FROM FOREST TO SEA

An Educator's Guide with Activities Focused on Carbon Sequestration

GRADES 6-8
DRAFT

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ACKNOWLEDGMENTS

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NOTE: This is a working draft. Please direct any questions, comments, suggestions, etc. to Ryan Keser (ryankeser@gmail.com) Thanks!

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FOREST CARBON SEQUESTRATION

Chapter 1: Forest Carbon Sequestration Unit Summary

In this unit, students will explore the role that trees and forests have in global carbon sequestration. Students will investigate how trees and forests remove carbon from the atmosphere and store it and, as a result, be able to identify the critical role that trees and forests play in regulating the global carbon budget and global climate change. This unit is comprised of three parts broadly designed to engage students in essential research, strengthen skills in quantitative reasoning and analysis, and enhance student ability to process and mobilize scientific findings.

In part one, students will hone their field sampling skills through the implementation of standard forest sampling methods in forests local to their schools. Students will use a pre-selected sample forest plot and will use quadrats to quantify tree species richness and density; measuring tapes to quantify tree diameter at breast height and total tree height; and visual estimates to derive crown diameter.

In part two, students will use the biological data collected in part one to calculate carbon sequestration per tree and per unit area using a mathematical equation. Values calculated for local forest plots will then be scaled up to build regional models.

In part three, students will summarize their research findings and mobilize them via the production of scientific tools (e.g., papers, proposals, and symposium posters), in-class debates (including discussion of ecosystem services and land use; forest vs. deforested, old growth vs. new growth) and civic engagement (e.g., writing to local government and conservation agencies, newspaper articles, local school community, op-ed pieces, and social media).

Students will emerge from this unit with the knowledge of how to design an effective experiment, conduct authentic field research, and use qualitative and quantitative modeling and spatial analysis to draw conclusions about their research findings. Ultimately, students will be challenged to question the merit of their research design, contribute to our collective understanding of the role of trees and forests in global carbon sequestration, and weigh in on a critical ecological, political, and socio-economic issue.

Unit Outline

Big Ideas:

1) The increase of green house gasses (CO_2, N_2O, CH_4) in the atmosphere is causing climate change, which is changing ecosystems- I.E. biome migration, decreased biodiversity.
2) When in tact, natural carbon storage provides an ecosystem-service that currently tempers climate change, as humans go about their activities.
3) Human activities are significantly affecting land, ocean, and atmosphere and those changes are altering global climate patterns. Human choices have the power to modify the current trajectory of global climate change.
4) Some systems are experiencing change at a more rapid rate than others. Certain species in these systems can be monitored as indicators of change.

Essential Questions for this unit of study:

1) Where is carbon produced (sources) and stored (pool) and how do humans perturb this cycle?
2) How do different ecosystems respond to long-term changes in climate?
3) How do our energy choices impact climate change?
4) Are there choices you, as a global citizen, can make to mitigate human impact on climate?

By the end of this unit students will be able to:

1) Estimate carbon in trees to quantify the carbon stock that trees offer.
2) Compare two different sites and their sequestration of carbon in trees.
3) Use collected data to create a two mathematical models: a) plot level to determine carbon stored in a plot with a given equation, and b) a forest level model – estimating stored carbon in a forested area.
4) Construct and present arguments supported by empirical evidence and science reasoning for multiple explanations for how variations in species richness, stand density, and age result in the potential storage of carbon.
5) Predict how changes to an ecosystems current status might affect future carbon sequestration.

Assessment Evidence:

1) Formative
    a. Collect Data is collected in a table
    b. Measurement includes a unit
    c. Demonstrate proper use of science tools
    d. Demonstrate consistent technique when collecting from different sample areas
    e. Science Talk
2) Summative
    a. Students will make a claim supported by no more than three pieces of evidence. Each piece of evidence will have two points of reasoning that all supports their claim. This will be presented through a group class presentation and an individual paper to the town mayor, city council, etc, arguing the importance of forested lands within a municipality.

Nature of Science Inquiry Considerations:

- What are the limitations of study?

- Is the data collected able to be generalized?

Lessons:

Part I: Measuring up

- Quadrats (nearest neighbor, tree height, DBH, tree type) data

Part II: Model Measures

- DBH of a tree –> Carbon stored calculation
- How to input/process data into Excel
- Sum Carbon content of plots and create a metric – Kg C/unit area
- Forest Level Model

Part III: Stand and Deliver

- Classroom Debate/Discussion/Presentation.
- Argument Paper

Vocabulary

- Biomass
- Carbon cycling
- Carbon sequestration
- Climate change
- DBH
- Nearest Neighbor
- Percent Cover
- Plot
- Pool
- Relative Parallax
- Sample
- Sample Area
- Sink
- Species Diversity
- Storage
- Transect?
- Tree Density
- Tree height

Carbon Sequestration Links

- Carbon Storage Lab: Portland State
  http://www.ecology-climate.org/node/1086
- USFS Tree Carbon Calculator:
  http://www.fs.fed.us/ccrc/topics/urban-forests/ctcc/

Part 1: Measuring Up

Description: Students will apply standard methods to assess the amount of carbon stored in trees at a plot-level resolution. In groups, students will be taking measurements of tree height, diameter at breast height (DBH), and percent canopy cover. Students will also identify trees to species level and then map, using x and y-coordinates, the location of the trees within the plot.

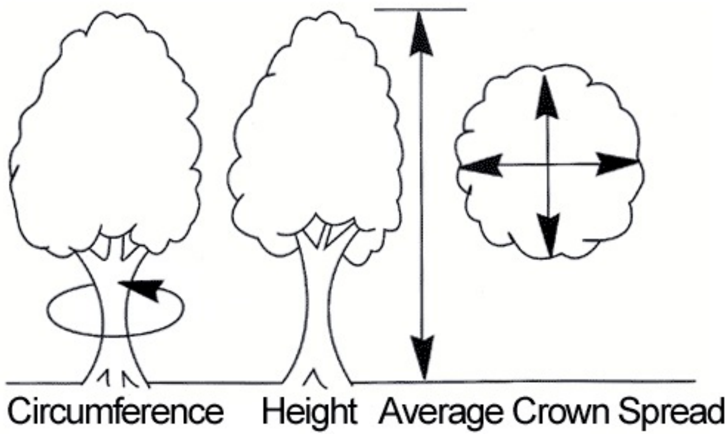


Figure 1.1

Learning Objectives

Students will be able to:

1) Demonstrate proper field methods when collecting data including tree height, DBH, percent canopy cover, and mapping tree location within a plot.
2) Demonstrate species identification.
3) Demonstrate proper data collection and management.
4) Use proper units.

Time Needed: Two 50-minute class periods.

Related Concepts

- carbon cycle
- carbon sequestration
- competition
- biodiversity
- ecological succession
- disturbance
- land-use change

Materials

- measuring tapes/ meter sticks
- flagging/ markers
- tree height estimation tool (stake, stick, etc.)
- data collection protocol handout

Assessments

1) Collect Data is collected in a table
2) Measurement includes a unit
3) Demonstrate proper use of science tools
4) Demonstrate consistent technique when collecting from different sample areas
5) Data collection sheet (collect)

Tips for teaching this lesson/Safety

- ID noxious plants prior to the lesson.

Teacher Background

- In order to make valid landscape level estimates, thought must be taken to apply universal data collection techniques and implement an experimental design, which captures system variation and controls for sampling bias.
- The cycling of carbon in an ecosystem underlies the equilibrium of that ecosystem. Human activity perturbs the carbon cycle, ramping up the greenhouse effect, which in turn causes landscape level changes such as species a range shift, species die-out, shift in weather pattern.
- Human activity (urbanization, agriculture, consumption of fossil fuels, etc.) increases the concentration of greenhouse gases in the atmosphere, such as carbon dioxide, ramping up the greenhouse effect, thus causing global climate change.

Resources (Books, Webs, Media)

- www.ecology-climate.org/node/1086
- www.fs.fed.us/ccrc/topics/urban-forests/ctcc/

Schedule:

Before you begin:

Locate areas outdoors where you will have students make tree measurements

Day One:

Do Now	10 min.
Activity	40 min

Day Two:

Review from Day One	10 min
Activity	40 min

DAY ONE

Do Now

Time: 10 min
Materials: science journals or Do Now record sheet

Before students enter the room, have the following writing prompt prepared (overhead, board, etc):

> *"Bio- = of or relating to life mass = quantity of matter in an object.*
> ***Biomass*** *is biological material derived from living, or recently living organisms.*
>
> *What is a tree's biomass composed of? What tree measurements might you take to estimate its total biomass?*
>
> *In your science journal* (or Do Now sheet, equivalent) *write your response then turn to a neighbor and share you thoughts. Be ready to share out to the whole group.*

Through discussion of student responses, draw the connection between tree biomass and the storage of carbon on land (photosynthesis and the draw-down of atmospheric carbon dioxide to be stored in trees).

Activity

Time: 1-2 class period(s)
Materials:
For each group of students:
- meter stick
- measuring tapes
- surveying flags or similar
- copies of the following protocols:
  - Estimating Tree Height
  - Circumference at Base Height
  - Estimating Crown Diameter.

For each student:
- data collection sheet
- clipboard
- pencil

In this activity students will be learning how to precisely and consistently record data about a given tree. Before this class, prepare 2-3 preselected data collection plots (10m x 10 m) using some type of makers to signify the 4 corners. Alternatively, if you have enough measuring tapes and time, have students mark out the plots themselves.

Tree Height:
1. Prior to this activity, students should be broken into groups of four, and 3-7 trees should be preselected. Two groups will be assigned to each tree for data collection. It may be helpful to

assign role for each member of the group:

a. *Task manager:* is responsible for knowing what needs to be completed and can provide directions. Needs: Lab directions.
b. *Recorder:* writes down all measurements with the correct units. Needs: Data sheet and pencil.
c. *Measurer:* makes all the measurements and is responsible for collecting and returning all measuring tools. Needs: measuring tools.

2. After taking students outside, direct their attention to a specific tree. Pose the following question: *How might we calculate the height of the tree?*

3. Allow 3-5 minutes for students to brainstorm solution in groups. Elicit student responses and if possible, test a few suggestions. (*Note: you may skip right to the protocol if time is a consideration)*

4. After certain attempts have been made and estimates of tree height have been suggested, introduce the standard method the class will be using to estimate tree height. (see Estimating Tree Height Protocol below)

5. Students collect data with their groups.

Estimating Tree Height Protocol

1. For the measurer: Use the meter stick to measure the length of the distance from cheek just below your eye to the center of you palm with your arm outstretched in front of you.

