INQUIRY & INVESTIGATION

Floating Fishes: An Activity Investigating Overfishing, Buoyancy & Gas Compressibility

DONOVAN P. GERMAN, DORIS A. RAVEN, NANCY AGUILAR-ROCA

Abstract

Fish species are an important food resource all over the world, but the fishing practices of human beings are slowly driving many fish species to extinction. However, little is being done to communicate the problem of overfishing to the general public. In this three-part activity, students are introduced to the concepts of buoyancy and overfishing in an effort to provide a glimpse of how interesting fish are, and to raise awareness of overfishing. The students investigate buoyancy and gas compressibility by recreating a mysterious boat-sinking in the classroom, and by manipulating the buoyancy of artificial fish. By engaging in "fishing expeditions" with diminishing returns, the students learn why fish populations decline when we take too many of them. Throughout the activity, students have the opportunity to learn science as inquiry and the nature of science as presented in the National Science Education Standards.

Key Words: *Buoyancy; overfishing; gas compressibility; inquiry.*

Introduction

Human beings have become increasingly detached from nature in recent years. In no demographic is removal from the natural world more obvious than in children, which in Western industrialized nations know more of cartoon characters and "charismatic" taxa (e.g., lions) than of animals in their surrounding environment (Balmford et al. 2002, 2015; Genovart et al., 2013). This detachment from nature is further evident in the indifference people express toward the extinction of animals, both aquatic and terrestrial. Unless people feel connected to an organism (e.g., blue whale), they will care nothing about its disappearance. We have designed an inquiry-based activity to introduce students to fish, many species of which are quietly being driven toward extinction by fishing practices. Through exercises integrating physics (buoyancy), the biology of fish, and the consequences of overfishing (Table 1), we hope to pique the interests of students regarding fish species and their conservation.

Hundreds of years of research have discovered many interesting facts about fish, one of which is how these animals regulate buoyancy.

Overfishing

A species is said to be overfished when its population size is "exhausted," or when fishing effort is rewarded with diminishing returns (Figure 1). Fisheries all over the world have been experiencing decreased catches (World Resources Institute, 1994; Dulvy et al., 2003), with some estimating that as little as 10% of original populations remain (Myers et al., 1997; Dulvy et al., 2003; World Wildlife Fund, 2015). Moreover, large-scale fishing efforts often capture nontarget species that are undesirable to fishermen, and this "bycatch" is simply discarded, dead, back into the ocean, providing little value economically or ecologically; indeed, the fish are often left floating on the surface of the ocean.

Overall, the urgent problem of overfishing has not been well communicated to the public (but things are changing; see World Wildlife Fund, 2015), in part because fish are a great dietary resource, providing protein as well as essential omega-3 fatty acids, and because the populace knows little of the life histories or biology of fish species. The transition from a mindset of inexhaustibility to one of fragility requires awareness of what fish are, what their roles are in aquatic environments, and what happens when we catch them.

Purpose

Hundreds of years of research have discovered many interesting facts about fish, one of which is how these animals regulate buoyancy. Furthermore, buoyancy is one of the more lackluster topics taught

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Table 1. Potential uses of “Floating Fishes” for different topics in different classes.

Potential Classes	Topics Covered	*Next Generation Science Standards*
Physical science	Pressure, buoyancy, swimming and movement, density, confined gases, Pascal’s principle	MSPS2-2, HS PS2-3
Biology	Fish biology, ecology, overfishing, bycatch, physiology, biochemistry	MS LS2-4
Earth system science	Pressure, buoyancy, saltwater vs. freshwater, density	HS ESS3-1, HS ESS3-3

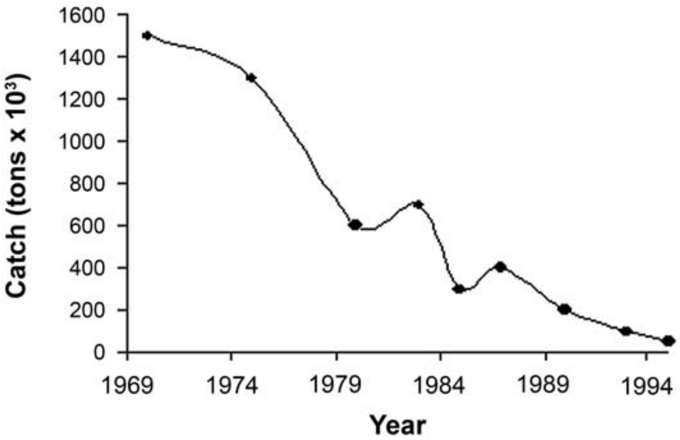


Figure 1. Newfoundland cod fishery catch, 1969–1995. Modified from Roughgarden and Smith (1996).

