199), as well as the following Science Content Standards for California Public Schools:

Biology-Life Sciences, 6. Ecology: Stability in an ecosystem is a balance between competing effects.
b. Students know how to analyze changes in an ecosystem resulting from changes in climate, human activity, introduction of nonnative species, or changes in population size (p. 45).

Investigation and Experimentation, 1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing content in the other four strands, students should develop their own questions and perform investigations. Students will:
a. Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.
c. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
d. Formulate explanations by using logic and evidence.

NSES (http://www.nap.edu/catalog/4962.html)
SCSCPS (http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf);

Project Description

In this project, each class determines a research question, hypothesis, procedures, and datasheet before dissecting albatross boluses from the Northwestern Hawaiian Islands. Students learn about what seabirds eat, how scientists learn what organisms eat, and how pollution affects organisms even in remote places far from populated areas. Students work together with facilitators to design their study, conduct the study, and analyze their results. This project should prompt discussion of how plastic debris impacts marine organisms and how humans can reduce their use and waste of plastics.

Materials

Day 1 & 2:

- Computer with provided Powerpoint presentations
- LCD projector
- Document camera (optional)
- 1 or 2 boluses, probe, forceps
- White board and markers

Day 2 (for each group of 2-4 students):

- Datasheet based on previous day's class decisions on question & procedures
- Bolus (1)
- Tray (1)
- Forceps/tweezers (2)
- Hand magnifying glass (2)
- Probes (2)
- Lab gloves (2 per person - optional)
- Plastic cups (5-7)
- Calculator or computer
- Ruler (2 – depending on question)
- Scale or triple beam balance (1 per group or 2-3 for whole class – depending on question)

Preparation

Unfortunately, US Fish and Wildlife Service is no longer able to provide albatross boluses to teachers, due to budget cuts. You may be able to obtain albatross boluses by contacting Michelle Hester (michelle@oikonos.org) or Kristin McCully (mccully@biology.ucsc.edu – particularly Monterey Bay area schools) at least one month in advance. Teachers in Hawaii, California, Massachusetts, and Oregon can also request Marine Debris Kits through the C-MORE website (http://cmore.soest.hawaii.edu/education/teachers/science_kits/marine_debris_kit.htm), which include albatross boluses. If teachers cannot obtain albatross boluses, Oikonos is posting photographs of boluses specifically for student activities on their website (http://www.oikonos.org/education).

Boluses are difficult to obtain (although they are plentiful at Midway), so please consider re-using boluses by re-compiling them in a labeled plastic bag. Teachers should consider keeping at least one bolus intact for students to see.

Before Day 1, teachers should familiarize themselves with the Powerpoint presentations and background material, look through some of the supplemental resources suggested, choose which videos to use, and dissect a bolus themselves.

Before Day 2, teachers should photocopy the datasheet students design in Day 1, divide the class up into groups of 2-5 students, and prepare trays with supplies for each group.

Timeline

Day 1 (40 min)

1. Powerpoint presentation #1 on albatross life history & conservation (20 minutes)
2. Quick dissection of bolus on document camera (5 minutes)
3. Class discussion of research question, procedures, and datasheet. (15 minutes)

Day 2 (1 hr 45 minutes):

1. Review research question, procedures, and datasheet (5 minutes)
2. Groups dissect boluses & fill out datasheet (35 minutes)
3. Compile class data on whiteboard or computer & projector (5 minutes)
4. Class discussion on data analysis (10 minutes)
5. Groups analyze data & begin written report (20 minutes)
6. Class discussion of results & conclusions (10 minutes)
7. Class discussion, with Powerpoint presentation, of Garbage Patches, other impacts of plastic on marine organisms, and how to reduce amount of plastic reaching the sea. (20 minutes)

Procedure

Day 1:

1. Instructor/fellow will go through Powerpoint presentation with background information on albatrosses as students follow along taking notes or filling out worksheet. Powerpoint presentation is provided and includes basic biological,

geographic, and conservation information on albatrosses. Instructors can also show videos at links provided below. (20 minutes)

- Video of adult Laysan albatross feeding chick: http://www.youtube.com/watch?feature=player_embedded&v=S83TP_iaEg8
- Video of Laysan albatross chick regurgitating bolus from Michelle@oikonos.org: http://www.flickr.com/photos/oikonos/5583087077/
- Video of Laysan albatross courtship: http://www.youtube.com/watch?feature=player_embedded&v=YvpHBALOCAI
- Video of blackfooted albatross courtship: http://www.youtube.com/watch?feature=player_embedded&v=8qYCCbgKzgM#!