2. Facing the tree with your arm outstretched, hold the yardstick in your hand at this distance with the rest of the stick extending upward (forming a 90^0 angle). For instance, if measured 70 cm from your nose to your hand, hold the meter stick so that only 70 cm are extended above your hand.

3. Carefully back up from the tree (be careful not trip) until the top of the stick appears to be as tall as the top of the tree. Close one eye and line the meter stick up with the tree. Keep backing up until the height of the tree from base to the top is obscured behind the length of the meter stick.

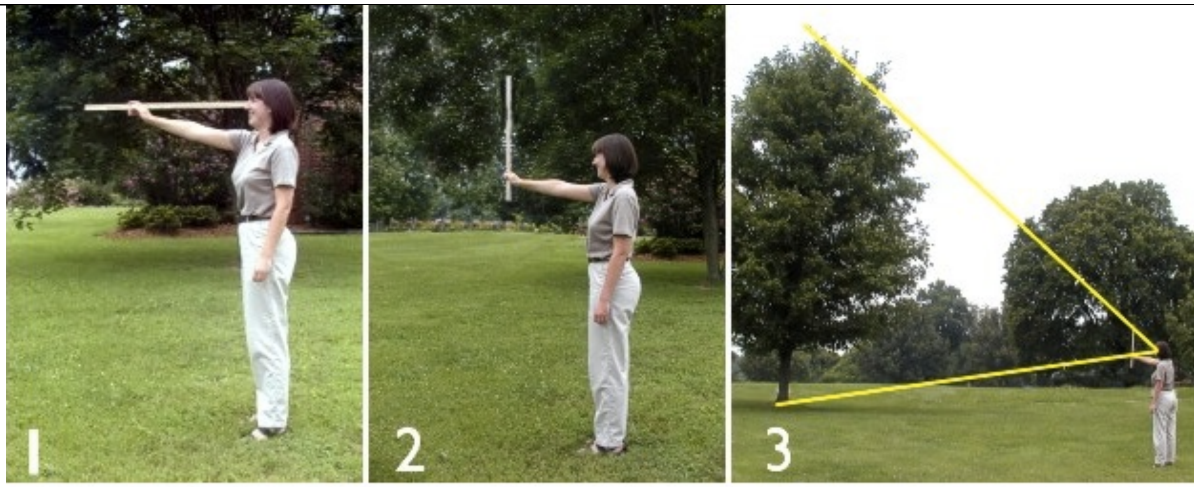


Figure 1.2

4. Measure from the tree to the point where you are standing. This is a rough estimate of tree height.

5. Record your measurement using correct units.

CBH (Circumference at Breast Height):

1) As students finish height estimation, call the class back to attention and pose a second question: *How might we determine the biomass or amount of material in a tree?* (Base this on the ***Do Now*** responses from earlier)
2) Allow 3-5 minutes for students to brainstorm solution in groups. Elicit student responses and if possible, test a few suggestions. (Note: you may skip right to the protocol if time is a consideration)
3) After certain attempts have been made and estimates of tree biomass have been suggested, introduce the standard method the class will be using to estimate tree biomass. (see CBH Protocol below).
4) Students will now collect this data with their groups.

Circumference at Breast Height Protocol

1. Stand in front of your tree. Measure 1.35m from the ground up the trunk of the tree. Place your hand on the tree's trunk to mark the point.
2. From this point, wrap a measuring tape around the tree's trunk to measure the trunk circumference.
3. Record your measurement using correct units.
4. You will use this measurement on Day Two to calculate DBH (diameter at breast height).

Figure 1.3

NOTE: For trees with a buttress (large roots on all sides of shallowly rooted trees; ie. palms, etc.), take the measurement from the top of the buttress instead of from the ground.

Other Data collected –Crown diameter, Tree species Identification

1) Call student attention and explain the methods that will be used to collect tree crown diameter and how to use the tree identification tool.
2) Let groups collect these data points about their assigned tree.

Estimating Crown Diameter Protocol

1. Stand under your tree and identify all of its branches and leaves. These branches and leaves extend out from the trunk of the tree in a circular pattern, with the trunk located in the center of the 'circle'. These branches and leaves are called the tree's *crown*.
2. Locate the widest and narrowest part.
3. Walk to one edge of the tree's crown on one side of the widest part. Mark this location with a flag.
4. Walk to the opposite edge of the tree's widest part, as if you are drawing the diameter of the tree's crown. Mark this location with a flag.
5. Measure the distance from point A to point B. This is the widest diameter of the tree's crown.
6. Repeat steps 3 and 4 for the narrowest part.
7. Record your measurement using correct units.

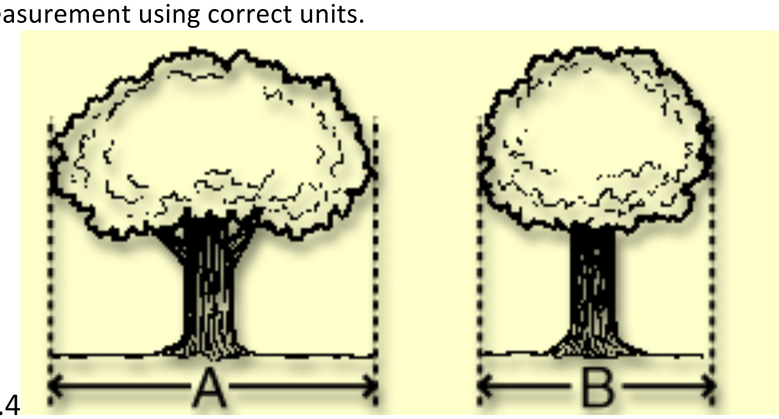
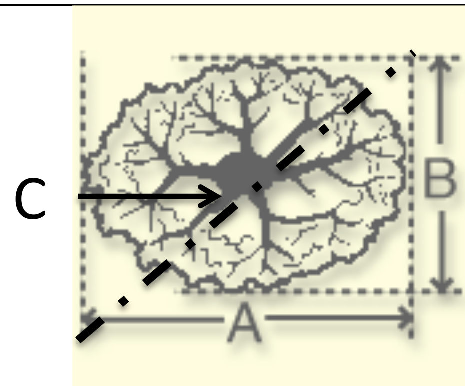


Figure 1.4

A. Widest part of tree. B. Narrowest part of tree.



Bottom view of tree showing both the widest and narrowest part of the tree.

8. Formula for computing the tree's average crown diameter:

$$A^2 + B^2 = C^2$$

9. *Day Two: On your mapping worksheet, draw the crowns of each tree that you have plotted with the tree's (x,y) point at the center of the crown. Represent the crown by drawing a circle with the same diameter as the measurement that you collected for the tree.*

Identify tree to species level: Use tree identification resources (ie. field guide, 'Leaf Snap', etc.) to identify the tree to species level. If this is not possible, identify to genus level.

DAY TWO

Review

Time: 10 min
Materials: Data collected from Day One
Begin by reviewing the previous day's activity and measurements. Address any questions or problems that may have come up. Preview the next activity and explain the measurements they will take and how they are to complete the plot.

Activity

Time: 40 min
Materials:
For each group of students:
- meter stick
- measuring tapes (15-30' field tapes preferred)
- surveying flags or similar
- copies of the following protocol:
    - Tree Mapping Protocol

For each student:
- data collection sheet
- clipboards w/pencils

Plot area data collection
Use the same 2-3 preselected data collection plots from Day One. Signify one corner and the "origin" of an X-Y coordinate plane. Along the X and Y-axis place a marker every meter, which will correspond to the plot map data sheet.

1) At the beginning of class, distribute and review data collection protocol and data collection worksheets.
2) Take students out to marked plots.
3) Draw student attention to the layout of each plot, and explain how they are going to treat each plot as an X-Y coordinate (see Tree Mapping Protocol). Demonstrate how to find and input data in the data sheet.
4) Assign 2-3 groups to each plot, and let them begin collection data and filling in their data tables.
5) Remind them to drawn in the tree crowns from Day One on their mapping worksheets.
6) Float among the groups, answering questions and clarifying confusion.

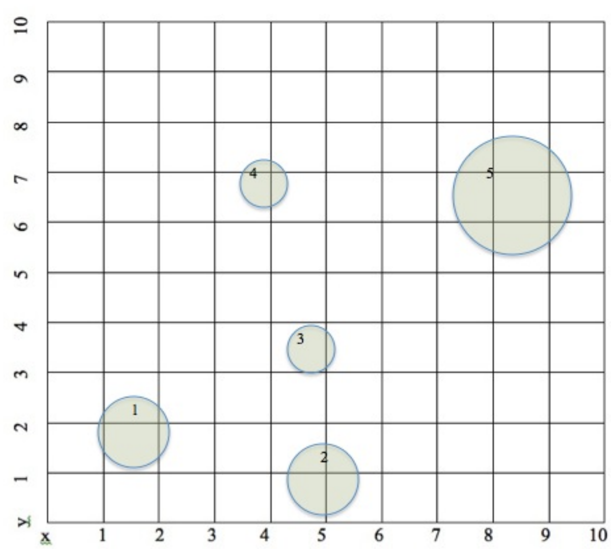


Figure 1.5

Tree Mapping Protocol:

1. Locate the x- and y-axis “edges” of your 10m by 10m plot. Identify the markers along these edges that are spaced at 1m intervals. Locate the point (0,0) on your plot -- this will be your point of reference for mapping tree location.
2. Measure the x- and y-coordinate for your tree using the markers on the x- and y-axis “edges” of the plot.
3. Plot the coordinates of your tree on your mapping worksheet. Record the coordinates next to the point you have drawn for your tree (x,y), as well as the tree number (ie. 1, 2, 3, etc.).
4. Draw the tree crowns (see you data from Day One)
5. Repeat this process for all trees in the plot.

