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The Ecotoxicology of Plastic Marine Debris

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ABSTRACT

The accumulation of plastic in the oceans is an ever-growing environmental concern. Plastic debris is a choking and entanglement hazard for wildlife; plastics also leach toxic compounds into organisms and ecosystems. Educating students about the marine debris problem introduces fundamental concepts in toxicology, ecology, and oceanography. Students will learn about the toxicity of plastics, collect and analyze data on plastic debris, and put their new knowledge to work by writing a congressional bill that addresses the problem of marine debris.

Key Words: Ocean pollution; toxicology; ecosystem health; ocean literacy; environmental science.

The National Oceanic and Atmospheric Administration (NOAA) defines marine debris as “any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment...” (<http://marinedebris.noaa.gov/>). This issue is but one example of numerous human impacts on the ocean. Unfortunately, most Americans are ocean-illiterate (Ocean Project, 2009) – that is, they do not understand “the ocean’s influence on you, and your influence on the ocean” (National Geographic Society, 2006). The activities described below will assist students in making connections to the ocean.

The ever-growing problem of marine debris begins on land, where streams and rivers carry debris to the coast. Ocean currents then transport debris to remote areas, where it may take centuries to break down (Goldberg, 1994). Awareness of the marine debris problem has increased because of recent reports on the Eastern Pacific Garbage Patch (EPGP). The EPGP is an area between California and Hawaii that contains a large quantity of small “microplastic” pieces derived from the breakdown of larger plastic items (Marks & Howden, 2008). The plastic debris both near the coast and in the EPGP can endanger the health of marine organisms (Derraik, 2002).

Plastic debris poses a danger to all forms of aquatic life. Many marine organisms can become entangled or can ingest plastic debris. Certain marine species, such as sea turtles and seabirds, mistake plastic for prey items (Nevins et al., 2005; Hyrenbach et al., 2009;

Mrosovsky et al., 2009). For example, adult albatrosses inadvertently feed their chicks plastics instead of natural food items, which affects chick growth and may cause mortality (Ryan & Jackson, 1987; Pierce et al., 2004). Furthermore, an insidious hazard lurks within plastics. The toxic chemicals added to make plastics more flexible, known as plasticizers, can leach out into the environment and into organisms that ingest plastic (Rahman & Brazel, 2004). Other dangerous chemicals can concentrate on plastic surfaces (Mato et al., 2001), increasing the toxicity of plastics.

A major concern about the toxic compounds associated with plastics is that they can disrupt hormone regulation in the cells of organisms (Oberdörster & Cheek, 2001). Hormone disruption occurs when a chemical acts as a natural hormone in a cell (Figure 1); it can change reproductive ability and mating behavior, contribute to tumor development, and negatively affect offspring (van de Merwe et al., 2010; Wuttke et al., 2010). For example, male fish exposed to hormone-disrupting compounds can develop ovaries (Gray & Metcalfe, 1997). Additionally, certain plastics, such as styrene (Styrofoam), are carcinogenic (Vodicka et al., 2006).

The lessons below (objectives listed in Figure 2, materials and equipment in Table 1) couple process skills with the underlying science of plastic pollution. They can be modified to be appropriate for grades 6–10. Oikonos Ecosystem Knowledge in partnership with many collaborators (see Acknowledgments) created the overall marine debris curriculum. The plastic-pollution curriculum described here was further developed and modified by CAMEOS, a National Science Foundation Graduate K–12 program, at the University of California Davis Bodega Marine Laboratory.

○ Lesson 1: Introduction to Marine Debris & Toxicology of Plastics

Lesson Time: 1 hour

This lecture familiarizes students with key concepts regarding the origin and transport of debris, the chemical structure of plastics,

Plastic debris poses a danger to all forms of aquatic life.

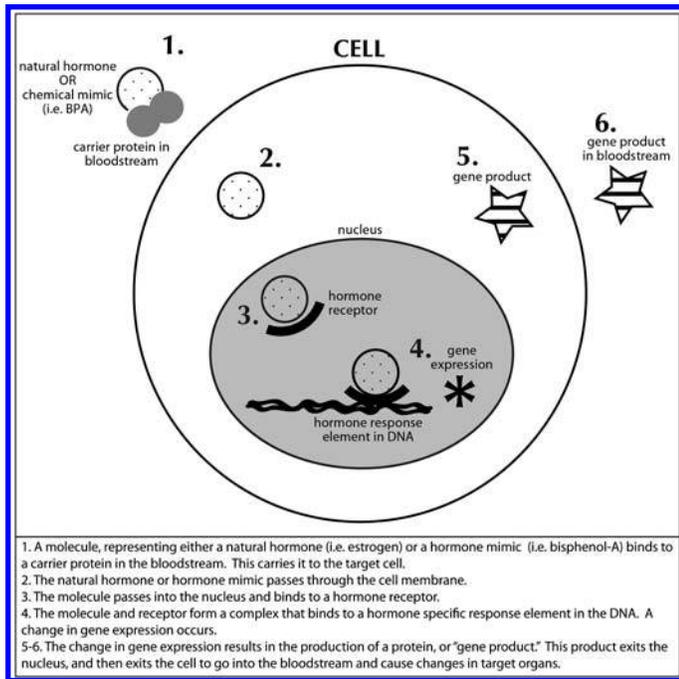


Figure 1. The cellular pathway of hormone disruption.