2. Instructor will help one or a few students conduct a preliminary dissection of a bolus under a document camera so all students can see. Alternatively, if document camera is not available, instructor could show bolus and items around class on tray. Whole class will compile a list of categories of items found in the bolus (squid beaks, plastics,rocks, etc.). (5 minutes)
3. Instructor will lead discussion and development of research question, procedures, and datasheet. Class decides on one class-wide set of research question, hypothesis, procedures, and datasheet. (15 minutes)

Possible research questions

- What color of plastics do albatrosses ingest most often?
- What size of plastics do albatrosses ingest most often?
- What proportion of items (count or mass) were natural vs. unnatural?
- How common are various identifiable types of plastic (cigarette lighters, toys, fishing line, etc.)?

Methods – mass, count, displacement volume, density

Day 2:

Before class starts, instructor will photocopy datasheet/procedures developed by class for each group or student and prepare trays of supplies for each group.

1. Students will review research question, procedures, and datasheet before moving lab with tray of bolus and tools at each station. (5 minutes)
2. Each group of students will dissect a bolus (optionally wearing lab gloves) and fill out datasheet. Instructor should circulate and help students; he/she may want to point out that some rocks float, which means they are pumice fed to the chicks from their parents, while others don't, which means the chick must have eaten the rock lying around its nest on land. Students should wash hands with soap and water after finishing dissection. Instructor may want to have students spend

a few minutes looking at other boluses. Students should return everything in bolus to labeled plastic bag. (35 minutes)

3. Students will compile data for whole class using whiteboard and/or computer & projector. (5 minutes)
4. Whole class will discuss how to analyze data, using appropriate statistical methods such as mean, bar graphs, etc, which depend on their question. (10 minutes)
5. Each group will analyze data using calculators or computer lab & begin written report. (20 minutes)
6. Whole class will discuss results & conclusions. (10 minutes)
7. Instructor will lead discussion, with Powerpoint, of Garbage Patches, other impacts of plastic on marine organisms, and how to reduce amount of plastic reaching the sea. (20 minutes)
   - Video of albatross necropsy: http://www.youtube.com/watch?v=FinDNPopXQY&NR=1

Figure 4: WHS teacher Jack Horner helps students dissect albatross boluses

Assessment Methods

Worksheet(s) on Powerpoint presentations
Lab report (format and rubric up to instructor)
Class discussion

Notes to Teachers

Students have probably heard that plastics are bad for the environment and that they should avoid using supermarket plastic bags, but may not understand *why* plastics are bad for the environment (e.g., entanglement, ingestion, concentration of pollutants) or may not have thought about how they can reduce plastics reaching the marine environment. They may not realize just how far the marine debris on the beach or in the storm drains can travel. One way to emphasize this is discussing soccer ball, boats, and more washing ashore on the West Coast from the Japan tsunami in March 2011.

Also, students (at least in coastal areas) are probably familiar with seagulls and have at least seen photographs of penguins, but probably have not seen albatrosses (although Monterey Bay Aquarium exhibits a Laysan albatross from Midway and black-footed albatrosses are sometimes observed on the Pacific coast). Students may also be familiar with Hawaii, but probably have not heard of the Northwestern Hawaiian Islands or Midway.

Students may have heard of the "Great Pacific Garbage Patch" and think it is "a large and continuous patch of easily visible marine debris items such as bottles and other litter" that should be visible with satellite or aerial photographs (NOAA Marine Debris 101). While litter items and derelict fishing nets are more common in this area, most of the debris is actually tiny pieces of plastic that may not even be visible to the human eye. (http://www.oceanconservancy.org/our-work/marine-debris/the-pacific-garbage-patch.html)

Instructors may chose to skip slide and question on albatross range and satellite tags, as it is not necessary, but supplementary, to the module's goals. Instructors may also choose to skip slide and question on "Garbage Patches" if students are unlikely to have heard them discussed previously.

This module should be adapted to the capabilities and experiences of students. For use with 9th graders, we created the datasheet and questions in the Appendix, rather than having students create their own datasheet and create a lab report because we ran out of time and students were not accustomed to creating datasheets and lab reports.