To assess student work:

Evaluate how well students did the following:

1) Data is collected in a table
2) Measurements include a unit
3) Demonstrate proper use of science tools
4) Demonstrate consistent technique when collecting from different sample areas

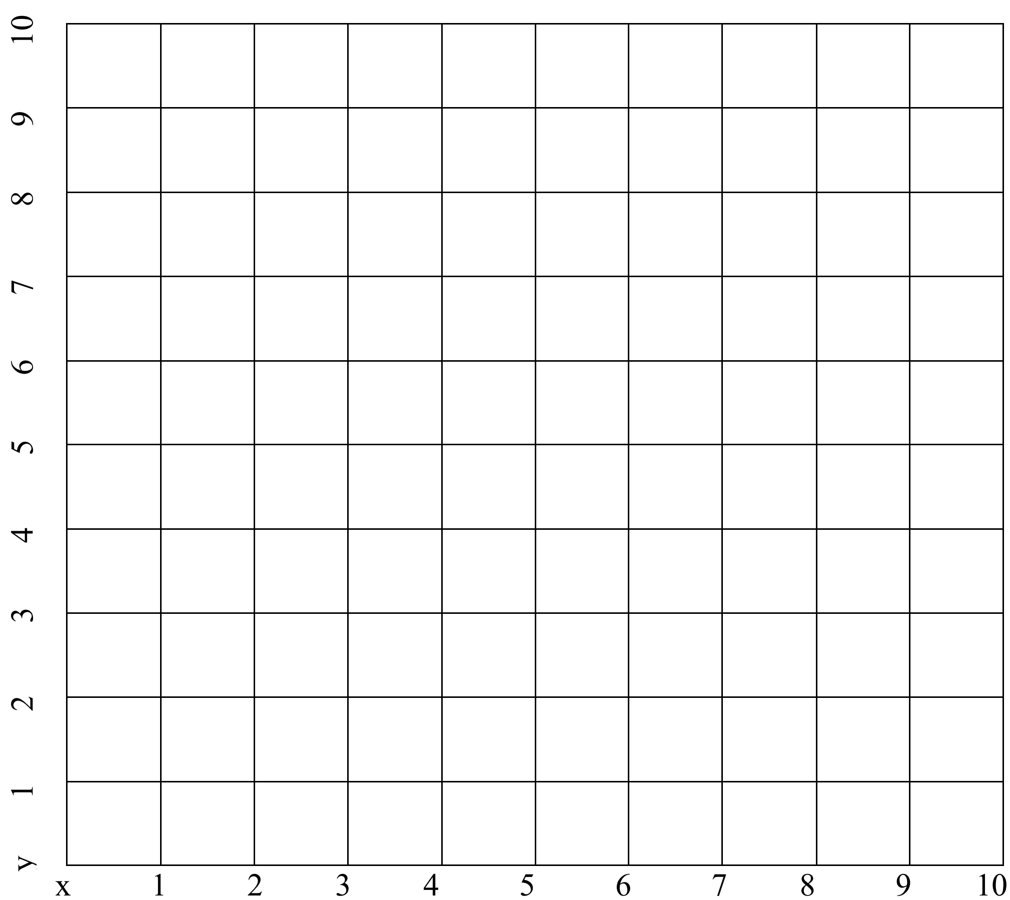
Name:______________________________ Class:________________ Date:_____________

Part 1. Measuring Up: Tree Plot Data Sheet

Day 1: Fill in the table with the data collected.

Tree				
No.	Species	Height (m)	CBH (cm)	Crown Dia. (m)

Day 2: Plot the trees in the graph below.

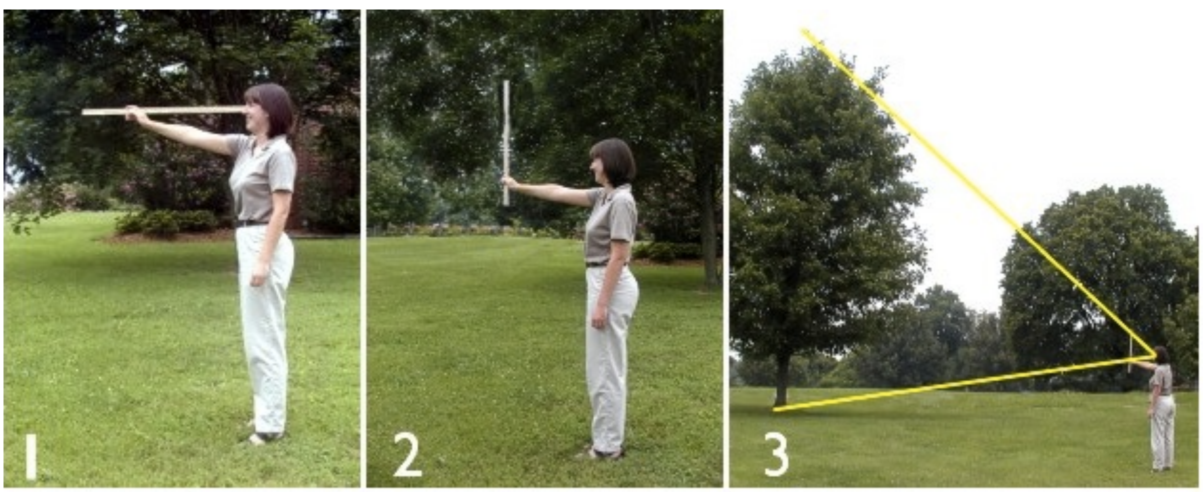


Part 1. Measuring Up: Estimating Tree Height Protocol

1. For the measurer: Use the meter stick to measure the length of the distance from cheek just below your eye to the center of you palm with your arm outstretched in front of you.

2. Facing the tree with your arm outstretched, hold the yardstick in your hand at this distance with the rest of the stick extending upward (forming a 90^0 angle). For instance, if measured 70 cm from your nose to your hand, hold the meter stick so that only 70 cm are extended above your hand.

3. Carefully back up from the tree (be careful not trip) until the top of the stick appears to be as tall as the top of the tree. Close one eye and line the meter stick up with the tree. Keep backing up until the height of the tree from base to the top is obscured behind the length of the meter stick.

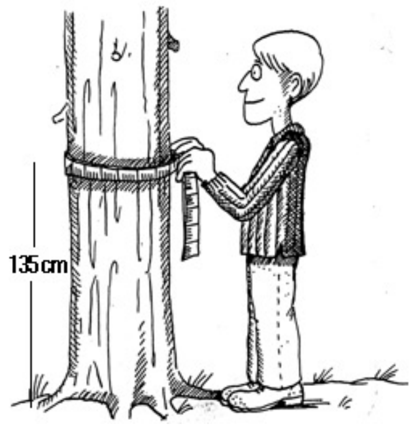


4. Measure from the tree to the point where you are standing. This is a rough estimate of tree height.

5. Record your measurement using correct units.

Part 1. Measuring Up: Circumference at Base Height Protocol

1. Stand in front of your tree. Measure 1.35m from the ground up the trunk of the tree. Place your hand on the tree's trunk to mark the point.
2. From this point, wrap a measuring tape around the tree's trunk to measure the trunk circumference.
3. Record your measurement using correct units.
4. You will use this measurement on Day Two to calculate DBH (diameter at base height).

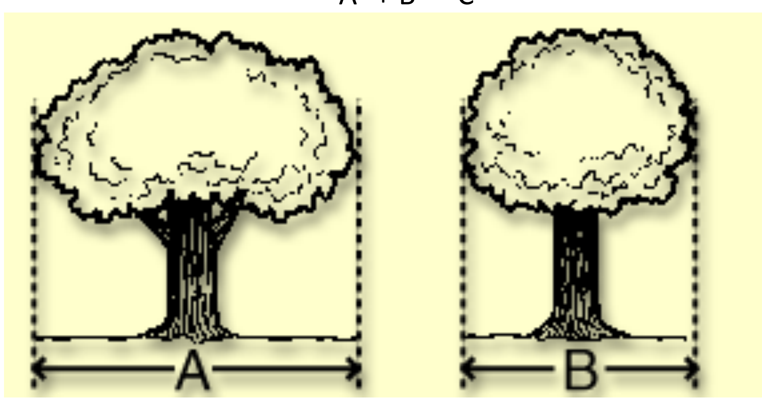


NOTE: For trees with a buttress (ie. palms, etc.), take the measurement from the top of the buttress instead of from the ground.

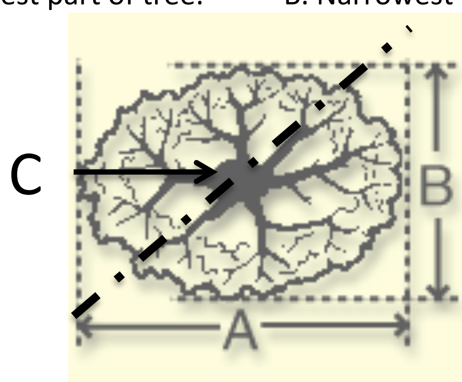
Part 1. Measuring Up: Estimating Crown Diameter Protocol

1. Stand under your tree and identify all of its branches and leaves. These branches and leaves extend out from the trunk of the tree in a circular pattern, with the trunk located in the center of the 'circle'. These branches and leaves are called the tree's *crown*.
2. Locate the widest and narrowest part.
3. Walk to one edge of the tree's crown on one side of the widest part. Mark this location with a flag.
4. Walk to the opposite edge of the tree's widest part, as if you are drawing the diameter of the tree's crown. Mark this location with a flag.
5. Measure the distance from point A to point B. This is the widest diameter of the tree's crown.
6. Repeat steps 3 and 4 for the narrowest part.
7. Record your measurement using correct units.
8. Formula for computing the tree's average crown spread:

