## 2007: Exploring the Inner Space of the Celebes Sea

# Great Blobs of Jelly!

### Focus
Ocean zooplankton

### Grade Level
9-12 (Biology)

### Focus Question
How may oceanic zooplankton influence global chemical processes?

### Learning Objectives
Students will explain how zooplankters such as salps may have significant impact on global processes.

Students will calculate plankton densities from appropriate information on sampling procedures.

Students will calculate carbon flux from experimental data.

### Materials
❒ Student Worksheet

### Audio/Visual Materials
None

### Teaching Time
One or two class periods, plus time for student research

### Seating Arrangement
Classroom style or groups of 2-3 students

### Maximum Number of Students
30

### Key Words
Plankton
Zooplankton
Salps
Celebes Sea
Carbon
Carbon dioxide
Global climate change
Worksheet calculation
Worksheet research

### Background Information
Indonesia is well-known as one of Earth's major centers of biodiversity. Although Indonesia covers only 1.3 percent of Earth's land surface, it includes:
- 10 percent of the world's flowering plant species;
- 12 percent of the world's mammal species;
- 16 percent of all reptile and amphibian species; and
- 17 percent of the world's bird species.

In addition, together with the Philippines and Great Barrier Reef, this region has more species of fishes, corals, mollusks, and crustaceans than any other location on Earth.

What, exactly, is meant by biodiversity, and why is it important? The term "biodiversity" is usually understood to include variety at several levels:
- variety of ecosystems: high biodiversity suggests many different ecosystems in a given area;
- variety of species: high biodiversity suggests

many different species in a given area;
- variety of interactions between species; and
- variety within species (genetic diversity): high biodiversity suggests a relatively high level of genetic variety among individuals of the same species.

A simple definition of biodiversity could be "The variety of all forms of life, ranging in scale from genes to species to ecosystems."

Biodiversity is important to humans because our survival depends upon many other species and ecosystems. Some examples of our dependence on biodiversity include:
- fresh air containing oxygen;
- clean water;
- productive soils;
- food, medicines and natural products;
- natural resources that provide the basis for human economies; and
- natural beauty that improves our quality of life.

(adapted from the Biodiversity Project, http://www.biodiversityproject.org/bdimportant.htm)

Quite a lot is known about Indonesia's terrestrial and shallow-water ecosystems. But scientific knowledge and understanding of midwater ocean communities is generally sketchy, and many midwater animals have not been studied at all—even though the midwater ocean environment is our planet's largest ecosystem. Midwater animals range from microscopic zooplankton to the largest animals on Earth, provide a major source of nutrition for benthic (bottom) communities, and are an important link in the transfer of energy and materials from the top to the bottom of the ocean. Note that the term "midwater" as used here includes the entire water column, but the same term has also been used to refer to only part of the water column. Scientists often divide the ocean water column into three zones: the "epipelagic zone" (also called the "sunlit" or "euphotic" zone) from the surface to a depth of about 200 m; the "mesopelagic zone" between 200 m and 1100 m; and the "bathypelagic zone," which is deeper than 1100 m.

Because so little is known about organisms in Indonesian midwater communities, there are probably many other ways in which these organisms are important. For example, salps are transparent planktonic animals belonging to the subphylum Tunicata (also known as Urochordata). They are chordate animals like humans and other vertebrates, but look more like jellyfish. Salps are found throughout Earth's ocean, but are rarely seen because their jelly-like bodies are easily damaged by nets. Even so, they can multiply into dense "swarms" containing billions of individual animals. Each animal consumes microscopic plants (phytoplankton), and a large swarm may remove as much as 74% of the phytoplankton present in surface waters in a single day. Carbon compounds contained in the phytoplankton are eventually excreted in the salps' fecal pellets, which sink rapidly to the bottom of the ocean. In this way, scientists estimate that a swarm of salps may transport up to 4,000 tons of carbon into deep water each day. Because the carbon in phytoplankton is derived from atmospheric carbon dioxide, carbon transport by salps may have a significant impact on removing this greenhouse gas from the atmospheric circulation.