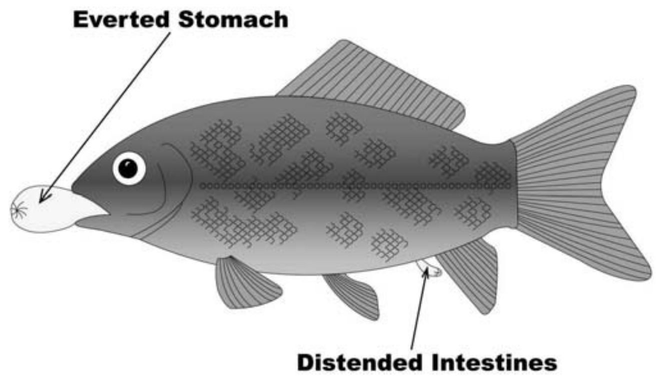


Figure 3. Sketch of a fish with stomach and intestine distended because of swim bladder expansion caused by a rapid decrease in pressure.

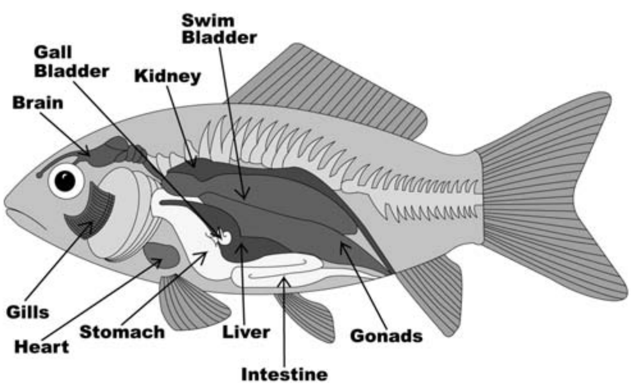


Figure 2. Anatomy of a generalized fish.

in physical sciences, and this activity, using fish as the subject, makes buoyancy more interesting to students.

Buoyant force is the upward force (upthrust) that water exerts on an object, counteracting the downward force due to gravity that the object is applying to the water. Bouyancy is based on Archimedes’ principle, which states that buoyant force is equal to the weight of the fluid displaced by an object, such that objects with greater volume displace more fluid and, hence, will experience greater upthrust. If an object is less dense than the water around it, the gravitational force (GF) is less than the buoyant force (BF) {GF < BF}. Therefore, such an object is positively buoyant; it floats, like a boat. If GF > BF, then the object is more dense than water and will sink (i.e., it is negatively buoyant) like a stone. If GF = BF, then the object will neither sink nor float to the surface and is considered neutrally buoyant. Fish are the best example of neutrally buoyant objects. But what allows a fish to be neutrally buoyant? Fish possess a special organ called a “swim bladder” (Figure 2) that they fill with oxygen.

Because gases are compressible, and because pressure increases with depth, fish have to monitor the amount of gas in their swim bladders to ensure neutral buoyancy. For example, if a minnow swimming at the surface suddenly dives deeper to avoid being eaten by a bird, the gas in its swim bladder becomes compressed to the point that the fish is no longer neutrally buoyant (i.e., the gas now takes up less space and provides less buoyancy). Thus, the minnow needs to place more air into the swim bladder to maintain neutral buoyancy at the new depth. If the minnow then shoots to the surface to avoid being eaten by a largemouth bass, the fish must release some air from its swim bladder to avoid floating on the surface and compromising its escape. An unfortunate side effect of this buoyancy strategy is that when fish are captured by fishermen, either in nets or by hook and line, they are pulled from depth more rapidly than they usually experience, and against their will. In these scenarios, fish do not regulate the volume of their swim bladders, and, consequently, their swim bladders expand rapidly due to the loss in pressure and force the fish’s gut lining and stomachs to protrude from any open avenue (i.e., their mouth and anus; Figure 3).

Sharks do not possess a swim bladder and instead have an enlarged oily liver. The less dense oil in the liver allows them to maintain a more neutrally buoyant position in the water column. Furthermore, because liquids (in this case, oil) are incompressible, sharks are neutrally buoyant at all depths and do not need to regulate the amount of oil in their livers for buoyancy.

Asking students if they have been fishing elicits positive responses. Further, when asked if they have seen a fish’s stomach protruding from its mouth after catching it (Figure 3), many students affirm this observation but do not know its meaning.