$$A^2 + B^2 = C^2$$



A. Widest part of tree. B. Narrowest part of tree.

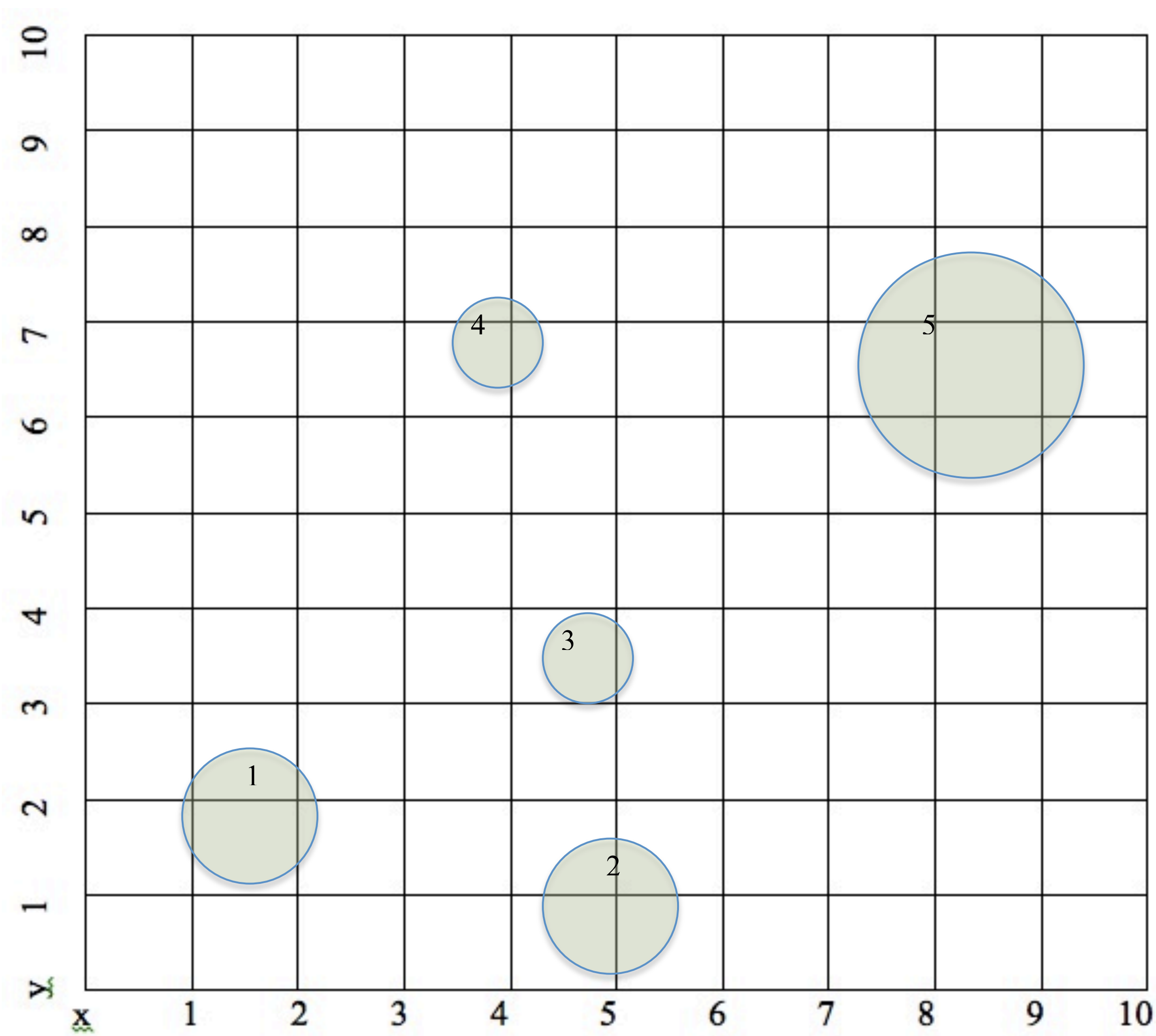


Bottom view of tree showing both the widest and narrowest part of the tree.

Day Two: On your mapping worksheet, draw the crowns of each tree that you have plotted with the tree's (x,y) point at the center of the crown. Represent the crown by drawing a circle with the same diameter as the measurement that you collected for the tree

Part 1. Measuring Up: Tree Mapping Protocol

1. Locate the x- and y-axis “edges” of your 10m by 10m plot. Identify the markers along these edges that are spaced at 1m intervals. Locate the point (0,0) on your plot -- this will be your point of reference for mapping tree location.
2. Measure the x- and y-coordinate for your tree using the markers on the x- and y-axis “edges” of the plot.
3. Plot the coordinates of your tree on your mapping worksheet. Record the coordinates next to the point you have drawn for your tree (x,y), as well as the tree number (ie. 1, 2, 3, etc.).
4. Draw the tree crowns (see you data from Day One)
5. Repeat this process for all trees in the plot.



Part 2: Model Measures

Description: Students will determine the DBH and carbon stored in measured trees using a given equation then use this data to describe carbon stored in a particular forested area.

Learning Objectives:

1) Use collected data to create a two mathematical models: a) plot level to determine carbon stored in a plot with a given equation, and b) a forest level model – estimating stored carbon in a forested area.

Time Needed: One 50-minute class period

Related Concepts

- Forest ecosystem services
- Human choices impact the environment

Materials

- Pre-collected datasheets, maps, case studies
    - http://www.fs.fed.us/pnw/mdr/mapss/publications/pdf/17color.pdf
    - http://www.wrcc.dri.edu/precip.html
    - http://www.census.gov/geo/maps-data/
    - http://cfpub.epa.gov/npdes/stormwater/urbanmaps.cfm
- Computers with a spreadsheet program (Excel, etc) and/or DBH worksheet
- Calculators
- Forest Carbon Storage Calculation Worksheet (see Appendix)

Assessments

Formative:

- Demonstrate proper use of science tools
- Demonstrate proper use of units throughout calculations.

Teacher Background

Conservation groups, like the Programme for Belize, use this method of estimating carbon storage in forests at a large scale. Using DBH, height, and species-specific equations for carbon in biomass, conservationists can approximate the amount of carbon being stored in intact natural areas. This carbon can eventually be sold to energy corporations as a "carbon credit" or "carbon offset" for carbon dioxide emissions from the burning of fossil fuels. As an example, the Rio Bravo Conservation Area has 90,000 acres set aside for carbon sequestration. To estimate the total carbon stored in this area, the group has been measuring the DBH of trees in 240 circular plots (with radius of 20 m) in five different forest ecosystems (e.g. lowland broadleaf forest, upland tropical semi-deciduous moist forest, etc.) for 15-20 years. The measurements from these plots are used to scale up to an estimate of carbon stored in the entire 90,000 acre Rio Bravo carbon sequestration conservation area.

Equations for converting DBH and height measurements to mass of carbon are developed by destructively sampling an appropriate number of trees which have been measured for these characteristics. These trees are then cut into manageable pieces, dried, and weighed. The relationship between DBH and mass of carbon is then described using a mathematical model, from which an equation is developed to estimate mass of carbon in any given tree by inputting only the DBH and height. This is an important illustration of the application of math in science.

Carbon storage in forested ecosystems is an important ecosystem service for limiting carbon dioxide accumulation in the atmosphere. Together, terrestrial ecosystems and marine ecosystems absorb approximately 50% of all carbon dioxide emitted by human activities. Without this critical ecosystem service, carbon dioxide would be accumulating much more rapidly in the atmosphere. Therefore, it is very important to preserve forests.

Equations:

1. Diameter=Circumference ÷ π
2. Total mass of tree = 2.4 × DBH^3
3. Total mass of trees in plot = Sum of mass of each tree in plot
4. Carbon stored in plot = Total mass of trees in plot x 0.5
5. Carbon stored per Area = Carbon stored in plot ÷ Area of Plot
6. Carbon stored in forest = Carbon stored per Area × Area of forest

Resources (Books, Webs, Media)

The United States Forest Service Tree Carbon Calculator can be used in place of the provided equation for converting DBH to mass of tree and for mass of tree to mass of carbon: http://www.fs.fed.us/ccrc/topics/urban-forests/ctcc/

A sample data set (excel file) is located at our website *Boston University GLACIER GK-12 website (http://gk12glacier.bu.edu/pages/resources.php:)*

You can find the additional background information by visiting the Resources page of the Boston University GLACIER GK-12 website (http://gk12glacier.bu.edu/pages/resources.php:)

Articles include:

- *International Forest Carbon Sequestration in a Post-Kyoto Agreement, Oct. 2008*
- *Inconsistent definitions of ''urban'' result in different conclusions about the size of urban carbon and nitrogen stocks*
- *The leaky sink: persistent obstacles to a forest carbon sequestration program based on individual projects*
- *Forest Carbon Trading and Marketing in the United States*

Map Resources (from above)

- http://www.fs.fed.us/pnw/mdr/mapss/publications/pdf/17color.pdf
- http://www.wrcc.dri.edu/precip.html
- http://www.census.gov/geo/maps-data/
- http://cfpub.epa.gov/npdes/stormwater/urbanmaps.cfm

Modifications

This lesson can be completed using Microsoft Excel or manually using calculators.

Schedule:

Before you begin:

Print data sets and maps.

Part One	20 min.
Part Two	35 Min

DAY ONE

Activity

Time: 1 class period

Materials:

- sample datasheets and maps (One set for each group)
- Forest Carbon Storage Calculation Worksheet
- calculators
- *optional* : computer with spreadsheet application (Excel, Google Docs)

In this activity, student will reflect on what they know about the process of collecting data, sampling design, and what data they have collected then discuss the value of the information they have collected and what the next steps in processing might look like. Finally students will consider how to convert the data they have into a more useful form, in this case converting DBH and height into mass of carbon.

Students should be in groups of 3-5 students for this activity. The same groups from the previous activity may make the most sense.

Part One

1. Begin by sharing samples of datasheets and maps reflecting studies from the local community, such as census maps, forest distribution in urban areas, rainfall contour maps. Hand out a data set to each group.

2. Ask students to record in their science journals 3 observations, 2 questions and 1 inference from the datasheets and maps.

3. Give them 10-15 minutes then bring them back together and ask each group to share their observations, questions and inferences.

4. Make the connection between the data sets and maps to their measurements from the first lesson.

Part Two

1. Students will complete Forest Carbon Storage Calculation Worksheet using provided equations to estimate carbon storage at the plot level and then at the forest level then share and defend their results. See worksheet for directions.

2. Connect the calculations completed by students to applications and broader use, for example, the use of this method in the Rio Bravo Conservation Area carbon sequestration plots (http://www.pfbelize.org/conservation/?page_id=137)

To assess student work:

1. Formative:
    a. Demonstrate proper use of science tools
    b. Demonstrate consistent technique when collecting from different sample areas
    c. Demonstrate proper use of units throughout calculations.
2. Summative:
    a. Discussion participation and response to worksheet questions.

Name:______________________________ Class:________________ Date:_____________

Part 2. Model Measures: Forest Carbon Storage Calculation Worksheet

Using your field notes from data collection and the following equations, complete the table below to calculate carbon stored in the forest plot.

1. Transfer your data on tree circumference at breast height (CBH) into the table below.

2. Convert CBH to diameter at breast height (DBH) using the equation for circumference of a circle:

Diameter=Circumference ÷ π

3. Using the DBH, calculate the total mass of the tree using the given equation that is based on prior sampling of many trees:

Total Mass of Tree = 2.4 × DBH^3

Tree	**CBH** *Circumference at Breast Height* ***[m]***	**DBH** *Diameter at Breast Height* ***[m]***	**Mass** *Mass of Tree* ***[kg]***
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

4. Calculate the sum of mass of trees in the plot (include units). _____________
5. Approximately one half of the mass of trees is actually composed of carbon. To estimate the total carbon stored in the plot, multiply the total mass of trees by 0.5.

Total Mass of Carbon in Plot = Total Mass of Trees in Plot × 0.5
Total Mass of Carbon in Plot = ___________________________

6. Using your representative sample plot data, estimate carbon storage in the entire forest by generating a value for carbon stored in a given area.