The 2007: Exploring the Inner Space of the Celebes Sea Expedition is focused on exploring the variety of midwater organisms in the most biologically-diverse region on Earth. Key expedition questions include:
- What animals are found in Indonesian midwater communities?
- How does the biodiversity of Indonesian midwater communities compare with other marine communities in this region, and with other midwater communities in other regions?
- What proportion of animal species in Indonesian midwater communities is endemic to this region (found nowhere else on Earth),

and how does this degree of endemism compare with that of other regions?

In this lesson, students will investigate some aspects of the natural history of salps, and how they may impact carbon cycling in the open ocean.

## Learning Procedure

1. To prepare for this lesson, review the introductory essays for the 2007: Exploring the Inner Space of the Celebes Sea Expedition at http://oceanexplorer.noaa.gov/explorations/07philippines/.

   Review the Student Worksheet, and calculations in Questions 6 and 7.

2. Briefly introduce the 2007: Exploring the Inner Space of the Celebes Sea Expedition, highlighting the Expedition's emphasis on midwater communities and the fact that these communities have not been well-explored, even though they are part of Earth's largest ecosystem. Discuss the role of plankton in ocean ecosystems. Point out that phytoplankton are responsible for the majority of primary production in the ocean, and produce at least half of the oxygen we breathe. This is a good opportunity to highlight the importance of species that might initially appear "insignificant." Ask students whether they think that scientific research might be affected by this sort of bias. Say that historically, many ocean research expeditions have ignored some groups of species because they were difficult to collect or simply didn't seem important. The gelatinous plankton are prime examples, because they are likely to be destroyed by traditional collection methods, and are not particularly impressive in their appearance. Tell students that they are going to investigate one group of these animals, and find out why scientists now think they may be much more important than was once believed.

3. Provide each student or student group with a copy of the Student Worksheet. Answers to the first series of questions are readily available from Internet or library sources. The last two questions involve mathematical calculations that are straightforward, as long as students keep track of the decimal point!

4. Lead a discussion of students' answers to worksheet questions. The following points should be included:

   (1) What is a salp? What phylum includes salps?
   *Salps are free-floating tunicates that belong to the phylum Chordata.*

   (2) What do salps eat?
   *Salps consume small particles, particularly phytoplankton, and are generally thought to be indiscriminate feeders.*

   (3) What is unusual about the response of salp populations to the availability of food?
   *When food is abundant, salps can reproduce asexually and grow extremely rapidly to form "swarms" or "blooms" that can cover hundreds of square miles. Reproduction rates may equal the reproduction rates of phytoplankton, so that a swarm of salps may consume most of the phytoplankton in a large area of ocean. So these "insignificant" animals may directly compete with all other species that feed on floating particulate material.*

   (4) How have salps been linked to global climate change?
   *Because salps are voracious feeders and form swarms that can cover large areas of ocean, some scientists have suggested that fecal pellets from salps may transport significant quantities of carbon into deep ocean waters where it is unavailable to atmospheric circulation, thus potentially lowering the concentration of atmospheric carbon dioxide.*

(5) The first paper indicates that fecal pellets from salps sink rapidly, and could reach very deep water in less than one day, and that they carry significant amounts of carbon. The second paper indicates that decomposition would not release large quantities of carbon from fecal pellets before the pellets reached deep water.

(6) Here are the calculations:

**Step 1. Calculate the volume of water sampled by the net:**

First, find the area of the net opening. Since the diameter of the net is 0.5 m, and area is equal to $\pi \bullet r^2$ , the area of the net opening is (3.14) • (0.25 m)$^2$ = (3.14) • (0.0625 m$^2$) = 0.196 m$^2$

Next, calculate the distance the net was towed. A speed of 2 knots is equal to 2 nautical miles (nm) per hour. Since there are 1,853 m in one nautical mile, and the net was towed for 0.5 hour, the distance covered is (2 nm/hr) • (1,853 m/nm) • (0.5 hr) = 1,853 m

Finally, multiply the area of the net by the distance towed to find the total volume sampled by the net:
(0.196 m$^2$ ) • ( 1,853 m) = 363 m$^3$

**Step 2. Calculate the average number of each species in a given volume of sample:**

Since there were 740 plankters in 5 drops, the average number of plankters per drop is:
(740 plankters) ÷ (5 drops) = 148 plankters /drop