and the toxicology of plastic-associated chemicals and how they can affect marine organisms. The presentation, found on the CAMEOS website (<http://bml.ucdavis.edu/education/cameos/resources/ecotoxicology/>) includes extensive teacher notes. Following Lesson 1, students will be able to define terms (e.g., plasticizer, bioindicator species) and understand concepts (e.g., how certain compounds disrupt hormones).

Lesson 2: Campus Debris Survey & Plastic Analysis

Lesson Time: 90–120 minutes

Lesson 2 involves a campus debris survey and analysis of debris found. Students will formulate a scientific protocol; collect, analyze, and interpret data; and compare results.

Table 1. Materials and equipment needed.

Lesson 1	Lesson 2	Lesson 3
Computer	Transect tape	"Making a Bill" worksheet ^a
Projector	Oikonos data sheet for campus debris survey ^a	Computer lab with Internet access ^b
Introduction to Marine Plastics Presentation ^a	Clipboards	
	Trashbags Plastic gloves Stopwatches ^b Tables of plastic types and toxic compounds Data sheet for plastic analysis ^a	

^aAvailable on CAMEOS website, <http://bml.ucdavis.edu/education/cameos/resources/ecotoxicology/>

^bOptional, lesson can be done without

Students will be able to ...

- ★ Describe issues associated with marine debris and give examples of their impact on the aquatic environment.
- ★ Implement scientific sampling methods, and use Microsoft Excel to visualize data and interpret results.
- ★ Relate the issue of marine debris to the endocrine system, cell function, and ecosystems.
- ★ Formulate policy solutions based on scientific understanding.

Figure 2. Ecotoxicology of Marine Debris lesson objectives.

Campus Debris Survey

- Assemble debris collection teams of 4 or 5 students. (Alternatively, students can bring in a variety of plastic debris from home).
- Give students the list of materials in Table 1 and discuss the importance of each debris-collection team using the same protocol. For example, in order to have comparable data between groups, students should be collecting in areas of similar size and over similar time intervals.
- Assign each team to a distinct area, such as a sports field (equivalent areas approximately 20 × 20 m are best).
- Teams should measure and mark their collection area. One student will record data (using clipboard with data sheet) while others wear protective gloves and place trash collected into two bags, one for plastics and one for nonplastics. All debris should be recorded and students should collect as much debris as possible in their designated area during the collection time (~15-minute collection period is best).
- Remind students to record any observations as they are conducting the survey. Students should save plastic trash for part 2 of this lesson.

Table 2. Types of plastics.

Plastic Type	Full Name	Code	Examples	Recyclable?
PETE	Polyethylene terephthalate	1	Soda bottles	Yes
HDPE	High density polyethylene	2	Milk jugs, shampoo bottles, yogurt containers	Yes
PVC	Polyvinyl chloride	3	Clear food packaging, candy wrappers, some bottles	Sometimes
LDPE	Low density polyethylene	4	Squeezable bottles, shopping bags	Yes
PP	Polypropylene	5	Caps, straws, some bottles	Yes
PS	Polystyrene	6	Disposable plates and cups, CD cases	Sometimes
PC, other	Polycarbonate	7	Water jugs, sunglasses, DVDs	Not usually

○ Plastic Data Analysis

In the second part of this lesson, students will categorize and analyze the plastic debris to understand the kinds of plastics and associated contaminants found on their school campus.

Groups will sort collected plastics into categories described in Table 2 and note the contaminants associated with each category (Table 3), following the example in Figure 3. Upon completion, data can be graphed using Microsoft Excel or by hand. Data sheets and Excel lessons with step-by-step instructions can be found on the CAMEOS website. Students can summarize Lessons 1 and 2 in a laboratory report assignment, using the background information from Lesson 1 and the methods and results developed in Lesson 2.

○ Lesson 3: Putting Science into Action

Lesson 3 requires students to combine new knowledge of marine debris and plastic pollution with concepts from civics and government classes. Students formulate and justify legislation on the basis of their scientific knowledge, reinforcing the importance of science to society.

- Give students the “Making a Bill” worksheet found on the CAMEOS website. The introduction describes how science influences policy and the actions a bill can mandate, such as pollutant monitoring.
- Have students go to the Library of Congress website (<http://thomas.loc.gov/bss/111search.html>) to search for

Table 3. Toxic compounds in or associated with plastics: their uses and effects.