Carbon stored per Area = Total mass of Carbon in Plot ÷ Area of plot

Plot Area: ____________m^2__

Total Mass of Carbon in Plot: _____________kg__

Carbon stored per Area (include units) = ____________________

7. This value can be used to estimate the carbon stored in any forested land of interest. For example the forest adjacent to the school or in a forest preserve. The area of the forest can be estimated from a map or obtained by landowners or local governments.

   If the forest is 10,000 m^2, how much carbon is stored in the forest?

   Carbon Stored in 10,000 m^2 Forest = ____________________

Discussion Questions:

1. Is it reasonable to use measurements from a small plot to estimate carbon storage in a larger area? How could you improve your estimate of carbon storage?

Compare your calculated value for carbon stored per area of forest to grasslands (lawns), which stores approximately ____ kg/m^2. Given this information, what are some recommendations to improve carbon storage in green spaces in your local community?

Part 3: Stand and Deliver

-Making a Case for Carbon Stores

Description: As the final part of a mini-unit on Carbon Sequestration, students will write a position paper arguing in support of forest carbon storage by making a claim about carbon sequestration, backing it up with evidence from lab/field work and supporting their evidence using scientific reasoning. The teacher may choose to have the students select a specific audience for these papers such as a government agency, nature conservancy organization, newspaper, school community, local community, etc.

Learning Objectives:

1) Construct and present arguments supported by empirical evidence and science reasoning for multiple explanations for how variations in species richness, stand density, and age result in the potential storage of carbon.

2) Predict how changes to current land use patterns might affect future carbon sequestration.

Time Needed:

- 2-3 days for paper (if using class time for writing and peer editing; less if assigned as homework).

Materials

- Student handouts
- Computers with internet access

Handouts

- Argument Writing Assignment and Rubrics

Assessments:

- Position paper and rubric

Tips for teaching this lesson:

- This final lesson could be structured as a science talk, a debate or other concluding activity that encourages students to take a position arguing for or against strategies for forest carbon sequestration.

Teacher Background

Prior to this lesson students should have completed Part 1 and Part 2 of this mini-unit. Prior experience with writing argument papers is helpful but not required.

Schedule

Day One:

Do Now	30 min.
Activity	20 min

Day Two:

Essay (complete for homework) 50 min

*additional time should be assigned for homework

DAY ONE
Do Now **Time:** 30 min **Materials:** Science journals Begin by posing the following prompt to students and ask them to write a short reflection in their journal: **“Now that you have collected data, made models, and presented your findings, what do you think is important to know about carbon stores? Should we care about these resources or not?”** • Give students time to think, write. (10 min) • When finished, tell them to share with a neighbor or lab group what their ideas are. (5 min) • Bring the group back together and have a representative at each table share out the ideas of the group. Teacher should asking guiding questions, clarifying questions and opposing questions to push student thinking. (15 Min)

DAY TWO

Activity
 	
Time: 1-2 class periods (or more if needed) plus time outside of class
Materials:
For each student:
- All data, notes and research collected from the previous activities
- Copies of
    ○ Paper on Carbon Sequestration
    ○ Common Argumentative Writing Rubric
    ○ Common Editing Rubric
 	
Students will write an essay on importance of trees and forest to carbon sequestration stating the importance of forest conservation to mitigate the accumulation of humans produce carbon in the atmosphere. Students will include supporting details from the findings obtained in part 1 and 2 of this unit. (**See Paper on Carbon Sequestration Directions and Writing and Editing Rubrics**)

Assessment:
Use the following documents as evidence of student work and learning:

- Paper: **Argumentative Writing and Editing Rubrics**

Optional: The student with the best paper will be selected to submit their paper either to the local newspaper, post it on school website or send to government agencies.

Part 3. Stand and Deliver: Position Paper on Carbon Sequestration

You will write an argumentative essay on what you have learned about carbon sequestration. The topic for you paper is:

> ***The importance of trees and forest to carbon sequestration stating the importance of forest conservation to mitigate the accumulation of human produced carbon in the atmosphere.***

The goal of a writing an argument in science is to refine and build consensus for your claim based on relevant evidence supported by sound reasoning in order to come as close as possible to making sense of the natural world.

Writers of good science arguments will:

- clearly state their claim
- support their claim with data and evidence
- organize reasons in a logical order, saving the strongest for last
- consider opposing claims
- include a strong conclusion

You will complete a peer check to evaluate each others work. Students can make comments and corrections on their partner paper after which you will revise your paper.

Name:______________________________ Class:________________ Date:_____________

COMMON ARGUMENTATIVE WRITING RUBRIC

My Claim:			
	My argument needs to be **revised.**	My argument needs to be **edited or revised.**	My argument is **complete.**
<u>Claim:</u> A statement or conclusion that answers the original question/problem.	I did not make a claim or my claim is inaccurate.	I made an accurate but incomplete claim.	I made an accurate and complete claim.
<u>Evidence:</u> Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.	I did not provide any evidence to support my claim or the evidence I provided may not support my claim.	I provided some evidence (1-2 pieces) but it may not be enough or it may not support my claim.	I provided <u>appropriate</u> and <u>sufficient</u> (3-4 pieces) evidence to support my claim.
<u>Reasoning:</u> A justification that connects the evidence to the claim. It shows why the data counts as evidence by using appropriate and sufficient scientific principles.	I did not provide reasoning, or I only provided reasoning that does not connect my evidence to my claim.	I provided reasoning that connects my claim and my evidence, but I may have repeated my evidence and/or included some scientific principles, but not enough.	I provided reasoning that connects my evidence to my claim and included <u>appropriate</u> and <u>sufficient</u> scientific principles that explain why the evidence supports my claim.
<u>Rebuttal:</u> Recognizes and describes alternatives explanations and provides counter evidence and reasoning for why the alternative explanation is not appropriate.	I did not recognize that an alternate explanation exits and did not provide a rebuttal or I made an inaccurate rebuttal.	I recognize an alternative explanation and provided some counter evidence and reasoning in making my rebuttal but it may not be enough.	I recognize an alternative explanation and provided <u>appropriate</u> and <u>sufficient</u> counter evidence and reasoning in making my rebuttal.

Name:_____________________________ Class:_______________ Date:____________

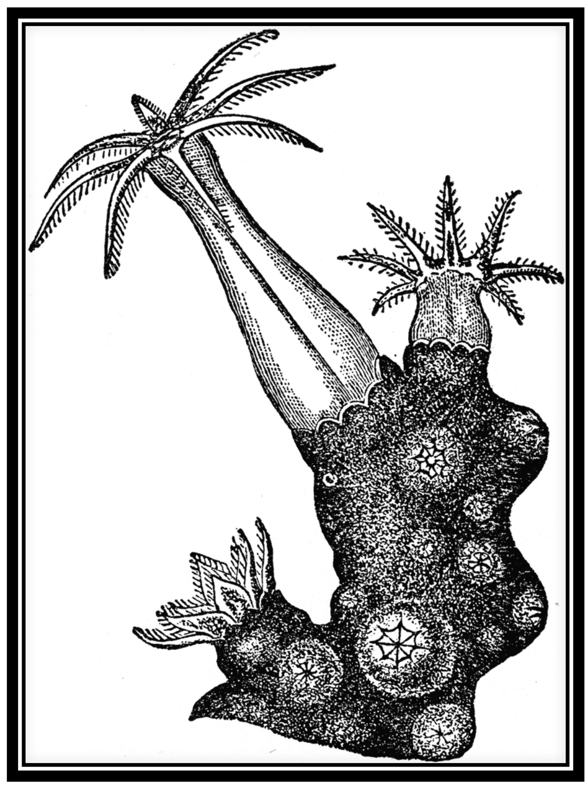
COMMON EDITING RUBRIC

WRITING STANDARD	My work is ready to be **revised**	My work is ready to be **edited**	My work is ready to be **proofread**	My work is ready to be **published**
A writer can self-assess their grammar by reading their piece aloud to ensure the piece makes sense.	I struggle to read my piece aloud. My grammar mistakes make it difficult to understand what I meant to say. I keep forgetting my point or say something different than what I wrote. I need to make major changes before someone else can read it.	I can read my piece aloud but need to stop to rewrite or restate confusing words or phrases. My ideas remain pretty much unchanged as I read aloud. I need to make changes before someone else can read it.	I can read smoothly through my piece without needing to correct my grammar. Words make sense and my thoughts flow from one to the other. Small errors do not interfere. I need someone else to read my piece to catch mistakes I can't see.	I can read smoothly through my piece without needing to correct my grammar. Anyone can pick up my piece and read throughout it without a problem. A copy editor would not be able to find any grammar errors in my piece.
A writer can self-assess their spelling and capitalization by reading their piece backwards from the end to beginning. Punctuation can be self-assessed by reading aloud and making sure your voice matches your punctuation choice (i.e. do you have a period to indicate the end of a thought? Do you have commas where you paused?)	My ideas are there but spelling, punctuation, and capitalization errors make it difficult for me to understand them as I re-read. Unless I fix these errors, the reader won't be able to understand me.	My ideas are there and spelling, punctuation, and capitalization errors slow me down as I re-read. Unless I fix these errors, the reader will struggle to understand me.	My ideas are there and are easily understood. Any spelling, punctuation, and capitalization errors are easily overlooked. Fixing the errors will polish off my writing.	My ideas are there and easily understood. I may deviate from traditional spelling, punctuation, or capitalization but I do it to help convey my ideas and can explain the reasoning for my decision.

2
MARINE CARBON SEQUESTRATION

Chapter 2: Coral Reef Health as Indicator for Marine Carbon Sequestration Unit Summary

In this unit, students will explore the role that coral reefs have in marine carbon sequestration and in the monitoring of global marine health. Students will investigate how intact coastal marine habitats remove carbon from the atmosphere via abiotic and biotic processes, i.e., the solubility pump and the biological pump, and will identify negative impacts to coral reef function, biodiversity, and ecosystem services associated with anthropogenic climate change.



This unit will challenge students to consider the validity of *the sentinel species concept*, the use of a single target species or a particular species assemblage as an indicator of overall ecosystem health. The identification of a potential sentinel species in ecosystems like coral reefs or forests can have significant impact on the magnitude of the conservation response and on the institution of environmental policy. The efficacy of the sentinel species approach to monitoring climate change is, however, currently debated among scientists. The Marine Carbon Sequestration Unit provides an opportunity for students to critically evaluate coral reefs as indicators of global marine health and will enable them to weigh-in on this timely debate. This unit is comprised of five learning activities broadly designed to engage students in critical marine biological research, strengthen skills in quantitative reasoning and analysis, and enhance student ability to process and mobilize scientific findings relevant to coral reef ecology and conservation.