Since there are 20 drops in 1 ml, the average number of plankters in 1 ml is:
(148 plankters /drop) • (20 drops/ml) = 2,960 plankters/ml

**Step 3. Calculate the number of each species in a cubic meter of seawater:**

Since the total volume of the cod end container is 1.0 l, the estimated number of plankters in the entire sample is:
(1,000 ml) • (2.96 x 103 plankters/ml) = 2.96 x 106 plankters

Since the total volume sampled by the net is 363 m$^3$ (from Step 1), there are: 2.96 x 106 plankters in 363 m$^3$ , so the number of plankters in one m$^3$ is:
(2.96 x 106 plankters) ÷ (3.63 x 102 m$^3$) = 8.15 x 103 plankters/m$^3$

7. The calculations are:

Since the diameter of the funnel mouth was 46 cm, the area of the funnel mouth was:
(23 cm)$^2$ • (3.14) = (529 cm$^2$) • (3.14) = 1,661 cm$^2$ = 1.661 x 10$^{-1}$ m$^2$

Convert 42 hours to days:
(42 hr) ÷ (24 hr/day) = 1.75 day

So the daily carbon flux is:
(2.36 mg C) ÷ (1.661 x 10$^{-1}$ m$^2$) ÷ (1.75 day) = 8.12 mg C/m$^2$/day

The number of square meters in a square kilometer is:
(1,000 m/km) • (1,000 m/km) = 1 x 10$^6$ m$^2$/km$^2$

So, total daily carbon flux over 100,000 square kilometers would be estimated as:
(1 x 10$^5$ km$^2$) • (1 x 10$^6$ m$^2$/km$^2$) • (8.12 mg C/m$^2$/day) = 8.12 x 10$^{11}$ mg C/day

which is equivalent to 8.12 x 105 kg C/day. Since there are 2.2 pounds in one kilogram, and 2,000 pounds in one ton, the estimated flux is:
(8.12 x 10$^5$ kg C/day) • (2.2 lb/kg) ÷ (2 x 10$^3$ lb/ton) = 8.9 x 10$^2$ tons per day

Not bad for an "insignificant " blob of jelly! The actual estimated carbon flux from this swarm was even larger; possibly as high as 4,000 tons per day.

## The Bridge Connection

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click on "Ocean Science Topics," then "Biology," then "Plankton" for information and activities involving phytoplankton, zooplankton, and bioluminescence.

## The "Me" Connection

Have students write a short essay discussing how an apparently insignificant organism might be found to have extraordinary importance to humans.

## Connections to Other Subjects

English/Language Arts, Mathematics

## Assessment

Worksheets and discussions provide opportunities for assessment.

## Extensions

1. Visit oceanexplorer.noaa.gov to keep up to date with the latest 2007: Exploring the Inner Space of the Celebes Sea Expedition discoveries, and to find out what researchers are learning.

2. See the following activity packages for additional activity ideas involving plankton:
   - http://www.msc.ucla.edu/oceanglobe/pdf/PlanktonPDFs/PlanktonEntirePackage.pdf – Plankton lesson plans from the University of California, Los Angeles Marine Science Center
   - http://www.msc.ucla.edu/oceanglobe/pdf/guide_plankton1.pdf – "A Guide to the Marine Plankton of Southern California" by Robert Perry
   - http://www.marine.usf.edu/pjocean/packets/f01/f01u6p2.pdf – Plankton unit from UCLA's Project Oceanography Science Standards with Integrative Marine Science (SSWIMS)
   - http://sealevel.jpl.nasa.gov/education/activities/ts3ssac3.pdf – Plankton identification activity from NASA's "Visit to an Ocean Planet" CD-ROM
   - http://www.oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_drifting.pdf – "Drifting Downward," lesson plan from the Ocean Explorer 2002 Islands in the Stream Expedition

## Multimedia Learning Objects

http://www.learningdemo.com/noaa/ – Click on the links to Lessons 8 and 12 for interactive multimedia presentations and Learning Activities on Ocean Currents and Food, Water, and Medicine from the Sea.