Toxic Compound	Use	Effect(s)	Plastic Type(s)	Concentration
Bisphenol A (BPA)	Plasticizer, can liner	Mimics estrogen	PVC, PC	43–483 mg/kg in PVC food wrappers ^a (López-Cervantes & Paseiro-Losada, 2003)
Phthalates	Plasticizer, artificial fragrances	Interferes with testosterone, sperm motility	PS, PVC	0.5–30.8 mg/kg in food wrappers ^b (Castle et al., 1988)
Persistent organic pollutants (POPs)	Pesticides, flame retardants, etc.	Possible neurological and reproductive damage	All plastics	
Dioxins	Produced in manufacture of PVC, during waste incineration	Carcinogen, interferes with testosterone	All plastics	
Nonylphenol	Antistatic, antifog, surfactant (in detergents)	Mimics estrogen	PVC	10–3300 µg/g ^c (Inoue et al., 2001)
Polyaromatic hydrocarbons (PAHs)	Produced when fossil fuels are burned	Developmental and reproductive toxicity	All plastics	
Polychlorinated biphenyls (PCBs)	Electronics manufacture	Interferes with thyroid function	All plastics	
Styrene monomer	Structure of polystyrene	Forms DNA adducts	PS	<0.001–0.071 mg/kg ^d (Tawfik & Huyghebaert, 1998)

^a Total amount detected in food wrappers.

^b Amount leached into various food products (i.e., candy bars, sandwiches).

^c Total amount migrated from PVC food wrap to various food products.

^d Amount leached into beverages from styrene cups (more styrene leached into beverages with higher fat content).

Data Collectors: Susanne, Rachel, Tawny, Michael			
High School, Class Name: Lincoln High School, Period 2			
Data Collection Site (descriptive or GPS coordinates): baseball diamond, Latitude: 38-15'03" N Longitude: 122-47'14" W			
Date: 10/13/2010			
Start Time: 10:43 AM		End Time: 10:58 AM	
Number	Plastic Type	Common Items	Number of Items (tally)
1	polyethylene terephthalate	Soft drink, water and beer bottles; mouthwash bottles; peanut butter containers; salad dressing and vegetable oil containers; ovenable food trays.	
2	high density polyethylene	Milk jugs, juice bottles; bleach, detergent and household cleaner bottles; shampoo bottles; some trash and shopping bags; motor oil bottles; butter and yogurt tubs; cereal box liners.	
3	vinyl or PVC	Window cleaner and detergent bottles, shampoo bottles, cooking oil bottles, clear food packaging, wire jacketing, medical equipment, siding, windows, piping, candy wrappers	contaminants: bisphenol-A, nonylphenol, phthalates

Figure 3. Sample data sheet for Lesson 2, which shows how to record data and add comments about contaminants found in plastics collected.

environmental terms related to this topic (e.g., plastic, pollution, conservation). This process will introduce students to the content and format of environmental bills. If you do not have computer access at school, example bills are available for printing on the CAMEOS website.

- Students will write a formal bill that includes a title, list of sponsors, background information, proposed action, and potential funding methods.
- Good bills should incorporate knowledge from the marine debris lessons and be creative. Once bills are complete, have each group outline their bill and present it to the class for debate, discussion, and possibly a vote.

Websites with Supplemental Materials & Information

Lesson materials on the CAMEOS website: <http://bml.ucdavis.edu/education/cameos/resources/ecotoxicology/>

Oikonos Ocean Stewardship's website contains additional ocean education activities and resources not covered in this article: <http://www.oikonos.org/projects/oceanstewardship.htm>

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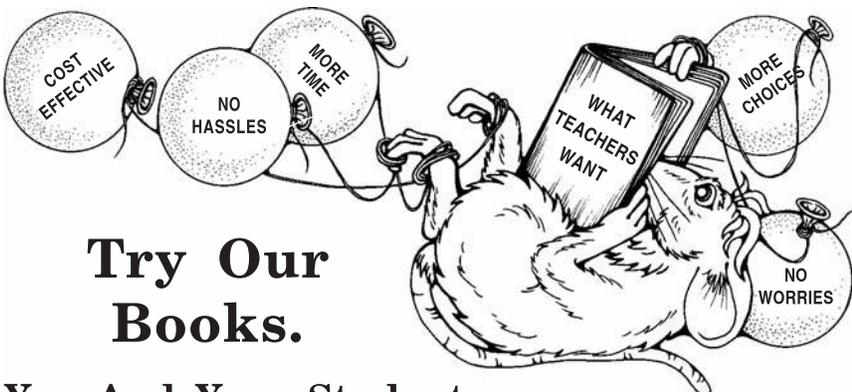
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