In part one, students will examine coral reef imagery and, based on their observations of species presence and absence and relative reef structural complexity, differentiate between healthy and unhealthy reefs. Exemplary photographs will illustrate symptoms of poor coral health associated with four principal anthropogenic impacts on marine ecosystems: increasing sea surface temperature, decreasing pH (i.e., ocean acidification), over-fishing, and the introduction of invasive species. Students will correlate visual information (effects) with contemporary marine processes (causes) and draw conclusions about relative reef health based on their observations of constituent species.

In part two, students will build and manipulate a model coral reef ecosystem in the classroom using coral reef species cards and standard underwater ecological sampling methods. This exercise will require students to key out species, interpret and record their life history characteristics, and develop a field "search image" for essential corals, algae, invertebrates, and fishes associated with healthy and unhealthy coral reefs. In this exercise the classroom floor will become a virtual reef that student *snorkeling buddy-pairs* will sample using transects and visual survey techniques. Students will identify and count species that occur along their transects and record raw field data on data sheets in preparation for data analysis.

In part three, raw species counts will be used to calculate relative species richness and abundance on virtual reefs. Students will generate quantitative data to support theories regarding the health of their virtual reefs and potential causes for the species assemblages they are observing. The "field sampling" and data analysis exercise will challenge students to apply their understanding of the characteristics of healthy and unhealthy coral reefs and the direct and indirect impacts associated with decreasing pH (ocean acidification), increasing temperature, over-fishing, and the introduction of invasive species on coral reef ecosystems developed in part one.

In part four, students will scale up their understanding of coral reef dynamics, ecosystem services, and vulnerabilities to climate change via a coral reef food web modeling exercise. Based on their research findings in parts 1 and 2, students will build food web models that utilize known species interactions and map the transfer of energy through intact and impacted trophic dynamic systems. Students will discuss how reef species presence and absence effects energy availability, investigate the role of individual species in overall ecosystem function, and consider the pros and cons of utilizing the sentinel species concept in resource conservation and environmental policy.

Students will emerge from this unit with the knowledge of how to design an effective experiment, conduct model field research, and use qualitative and quantitative modeling to draw conclusions about their research findings. Ultimately, students will be challenged to question the merit of their research design, contribute to our collective understanding of the role of coral reefs in global carbon sequestration, and explore the significance of utilizing indicator species as sentinels of global climate change.

Unit Outline

Big Ideas:

1) The increase of green house gasses (CO_2, N_2O, CH_4) in the atmosphere is causing climate change, which is changing ecosystems, i.e., shifts in global temperature and weather patterns are altering species ranges and decreasing biodiversity.
2) When intact, natural carbon storage systems such as forests and coral reefs provide an ecosystem-service that tempers climate change by mitigating the carbon that humans emit as they go about their daily activities.
3) Human activities are significantly affecting land, ocean, and atmosphere and those changes are altering global climate patterns. Human choices have the power to modify the current trajectory of global climate change.
4) Some natural systems are experiencing change at a more rapid rate than others. Certain species in these systems can be monitored as indicators of change.

Essential questions for this unit of study:

1) How does energy from the sun pass through a coral reef system?
2) How does disturbance- natural and anthropogenic- affect the health and long-term viability of coral reef ecosystems?
3) How does increased carbon in the atmosphere impact coral reefs?
4) What are the measures of health in a coral reef, and how do they vary between healthy and unhealthy reefs?

By the end of this unit students will be able to:

1) Evaluate real underwater images of coral reefs to quantify coral reef health using known indicator species (i.e., parrot fish and sea urchin presence and absence).
2) Manipulate a coral reef model to investigate how changes in pH, temperature, over-fishing, and the introduction of invasive species affect reef health.
3) Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
4) Identify the characteristics of healthy and unhealthy coral reefs (i.e., species richness and abundance, endemic vs. invasive).
5) Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.

Assessment Evidence

1) Formative:
    a. Construction of a coral reef food web diagram including primary producers, secondary - quaternary consumers, detritivores, and decomposers.
    b. Quantitative comparison of real underwater coral reef imagery.
    c. Creation of a data table and collection of data from transects sampled in a simulated coral reef.
    d. Analysis of collected data and final determination of coral reef health based on calculated species richness and abundance and indicators of disturbed vs. undisturbed coral reef health.

2) Summative:
    1) Given a particular global climate change scenario(s) impacting a healthy coral reef, predict the species assemblage that would most likely be present along an underwater transect.

Nature of Science Inquiry Considerations:

- What are the key research questions in this study?
- Who are the stakeholders in this issue and how will potential research findings impact them?
- What are the limitations of study?
- Is the data collected able to be generalized?
- In what ways can these research findings be applied to enact change and further school, community, and larger science community?

Lessons:

Part I: What's Going On?

- Coral Reef Image Comparison

Part IIa: Who Eats Whom?

- Coral Reef Food Web

Part IIb: Walk the Line?

- Model Reef Transect

Part III: Making Sense of Data

- Reef Transect Data Analysis

Part IV: Make a Model

- Disturbed Reef Modeling

Vocabulary

- abundance
- autotroph
- benthic sampling
- biota
- carnivore
- consumer
- corallivorous
- decomposer
- detritivore
- disturbance
- ecosystem
- food chain
- food web
- herbivore
- heterotroph
- indicator species
- invasive species
- omnivore
- pelagic sampling
- pH
- producer
- richness
- scavenger
- transect

-

Marine Carbon Sequestration Links:

- Interactive Oceans – The Carbon Cycle
  http://www.interactiveoceans.washington.edu/story/Carbon+Cycle
- The Ocean's Carbon Balance
  http://earthobservatory.nasa.gov/Features/OceanCarbon/
- Ocean Carbon Storage
  http://www.pmel.noaa.gov/co2/story/Ocean+Carbon+Storage
- Carbon and Climate – Ocean Uptake
  http://carboncycle.aos.wisc.edu/ocean-uptake/
- Carbon Sequestration to Mitigate Climate Change
  http://pubs.usgs.gov/fs/2008/3097/pdf/CarbonFS.pdf

Figure 2.1 Healthy coral reefs support a complex, colorful, and highly diverse assemblage of species. Image courtesy of National Geographic

Part 1. What's Going On?

Description: In this activity students look at a set of 5 reef images and write down their observations. Of the five images provided, only the healthy reef is labeled. The student's goal is to write a claim that explains what they think happened to each of the other four reefs. The claim should be backed up with the evidence they collect and include their reasoning for making the claim. In a later activity they will revisit these images and, if needed, revise their claims based on the activities that follow.

Learning Objectives:

1) Analyze and interpret pictorial data to compare patters of similarities and differences in coral reefs to identify the effects of damage caused by increase in pH, increase in temperature, overfishing, and the introduction of invasive species.

Time Needed: 1-2 class periods

Related Concepts/Prior Knowledge:

- Trophic Levels
- Energy transfer in a food web
- Carbon cycle

Materials:

- One set of color reef images for each group of students and/or projector to project each image

Handouts:

- Coral Reef Image Comparison Worksheet

Assessments:

- For each image students minimally included the following:
    - Three or more observations (evidence)
    - Two questions
    - One inference

Tips for Teaching this lesson/Safety:

For each of the unhealthy reef images, encourage students to place the healthy reef image side-by-side while observing. For students needing more support, ask them to perform a simple compare/contrast of the healthy reef versus each of the unhealthy reef pictures.

Teacher Background:

Refer to coral health readings below with special attention to the *Coral Health Index*

Resources (Books, Webs, Media):

- Coral Health Index pdf (http://science2action.org/files/s2a/chi-lowresolution.pdf)
- Reefs At Risk, A Map-Based Indicator of the Threats to the World's Coral Reefs (http://pdf.wri.org/reefs.pdf)

- Healthy Reefs for Healthy People, A Guide to Indicators of Reef Health and Social Well-being in the Mesoamerican Reef Region
  http://www.toniparras.com/stories/Healthy_Reef_24_complete-1.pdf

1. The Coral health Monitoring Program, NOAA (http://www.coral.noaa.gov/
2. Coral Reef Field Guides (helpful but not required)

Schedule:

Day One

Do Now	10-15 min or 50 min*

Day Two (if needed)

Activity	50 min

DAY ONE

Do now

Time: 10-15 min or one class period (see note below)*
Materials: science journal or Do Now record sheet, poster paper and markers (optional)

Have the following question on the board as students enter and have them create a written response. (8 min)

> **"What would a healthy coral reef look like?"**
>
> *In your science journal* (or Do Now sheet, equivalent) *write your response then turn to a neighbor and share you thoughts. Be ready to share out to the whole group.*

Bring the class back together and have each group share their ideas. Record student responses on chart paper and save for review later in the lesson.

*Optional: If time permits have each group of 4-5 students prepare a poster of their combined ideas and present to the class. (40 min)

DAY TWO*

Activity

Time: One class period
Materials: One set of color reef images for each group of 3-5 students, science journals or Coral Reef Image Comparison worksheet.

In this activity students will observe 5 images of coral reefs. They will record and share their observations. The images include:

IMAGE #1: Healthy Reef

IMAGE #2: Reef damaged by overfishing
IMAGE #3: Reef damaged by lowered pH
IMAGE #4: Reef damaged by invasive species
IMAGE #5: Reef damaged by high temperature.

If you do not have a structure in place for how you like students to make their observations we recommend a 3-2-1 approach; 3 observations, 2 questions, 1 inference. Observations could be both written and/or drawn. Students should have experience making inferences beforehand.

Hand out the Coral Reef Image Comparison Worksheet and have them read and complete part one as a group or individually. Time permitting, have groups share their observations.

Optional: If you are unable to make color copies you could project each image one at a time and have the class make observations. These could be recorded on chart paper or in their journals/worksheet.