## Other Relevant Lesson Plans from the Ocean Exploration Program

**Blinded By the Light!!** [http://www.oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_blinded.pdf] (6 pages, 460k) (from the Islands in the Stream 2002: Exploring Underwater Oases Expedition)

Focus: Absorption, Scattering, and Reflection of Light in the Deep Sea (Physical Science)

In this activity, students will recognize that the colors they see are a result of the reflection of light and that other colors of light are absorbed; predict what color an object will appear when light of different colors is shined upon it; predict what color(s) will be produced when different colors of light are mixed; and identify the three primary colors and three secondary colors of light.

**Drifting Downward** [http://www.oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_drifting.pdf] (6 pages, 464k) (from the Islands in the Stream 2002: Exploring Underwater Oases Expedition)

Focus: Adaptations of planktonic organisms in the ocean (Biology)

In this activity, students will describe the characteristics of plankton; develop abilities necessary to do scientific inquiry; test the effects of different salinity and temperature on the vertical movement of a model of a planktonic organism; and calculate the velocity of the plankton model.

**How Diverse is That?** [http://www.oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_hdiverse.pdf] (6 pages, 552k) (from the 2003 Windows to the Deep Expedition)

Focus: Quantifying biological diversity (Life Science)

In this activity, students will be able to discuss the meaning of "biological diversity" and will be able to compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity. Given abundance and distribution data of species in two communities, students will be able to calculate an appropriate numeric indicator that describes the biological diversity of these communities.

**Where Is That Light Coming From?** [http://www.oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/WhereisLight.pdf] (PDF, 208Kb) (from the 2004 Operation Deep Scope Expedition)

Focus: Bioluminescence

In this activity, students explain the role of luciferins, luciferases, and co-factors in bioluminescence and the general sequence of the light-emitting process. Additionally, students discuss the major types of luciferins found in marine organisms, define the lux operon and discuss at least three ways that bioluminescence may benefit deep-sea organisms. Students give an example of at least one organism that actually receives each of the benefits discussed.

## Other Links and Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration program

http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html – Ocean Explorer photograph gallery

http://www.st.nmfs.gov/plankton/ – NOAA's Coastal & Oceanic Plankton Ecology, Production & Observation Database (COPEPOD)

http://www.oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_drifting.pdf – "Drifting Downward," lesson plan from the Ocean Explorer 2002 Islands in the Stream Expedition

http://www.whoi.edu/oceanus/viewArticle.do?id=13954 – Oceanus article on the potential role of salps in ocean carbon cycling

Iseki, K. 1981. Particulate organic matter transport to the deep sea by salp fecal pellets. Marine Ecology Progress Series 5:55-60; technical journal article on which part of this lesson is based

http://www.msc.ucla.edu/oceanglobe/pdf/PlanktonPDFs/PlanktonEntirePackage.pdf – Plankton lesson plans from the University of California, Los Angeles Marine Science Center

http://www.msc.ucla.edu/oceanglobe/pdf/guide_plankton1.pdf – "A Guide to the Marine Plankton of Southern California" by Robert Perry

http://www.marine.usf.edu/pjocean/packets/f01/f01u6p2.pdf – Plankton unit from UCLA's Project Oceanography Science Standards with Integrative Marine Science (SSWIMS)

http://sealevel.jpl.nasa.gov/education/activities/ts3ssac3.pdf – Plankton identification activity from NASA's "Visit to an Ocean Planet" CD-ROM

http://www.imagequest3d.com/catalogue/larvalforms/ – Image Quest 3-D Web site, featuring images of numerous marine organisms; all images are copyrighted, but are still great to look at

Madin, L. P. 1982. Production, composition and sedimentation of salp fecal pellets in oceanic waters. Marine Biology 67:39-45.

Caron, D. A.; Madin, L. P.; Cole, J. J. 1989. Composition and degradation of salp fecal pellets: Implications for vertical flux in oceanic environments. Journal of Marine Research. 47:829-850.

Madin, L.P., Kremer, P. and Hacker, S. 1996. Distribution and vertical migration of salps (Tunicata, Thaliacea) near Bermuda. Journal of Plankton Research 18:747-755.