Suggested Extensions

- Map locations of satellite tagged albatross in relation to marine protected areas (sanctuaries) and garbage patches (maps and data available from Tagging of Pacific Predators project at topp.org)
- Discuss density of physical objects – albatrosses can only eat plastics & rocks that float!

- Individual or group reports on seabird species
- Compare measurements of bolus components to published papers (e.g., Young et al. 2009)
- Student reports on how to reduce one plastic object found in albatross boluses
- Letters to the editor about reducing plastic use and waste
- SCWIBLES modules (http://scwibles.ucsc.edu/SCWIBLESProducts.html) on "Road to Sustainability: Closing the Loop by Achieving Zero Waste" (by Tara Cornelisse) and Water Quality (by Yiwei Wang and Dan Johnston)

Appendices

1) Powerpoint Presentation
   Part 1: Seabird Ecology (slides 1-17)
   Part 2: Impacts of Marine Debris (slides 19-24)
2) Worksheets
   Worksheet for Powerpoint Presentation #1: Seabird Ecology (+ Key)
   Worksheet for Powerpoint Presentation #2: Impacts of Marine Debris (+ Key)
   Example datasheet & lab report used for 9th graders

List of References and Supplemental Resources

- Oikonos (environmental non-profit organization) information on using albatross boluses as outreach and education: http://www.oikonos.org/education
- Other lesson plans using albatross boluses: www.uhh.hawaii.edu/affiliates/prism/documents/BolusUnit.pdf
- Video of 2nd grade bolus dissection: http://www.youtube.com/watch?v=XilJm5dqbzI
- USFWS. Albatross fact sheets. http://www.fws.gov/midway/midwaywildlifebirds.html
- USFWS. 2011. Seabird Losses at Midway Atoll National Wildlife Refuge Greatly Exceed Early Estimates. http://www.fws.gov/midway/TsunamiSeabirdLossesFinal031811.pdf

  USFWS press release on how 2011 tsunami impacted Midway's seabirds.
- NOAA. Marine Debris 101. http://marinedebris.noaa.gov/marinedebris101/mdinfo.html

  Information on sources, marine debris, including Garbage Patches and impacts of 2011 tsunami in Japan.

- U.S. Environmental Protection Agency (EPA). Marine Debris Impacts. http://water.epa.gov/type/oceb/marinedebris/md_impacts.cfm
- GreenPeace. 2006. Plastic Debris in the World's Oceans. http://www.unep.org/regionalseas/marinelitter/publications/docs/plastic_ocean_report.pdf

  Compilation of research on impacts and distribution of marine debris
- Safina, C. 2003. Eye of the Albatross: Visions of Hope and Survival. Holt Paperbacks.

  Author describes his travels to the Northwestern Hawaiian Islands and what he learns of the issues and lives of seabirds, sea turtles, sharks, and seals, but focuses on albatrosses.
- Auman, HJ, JP Ludwig, JP Giesy, and T Colburn. 1997. Plastic ingestion by Laysan Albatross chicks on Sand Island, Midway Atoll, in 1994 and 1995. Albatross Biology and Conservation: pp. 239-44. http://www.5gyres.org/media/Plastic_ingestion_by_Laysan_Albatross_chicks_on_Midway_Atoll.pdf

  Comparison of plastic content in albatross chicks killed by vehicle collisions and by "natural causes" at Midway, which shows that birds killed by natural causes had more plastic in their guts and lower body masses and fat indices than birds killed by vehicle collisions. This shows that, although plastics may not be a direct cause of death, ingested plastic likely causes physiological stress as a result of satiation and mechanical blockages and indirectly contributes to deaths.
- Davison, P. and R.G. Asch. 2011. Plastic ingestion by mesopelagic fishes in the North Pacific Subtropical Gyre. Marine Ecology Progress Series 432:173-180. http://www.int-res.com/abstracts/meps/v432/p173-180/,http://scrippsnews.ucsd.edu/Releases/?releaseID=1174

  Mesopelagic fishes in the North Pacific Subtropical Gyre (which travel to the surface at night to feed on zooplankton) are shown to contain plastic in their guts.
- Gregory, M.R. 2009. Environmental implications of plastic debris in marine settings -- entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions of the British Royal Society 364:2013-2025. http://rstb.royalsocietypublishing.org/content/364/1526/2013.abstract

  Summary of impacts of plastic debris on marine habitats and organisms
- Kappes, MA, SA Shaffer, Y Tremblay, DG Foley, DM Palacios, PW Robinson, SJ Bograd, DP Costa. 2010. Hawaiian albatrosses track interannual variability of marine habitats in the North Pacific. Progress in Oceanography 86: 246–260.