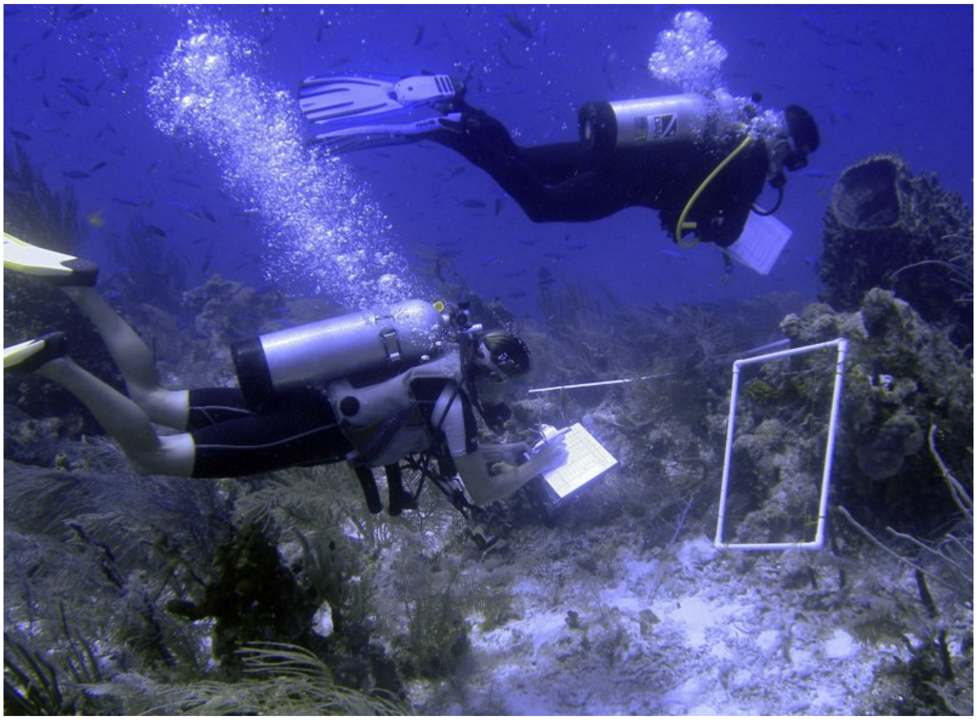
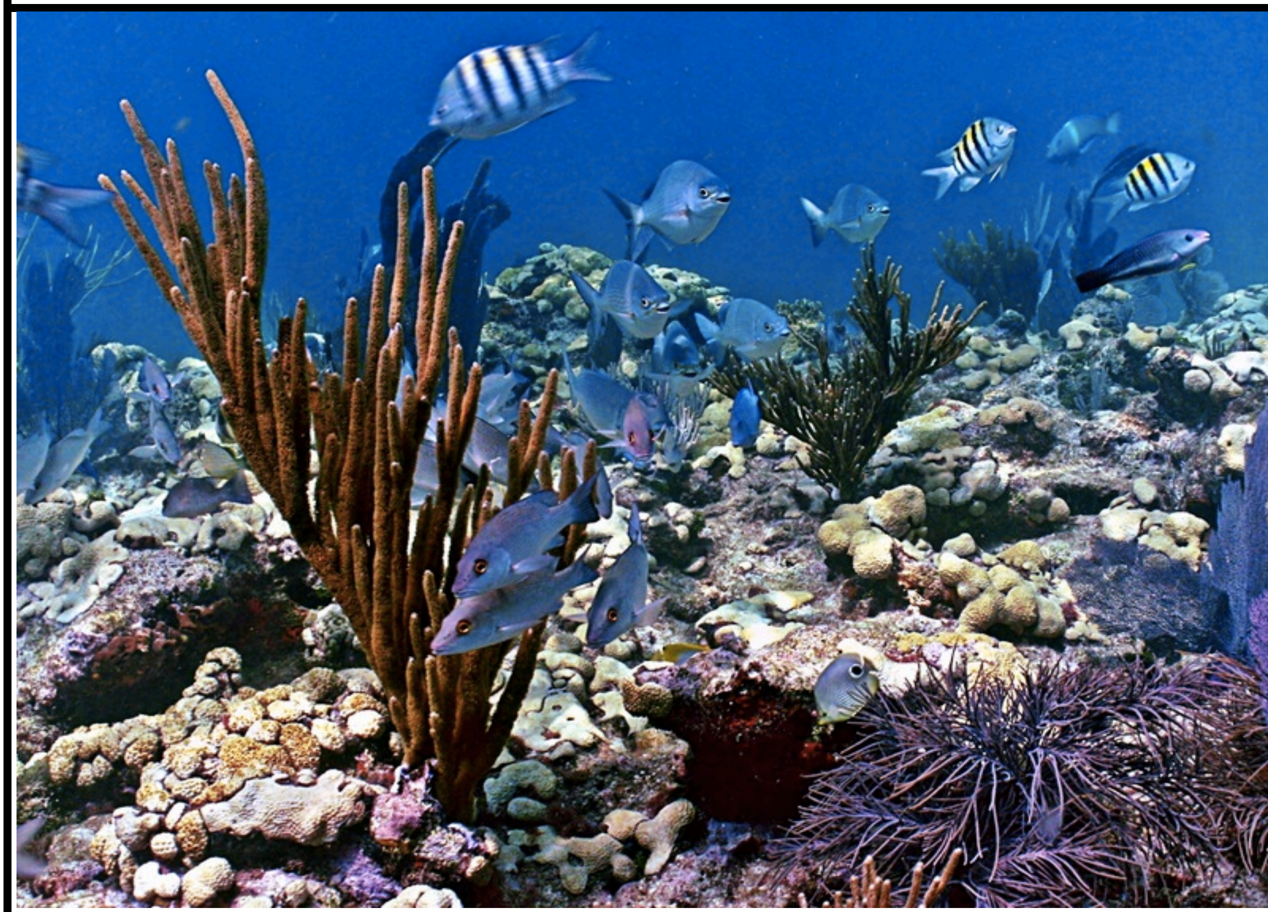


Figure 2.2 SCUBA divers sampling coral reef species richness and abundance using standard quadrat and transect sampling methods. Image courtesy of the Smithsonian Institute.

REEF IMAGES

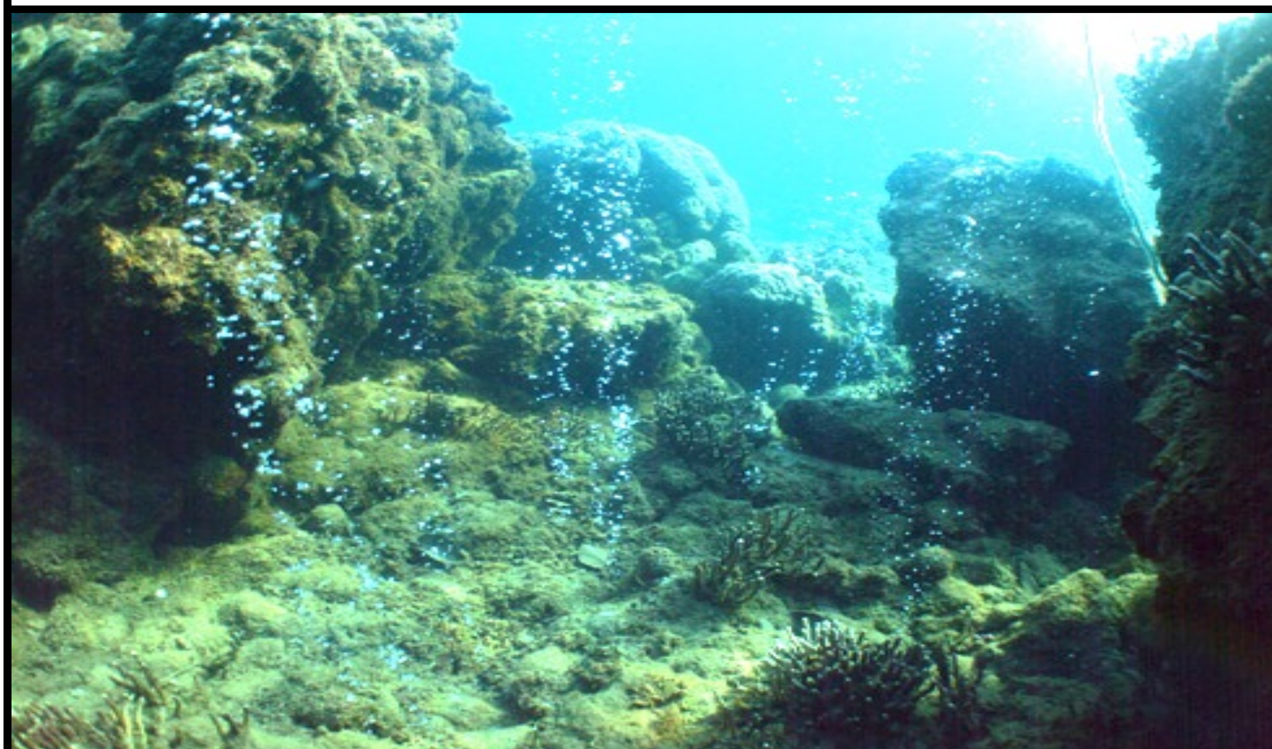
Directions to Teacher: Make enough color copies to provide a set of images to each group of 3-4 four students. We recommend color copies that are laminated as you will use these a few times.

HEALTHY REEF



DAMAGED REEF #1

DAMAGED REEF #2



DAMAGED REEF #3

DAMAGED REEF #4

Name:_____________________________ Class:_______________ Date:____________

Part 1. What's Going On? Coral Reef Image Comparison

The world's coral reefs are declining at a fast pace from a known group of local and global threats. Even though local efforts have been put into place to protect and rebuild coral reef ecosystems, detailed ecological information is still missing to determine if these attempts are working or not.

Directions: In this activity you are to take on the role of a marine scientist and make observations of coral reef images. First, observe the image of a health coral reef. What evidence can you see that would lead you to believe this reef is healthy? Record your observations then compare this image to the four images of damaged reefs that follow. In the space below each image jot down your observations and questions as you compare and contrast the images.

Healthy Reef
Observations/Evidence:

Damaged Reef #1	
Observations/Evidence	What might have happened?
Similarities/differences to other images	What you are wondering about this image.

Damaged Reef #2	
Observations/Evidence	What might have happened?
Similarities/differences to other images	What you are wondering about this image.

Damaged Reef #3	
Observations/Evidence	What might have happened?
Similarities/differences to other images	What you are wondering about this image.

Damaged Reef #4	
Observations/Evidence	What might have happened?
Similarities/differences to other images	What you are wondering about this image.

Part 2. Who Eats Whom?

Description:

Students will work in pairs to examine the coral reef organisms gallery provided in the *Coral Reef Species Key Sheet* and review the illustrations and information provided. They will build their own coral reef food webs using the organisms and species life histories referenced in the *Coral Reef Species Key Sheet*. Each pair of students will be provided with paper (poster paper or newsprint) and drawing materials to create a draft outline of their food web. After checking their food web outlines for completion and accuracy, each student pair will be given a poster board to illustrate the organisms and their interactions in the food web.