In this four-part activity, students are introduced to the concepts of overfishing, neutral buoyancy, and gas compressibility. By performing an investigation into a mysterious boat-sinking, the students will learn about buoyancy, and what might cause a boat to sink. By observing fish in an aquarium in the classroom, and by manipulating the buoyancy of artificial fish, students will examine how fish and sharks achieve neutral buoyancy in their watery world. By examining the effects of pressure on gases, students infer what happens to fish as they are pulled up quickly from depth. And, by engaging in "fishing expeditions" with diminishing returns, the students will learn how fish populations decline when we remove too many of them (i.e., we take more than can reproduce), and when bycatch levels can be so high. The modularity of these activities gives the instructor freedom to choose which activities to perform and the order in which they are used. For example, if one wishes to emphasize the biology of fish, our presented order works well, and the boat activity can be ignored (if short on time). However, if one wishes to emphasize overfishing, one can start with the activity from day 4, and proceed to the other activities following the overfishing activity. See the online supplementary materials (http://german.bio.uci.edu/Supplements.html).

○ Learning Objectives

After performing this activity, the student will be able to

- define negative, neutral, and positive buoyancy;
- explain how fish and sharks control buoyancy;
- demonstrate that gases are compressible; and
- articulate what overfishing is, how it is a problem, and what they can do to help remedy the situation.

○ Target Groups

The activity is appropriate for middle and high school students (grades 6–12) and can be used in an array of science classes to cover diverse topics (Table 1). See the supplementary material for more questions and follow-up activities: http://german.bio.uci.edu/Supplements.html.

The exercise takes at least four full class periods to complete. The discussions involve the whole class, but students can work in groups of three or four to complete the laboratory activities.

○ Materials (per Lab Group)

Day 2: Boat-Sinking Lab

- 1 cardboard "boat" (half-gallon milk carton cut in half long-ways)
- 2 cardboard strips: 3 × 13 cm and 3 × 5.8 cm
- Scissors
- 200–250 marbles or small rocks
- 1 water trough filled with water (10–15 L)
- 1 towel

Day 3: Fish Buoyancy Lab

- 1 balloon
- 1 empty small water bottle (237 mL)
- 1 small water bottle containing water and vegetable oil (237 mL)
- 1 Ziploc bag
- 1 measuring tape
- 1 water trough filled with water (11.34 L)
- 1 towel
- 1 aquarium housing at least one fish (optional)

Day 4: Fishing Expedition

- 3 small paper or plastic bowls (or more if you wish each fisherperson to have their own bowl)
- 1 Ziploc bag full of Goldfish crackers
- 50 colored beads
- 3 plastic spoons (one for each individual fisherperson)
- 1 plate
- 1 small plastic cup

○ Activity

Day 1: Introduction & Background

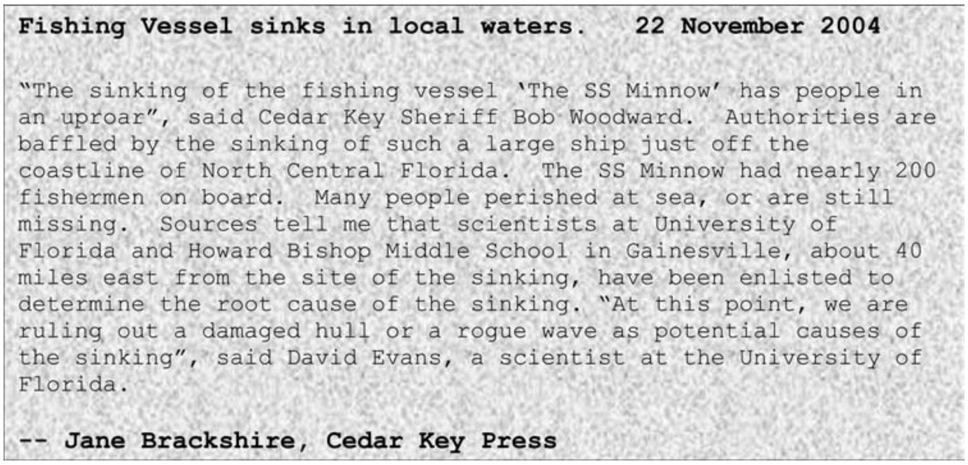
You will need one 50-minute class period to introduce the concept of buoyancy and prepare for the activity. We recommend introducing overfishing in the framework of renewable resources and reviewing pertinent information with the students. Open a discussion of fish as a food resource and where fish come from. A review of fish anatomy (Figure 2) would be helpful, focusing on the swim bladder, which is crucial to the success of the buoyancy activity. Showing pictures of large trawl nets filled with fish (obtained by searching the phrase "bycatch" in Google Images) can show how many fish can be caught in a commercial fishing operation.