Analysis of satellite location data of albatrosses from UCSC grad students & faculty.

- Moore, C.U., S.L. Moore, M.K. Leecaster, and S.B. Weisberg. 2001. A comparison of plastic and plankton in the North Pacific Central Gyre. Marine Pollution Bulletin 42(12):1297-1300. http://www.sciencedirect.com/science/article/pii/S0025326X0100114X, http://www.5gyres.org/media/Moore_2001_plastic_in_North_Pacific_Gyre.pdf

  North Pacific Subtropical Gyre has one of the highest measured open-ocean concentrations of plastic debris. The mass of plastic was approximately six times that of plankton, although plankton was more abundant. Although frequently quoted in the media, this study reflects one place at one time of day over 4 days in 1999 with debated methods (dry weight, nets that don't retain phytoplankton, daytime when vertical migrants would be much deeper). Plastics are definitely a big and growing problem in the ocean, but media stories too often generalize this paper incorrectly. Good discussion of the article in Wall Street Journal in 2009 (http://online.wsj.com/article/SB123793936249132307.html)

- Rios, L.M., C. Moore, and P.R. Jones. 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. Marine Pollution Bulletin 54:1230-1237. http://www.5gyres.org/media/Persistent_organic_pollutants.pdf

  Pre-production plastic pellets and post-consumer plastic fragments were collected from the North Pacific Gyre, California, Hawaii, and Mexico and analyzed for contamination by persistent organic pollutants (PCBs, DDTs, and PAHs).

- Ryan, P.G. 1990. The effects of ingested plastic and other marine debris on seabirds. pp. 623-634 in: R.S. Shomura and M.L. Godfrey (eds.), Proceedings of the Second International Conference on Marine Debris, April 2-7, 1989. Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-154. http://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-154_P623.PDF

  Review of research on effects of ingested plasatic and other marine debris on seabirds to 1990.

- Shaffer SA, Y. Tremblay, JA Awkerman, RW Henry, SLH Teo, DJ Anderson, DA Croll, BA Block, DP Costa. 2005. Comparison of light- and SST-based geolocation with satellite telemetry in free-ranging albatrosses. Marine Biology 147:833-843.

  Analysis of satellite location data of albatrosses from UCSC grad students & faculty.

- Sheavly, S.B. and K.M. Register. 2007. Marine debris and plastic: Environmental concerns, sources, impacts, and solutions. Journal of Polymers and the Environment 15:301-305. http://www.springerlink.com/content/914338t508377262/

Summary of impacts of plastic debris on marine habitats and organisms

- Sievert, P.R. and L. Sileo. 1993. The effects of ingested plastic on growth and survival of albatross chicks. In: Vermeer K, Briggs KT, Morgan KH, Siegal-Causey D, editors. pp. 212–17. The status, ecology, and conservation of marine birds of the North Pacific Ottawa: Canadian Wildlife Service Species Publication. http://www.pacificseabirdgroup.org/publications/MB_of_NOPAC/SP1993_CWS_EC_21.pdf

  Authors studied growth and survival of albatross chicks naturally and artificially fed plastic. They found that mechanical lesions caused by ingested plastic were the cause of death of only one of 93 examined dead albatross chicks They found that plastic ingestion reduced the growth of Laysan albatross, but not black-footed albatrosses and that plastic ingestion was not a significant direct cause of death in chicks. However, this is the experimental examination of the effects of plastic ingestion on albatross chicks and they only used 2 years and a relatively small sample size.

- Young LC, Vanderlip C, Duffy DC, Afanasyev V, Shaffer SA (2009) Bringing Home the Trash: Do Colony-Based Differences in Foraging Distribution Lead to Increased Plastic Ingestion in Laysan Albatrosses? PLoS ONE 4(10): e7623. www.plosone.org/article/info:doi/10.1371/journal.pone.0007623

  Comparison of bolus plastic content and foraging geography of Laysan albatrosses from Oahu and Kure. Chicks from Kure were fed much more plastic and adults from Kure foraged much more in the western garbage patch during the breeding season than albatrosses from Oahu.