## National Science Education Standards

**Content Standard A: Science As Inquiry**
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

**Content Standard C: Life Science**
- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

**Content Standard D: Earth and Space Science**
- Geochemical cycles

**Content Standard E: Science and Technology**
- Abilities of technological design
- Understandings about science & technology

**Content Standard F: Science in Personal and Social Perspectives**
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

**Content Standard G: History and Nature of Science**
- Nature of scientific knowledge

## Ocean Literacy Essential Principles and Fundamental Concepts

**Essential Principle 5.**
**The ocean supports a great diversity of life and ecosystems.**

*Fundamental Concept a.* Ocean life ranges in size from the smallest virus to the largest animal that has lived on Earth, the blue whale.
*Fundamental Concept b.* Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.
*Fundamental Concept d.* Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
*Fundamental Concept e.* The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.

**Essential Principle 6.**
**The ocean and humans are inextricably interconnected.**

*Fundamental Concept a.* The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.

**Essential Principle 7.**
**The ocean is largely unexplored.**

*Fundamental Concept a.* The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

*Fundamental Concept d.* New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

## Send Us Your Feedback

We value your feedback on this lesson.
Please send your comments to:
oceanexeducation@noaa.gov

## For More Information

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## Student Worksheet

1. What is a salp? What phylum includes salps?

2. What do salps eat?

3. What is unusual about the response of salp populations to the availability of food?

4. How have salps been linked to global climate change?

5. Here are parts of two reports on research that studied salp fecal pellets:

   A. Sinking rates were determined for fecal pellets produced by gelatinous zooplankton feeding in surface waters of the California Current. Pellets from the salps and pteropods sank at rates up to 2,700 and 1,800 m per day, respectively; such speeds exceed any yet recorded for zooplankton fecal pellets. Fecal pellets of salps were rich in organic material, with C:N ratios from 5.4 to 6.2, close to values for living plankton. [Bruland, K.W. and Silver, M.W. 1981. Sinking rates of fecal pellets from gelatinous zooplankton (Salps, Pteropods, Doliolids). Marine Biology 63:295-300]

   B. Changes in the fecal pellets of several species of oceanic salps were examined in ten-day decomposition studies. Although bacteria and protozoa became abundant in vessels containing the fecal pellets, most fecal pellets remained physically intact throughout the study. Bacterial activity in the pellets increased, but microbial degradation had little effect on the sinking speeds of most fecal pellets. [Caron, D.A., Madin, L.P. and Cole, J.J. 1989. Composition and degradation of salp fecal pellets: Implications for vertical flux in oceanic environments. Journal of Marine Research. 47:829-850]

   How are these results relevant to hypotheses linking salps with climate change?

6. The abundance of planktonic organisms is traditionally measured using various kinds of plankton nets. A typical plankton net consists of a cone of fine cloth mesh (usually nylon). The larger end of the cone is attached to a frame, which holds the net open and provides an attachment point for a tow lines from the research vessel. The smaller end (called the "cod end") is attached to a container to collect organisms trapped by the net as it is towed through the water.

   The 2007: Exploring the Inner Space of the Celebes Sea Expedition will use a high-tech type of plankton net called a MOCNESS trawl (MOCNESS stands for Multiple Opening and Closing Net, with an Environmental Sensing System). This system can include from six to twenty nets supported on a sturdy rectangular frame that is towed by a research vessel at a speed of two to three knots. In addition, sensors attached to the frame measure conductivity (salinity), temperature, depth, and chlorophyll, oxygen and light levels.

Regardless of the level of sophistication, calculating the abundance of planktonic organisms using towed nets involves three steps:

1. Calculating the volume of water sampled by the net;
2. Calculating the average number of each species in a given volume of sample from the container attached to the cod end of the net; and
3. Calculating the number of each species in a cubic meter of seawater.

For example:

Suppose a 1.0 m-diameter net is towed for one hour at a speed of 3 knots. A scientist examines several drops of water from the cod end container, and finds that there are a total of 235 plankters of the same species in five drops. Assuming that 20 drops equal 1 ml, and that the volume of the cod end container is 500 ml, what is the estimated abundance of plankters in the area sampled?