Day 2: Boat-Sinking Lab

This lab day is used to teach the students about positive and negative buoyancy as a primer for the activity. Before the students get to class, put all of the supplies at the student lab stations and fill water troughs with water. (*Note:* The boats maintain their resilience throughout the day and can be used multiple times.) See the supplementary questions online for assessment of this and the other activities. To start the class, we provide a "newspaper article" to the students to pique their interest about the activity (Figure 4). (*Note:* The article can be altered to suit your geographical needs.)

Procedure:

1. Have the students get around their water troughs in their groups. Instruct them to put their boats (see materials) in the water and confirm that they float evenly.
2. Instruct them to add marbles to their boat one at a time. Have the students record (on a separate piece of paper) what is happening to the marbles as they place them in the boat.



Fishing Vessel sinks in local waters. 22 November 2004

"The sinking of the fishing vessel 'The SS Minnow' has people in an uproar", said Cedar Key Sheriff Bob Woodward. Authorities are baffled by the sinking of such a large ship just off the coastline of North Central Florida. The SS Minnow had nearly 200 fishermen on board. Many people perished at sea, or are still missing. Sources tell me that scientists at University of Florida and Howard Bishop Middle School in Gainesville, about 40 miles east from the site of the sinking, have been enlisted to determine the root cause of the sinking. "At this point, we are ruling out a damaged hull or a rogue wave as potential causes of the sinking", said David Evans, a scientist at the University of Florida.

-- Jane Brackshire, Cedar Key Press

Figure 4. Sample newspaper article.

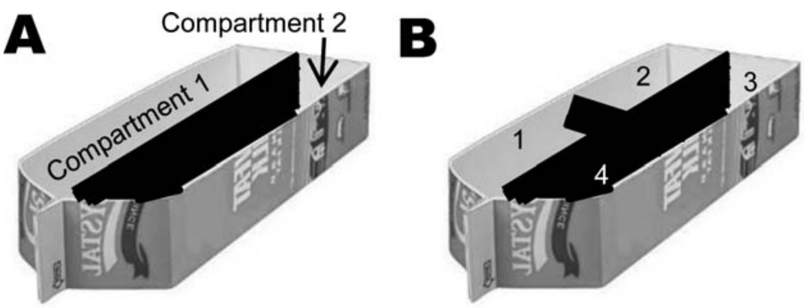


Figure 5. Cardboard strips placed in boat (**A**) along the beam and (**B**) crossways.

3. Allow the students to explore how many marbles it takes to sink their boat. Have them record what happens and have them articulate why they think they are seeing what they are.
4. Instruct the students to now add a compartment to their boat using the 3 × 13 cm cardboard strip, as illustrated in Figure 5A. (See supplementary materials for ideas on making this part more inquiry-based.)
5. Have the students add marbles to one side of the boat only. Have them record what happens. How many marbles could their boat hold?
6. Now have the students add marbles to both compartments. Ask them if their boat can hold as many marbles as when there were no compartments (in step 3).
7. Have the students add an additional cardboard wall by sliding the 3 × 5.8 cm cardboard piece into the boat, as illustrated in Figure 5B. It is helpful to add a slit vertically in the middle of this second cardboard piece so that it can slide over the first cardboard piece.
8. Now, have the students add marbles to the boat and record how many the boat can hold. Display Figure 6 on an overhead or LCD projector. Have the students study the illustration and hypothesize whether the *SS Minnow* sank bow first or stern first.

Day 3: How Do Fish Control Buoyancy?

We recommend having an aquarium with a fish in the classroom. By having fish for the students to observe, or at the very least a video of fish swimming, they can get a better appreciation of how fish maintain neutral buoyancy. Before the students get to class, make sure that the supplies are at their lab stations and that the water troughs are filled with water. If you conduct these laboratories on consecutive days, then you can leave the water troughs filled with water from day 2. It is crucial that you prepare an oil–water mixture in a bottle for each group. This bottle is to contain water and oil only (no air) and is to be neutrally buoyant when placed in the water trough. A ratio of 15:1 (v:v) water to oil works well, but due to inconsistencies among bottles, each bottle should be tested individually to confirm that it is neutrally buoyant. Water or oil can be decanted (with a dropper) and added until the right buoyancy is achieved. This oil–water mixture bottle is used to represent sharks, which use an oily liver to maintain neutral buoyancy.

Procedure:

1. Have the students gather around their water troughs in their groups.
2. Have the students place the bottle with the oil–water mixture in the water trough and have them record their observations (Figure 7).
3. Next have the students place the empty bottle in the water trough and record their observations (Figure 7).
4. Now have the students fill the empty bottle with water by placing the uncapped bottle underwater in the water trough and letting the water fill the bottle. Make sure the students cap the bottle while it is underwater to ensure that NO AIR is in the bottle. Instruct them to let the bottle go and record their observations (Figure 7).
5. Now challenge the students to make the bottle with just water in it be neutrally buoyant like the bottle with the oil–water mixture. As they ask questions, inform them that they cannot add oil to that bottle and that they are to find another way to

Figure 6. The *SS Minnow* on the sea floor off Cedar Key. Figure available online (http://german.bio.uci.edu/Supplements.html).

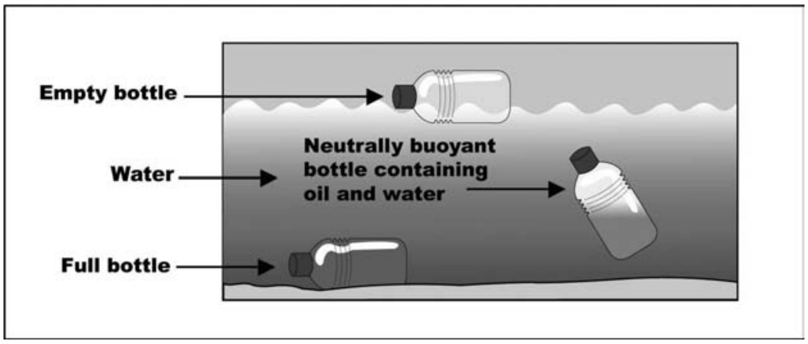


Figure 7. Schematic of the bottles used in day 3, fish buoyancy lab.

make the bottle neutrally buoyant. Most students will quickly discern that they are to use air. But how much? This is where the students have to figure out just how much air to add to the bottle to make it neutrally buoyant.

6. Once the students have made their bottles neutrally buoyant, have them fill the Ziploc bag with air and seal it almost completely, leaving a small opening (maybe 0.75 cm) in the Ziploc at the top. Now, have them gently force the bag into the water, pulling it down from its bottom but maintaining the its upright position. Have them stop when the top of the bag reaches the surface of the water and record their observations.
7. Have the students fill a balloon with a SMALL AMOUNT OF AIR, such that the balloon is about 1 foot in circumference (use the measuring tape). Once the balloon is the correct size, have them tie it off and, one more time, confirm its circumference _________. [1 foot]
8. Instruct the students to force the balloon underwater to the bottom of the water trough. Emphasize that the balloon is not to be pushed onto the bottom and is to just be held down. Tell the students that as one lab partner holds the balloon underwater, another should use the tape measure to determine the circumference of the balloon underwater. What is it? _______. [<1 foot] Is it smaller or larger than the circumference of the balloon when it was in the air? ___________. [smaller]

Day 4: Fishing Expedition

We recommend reviewing the concept of overfishing and any pertinent information with the students.

Procedure:

1. Have the students wash their hands and get into their groups.
2. Give each group of students three bowls: one is to be filled with crackers and colored beads, another is to be empty and labeled "ocean," and the third is to be empty and labeled "boat." Assign roles in each group; they will need one "fish filler," and the rest of the group are fisherpersons. In a modified version, each fisher can have an individual boat.
3. Have the "fish filler" fill one small plastic cup with crackers and colored beads from the full bowl and pour the contents into the "ocean" bowl. Keep the "boat" close by.
4. Instruct the fisherpersons to "fish" the crackers and beads from the "ocean" with spoons and place them into the "boat." Once the "ocean" is empty, instruct the "fish filler" to pour another small plastic cup full of crackers and beads into the "ocean." Have the students repeat these steps, but tell them to speed up the process for each new filling and observe whether the new introduction of crackers and beads can match the fishing of them from the "ocean." Have the students repeat these exercises until the original full bowl is empty and all the crackers and beads are in the "boat." By allowing each fisherperson to have an individual boat, and allowing the fisherpersons to use their hands instead of spoons, the activity can address human population size and fishing technology.
5. Next, tell the students to sort their catch into crackers and beads on a clean plate.
6. Instruct the students to enjoy their crackers as a group, and pour their beads back into the ocean.

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