**Step 1. Calculate the volume of water sampled by the net:**

First, find the area of the net opening. Since the diameter of the net is 1.0 m, and area is equal to $\pi \bullet r^2$, the area of the net opening is $(3.14) \bullet (0.5 \text{ m})^2 = (3.14) \bullet (0.25\text{m}^2) = 0.785 \text{ m}^2$

Next, calculate the distance the net was towed. A speed of 3 knots is equal to 3 nautical miles (nm) per hour. Since there are 1,853 m in one nautical mile, and the net was towed for one hour, the distance covered is (3 nm/hr) • (1,853 m/nm) • (1 hr) = 5,559 m

Finally, multiply the area of the net by the distance towed to find the total volume sampled by the net:

$(0.785 \text{ m}^2) \bullet (5{,}559 \text{ m}) = 4.364 \times 103 \text{ m}^3$

**Step 2. Calculate the average number of each species in a given volume of sample:**

Since there were 235 plankters in 5 drops, the average number of plankters per drop is:

(235 plankters) ÷ (5 drops) = 47.0 plankters/drop

Since there are 20 drops in 1 ml, the average number of plankters in 1 ml is:

(47.0 plankters/drop) • (20 drops/ml) = $9.40 \times 10^2$ plankters/ml,

**Step 3. Calculate the number of each species in a cubic meter of seawater:**

Since the total volume of the cod end container is 500 ml, the estimated number of plankters in the entire sample is (500 ml) • ($9.4 \times 10^2$ plankters /ml) = $4.70 \times 10^5$ plankters

Since the total volume sampled by the net is $4.364 \times 10^3 \text{ m}^3$ (from Step 1), there are $4.70 \times 10^5$ plankters in $4.364 \times 10^3 \text{ m}^3$, so the number of plankters in one $\text{m}^3$ is

($4.70 \times 10^5$ plankters) ÷ ($4.364 \times 10^3 \text{ m}^3$) =$1.07 \times 10^2$ plankters/$\text{m}^3$

Now it's your turn!

Suppose a 0.5 m diameter net is towed for 0.5 hour at a speed of 2 knots. A scientist examines several drops of water from the cod end container, and finds that there are a total of 740 plankters of the same species in five drops. Assuming that 20 drops equal 1 ml, and that the volume of the cod end container is 1.0 l, what is the estimated abundance of plankters in the area sampled?

7. A research project in the North Pacific investigated the amount of carbon transported into the deep sea by fecal pellets of salps. Sediment traps were suspended on long lines at a depth of 900 m, and allowed to remain in place for approximately one day. The traps were constructed from large polyethylene funnels with a collecting jar attached to the stem of the funnel. When the sediment traps were retrieved, the contents consisted almost entirely of salp fecal pellets. The contents of the collecting jars were filtered, dried, and analyzed for carbon using an infrared carbon analyzer. The average carbon content from several bottles was 1.89 mg C per bottle. To calculate the daily carbon flux per sq m per day, the researchers divided the amount of carbon in each bottle by the mouth area of the funnel, and then divided the result by the length of time the sediment traps were in the water.

Since the diameter of the funnel mouth was 56 cm, the area of the funnel mouth was
$(28\ cm)^2 \bullet (3.14) = (784\ cm^2) \bullet (3.14) = 2{,}462\ cm^2$

There are $1 \times 10^4\ cm^2$ in one square meter, so the area of the funnel mouth was
$(2.462 \times 103\ cm^2) \div (1 \times 104\ cm^2/m^2) = 2.462 \times 10^{-1}\ m^2$

If the sediment trap remained in the water for 1.5 days, the daily carbon flux into the sediment trap would be

$(1.89\ mg\ C) \div (2.462 \times 10^{-1}\ m^2) \div (1.5\ day) = 5.12\ mg\ C/m^2/day$

Suppose a sediment trap constructed with a 46 cm diameter funnel was suspended for 42 hours and collected 2.36 mg of carbon. What would be the estimated daily carbon flux based on these data?

Some salp swarms have been found that cover an area of 100,000 square kilometers. How much carbon might such a swarm send into the deep ocean in one day, based on the estimated daily carbon flux in the last problem?