The food web poster will represent individual organisms and their relative trophic level in a coral reef ecosystem. Each organism will occupy a position in the web and will be connected to other organisms with arrows. Arrows represent the flow of energy and biomass from one organism (trophic level) to another and will be justified with known species life history information provided in the *Coral Reef Species Key Sheet.*
The food web poster must include the following:

- 7 primary producers (photosynthetic autotrophs)
- 4 primary consumers (carnivore or omnivore)
- 3 secondary consumers (carnivore or omnivore)
- 2 tertiary consumers (carnivore or omnivore)
- 1 quaternary consumer (carnivore or omnivore)
- 2 detritus feeders (detritivore)
- 1 scavenger
- 1 decomposer

Learning Objectives:

1) Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

Time Needed: One 50-minute class period.

Related Concepts/Prior Knowledge:

- Trophic Levels
- Energy transfer in a food web
- Carbon cycle

Materials:

- *Coral Reef Species Key Sheet*
- newsprint, poster board
- markers
- colored paper
- pencils

- scissors
- glue

Handouts:

- *Coral Reef Species Key*

Assessments:

- -Each poster should include the following labeled organisms: 7 primary producers (photosynthetic autotrophs); 4 primary consumers (carnivore or omnivore); 3 secondary consumers (carnivore or omnivore); 2 tertiary consumers (carnivore or omnivore); 1 quaternary consumer (carnivore or omnivore); 2 detritus feeders; 1 scavenger; 1 decomposer
- Name, date, class info on poster.

Tips for Teaching this lesson/Safety:

Organisms can be depicted using their common names, scientific names, picture or key symbol provided in the *Coral Reef Species Key Sheet.* Species relationships, i.e., predator and prey, should be clearly delineated with arrows. Arrows will inevitably overlap one another, encourage students to manipulate their food web diagrams spatially to increase flow and readability. Note: all food webs need not look the same, accuracy of relative trophic position is most important.

Teacher Background:

Food webs display the interconnectedness of species within an ecosystem. Food chains, found within food webs, are linear and often illustrate only one path of food and energy through an ecosystem. Though helpful in understanding the relationship between producers and consumers in ecology, food chains are simplified representations of complex species interactions. In most ecosystems, organisms utilize numerous simultaneous sources of food and may have significantly more than just one predator. Healthy, well-balanced ecosystems are made up of multiple, interacting food chains, called food webs. The “connections” between species in food web (i.e., plants and herbivores, predators and prey) are illustrated using arrows that represent the direction of the flow of energy and biomass between trophic levels.

Food Chain **Food Web**

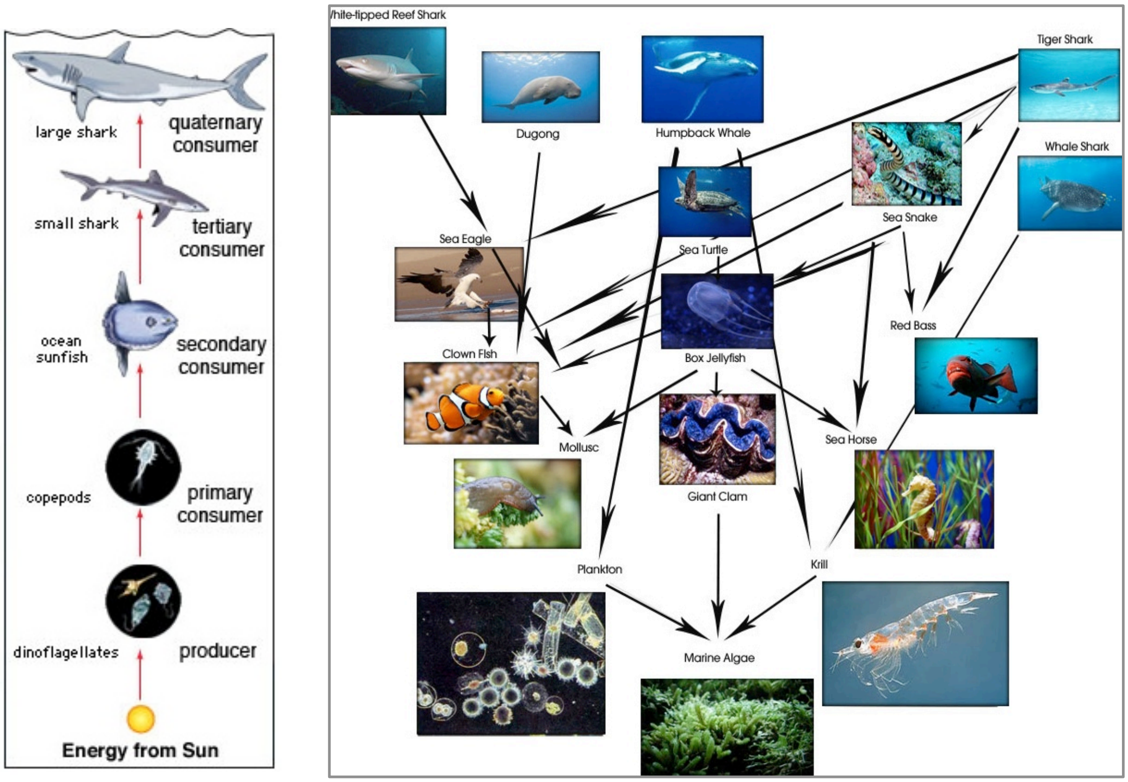


Figure 2.3 A coral reef food chain and food web diagram from the Great Barrier Reef, Australia.
Images courtesy of http://www.greatbarrierreef.com.au

Resources (Books, Webs, Media)

- Coral Health Index pdf: (http://science2action.org/files/s2a/chi-lowresolution.pdf)
- Journey Through the Trophic Levels of a Coral Reef Food Web, National Geographic: http://education.nationalgeographic.com/education/media/coral-reef-food-web/?ar_a=1
- Illustrated Coral Reef Food Web, NOAA: http://coralreef.noaa.gov/education/educators/resourcecd/posters/resources/iyor_foodweb_p.pdf
- Interactive Coral Reef Food Web, The Blue Planet, BBC: http://www.bbc.co.uk/nature/blueplanet/webs/flash/main_game.shtml
- Interactive Reef, NOAA: http://coralreef.noaa.gov/aboutcorals/interactivereef/
- Disappearance of Coral Reefs, Drastically Altered Marine Food Web On the Horizon, *Science Daily*: http://www.sciencedaily.com/releases/2013/08/130805133630.htm
- Coral Reef Field Guides (helpful but not required)

Schedule

Day One

Activity 50 min

DAY ONE
Activity **Time:** One class period **Materials:** Coral Reef Species Key Sheet; newsprint, poster board, markers, colored paper, pencils, scissors, glue. Begin by explaining the Coral Reef Food Web activity (see above). Hand out the species key and review the species indicated. Challenge students to begin piecing together linear food chains based on species life history details and then combing those chains into overlapping networks. If you students are not familiar with food chains and food webs, present a simplified model of how they are constructed. Students should be prepared to defend the position of any given species in their food web. To illustrate just how complex these 2D food web models can become, see the *Simplified Atlantic Food Web* at the end of this lesson.

Figure 2.4 Multiple trophic levels on a healthy coral reef, from primary producers to higher order consumers. Image courtesy of National Geographic

CORAL REEF SPECIES KEY

Organism	Description
CORALS	
	**Finger Coral,** *Porites porites* Habitat: most reef environments Diet: photosynthetic; zooxanthelle symbiosis Predator: parrot fish, diadema, butterfly fish Vulnerability: coral bleaching, bacteria & disease, high temperatures lead to death of symbiont , skeletal dissolution by increase in pH
	**Mustard Hill Coral***, Porites astreoides* Habitat: most reef environments Diet: photosynthetic; zooxanthelle symbiosis Predator: parrot fish, diadema, butterfly fish Vulnerability: coral bleaching, bacteria & disease, high temperatures lead to death of symbiont ,skeletal dissolution by increase in pH
	**Brain Coral**, *Diploria strigosa* Habitat: most reef environments Diet: photosynthetic; zooxanthelle symbiosis Predator: parrot fish, diadema, butterfly fish Vulnerability: coral bleaching, bacteria & disease, high temperatures lead to death of symbiont ,skeletal dissolution by increase in pH
	**Lettuce Coral**, *Agaricia agaricites* Habitat: most reef environments, mangroves Diet: photosynthetic; zooxanthelle symbiosis Predator: parrot fish, diadema, butterfly fish Vulnerability: coral bleaching, bacteria & disease, high temperatures lead to death of symbiont ,skeletal dissolution by increase in pH

Organism	Description
	**Massive Starlet Coral**, *Siderestres sidrea* Habitat: shallow to moderate reefs Diet: photosynthetic; zooxanthelle symbiosis Predator: parrot fish, diadema, butterfly fish Vulnerability: coral bleaching, bacteria & disease, high temperatures lead to death of symbiont ,skeletal dissolution by increase in pH.
PRODUCERS	
	**Crustose Coralline Algae**, Rhodophyta Habitat: shady areas of marine environment Diet: photoautotroph Predator: parrot fish, diadema, urchin, butterfly fish Vulnerability: sedimentation, high temperatures
	**Turtle grass**, Thalassia testudinum Habitat: grow on sandy bottoms and areas of mixed sand and coral rubble Diet: photoautotroph Predator: turtles, snapper, reef urchin, slate pencil urchin, damsel fish Vulnerability: sedimentation, bacteria & disease
	**Encrusting Leaf Fan Algae***, Lobophoa verigate* Habitat: grow on shady, rocky subrate Diet: photoautotroph Predator: turtles, snapper, reef urchin, slate pencil urchin, damsel fish Vulnerability: sedimentation, bacteria & disease

Organism	Description
	**Bocas Algae**, *Sargassum polyceratium* Habitat: grow on shady, rocky subrate Diet: photoautotroph Predator: turtles, snapper, reef urchin, slate pencil urchin, damsel fish Vulnerability: sedimentation, bacteria & disease
	**Forked Sea Tumbleweed**, *Dictyota menstrualis* Habitat: grows on shady, rocky subrate Diet: photoautotroph Predator: turtles, snapper, reef urchin, slate pencil urchin, damsel fish Vulnerability: sedimentation, bacteria & disease
FISH	
	**Bluehead Wrasse,** *Thalassoma bifasciatum* Habitat: Coral reefs Diet: Acting as cleaners, eating parasites off larger fish Predator: Grouper, Barracuda, jacks Lion fish, Vulnerability: Fish leaving due to habitat loss → loss of cleaner stations
	**Foureye Butterfly Fish**, *Chaetodon capistratus* Habitat: reef tops Diet: Worms, corals, crabs Predator: Grouper, lionfish, barracuda, sharks Vulnerability: high temperatures, coral bleaching makes them abandon reefs

Organism	Description
	**Dusky Damselfish,** *Stegastes adustus* Habitat: shallow reefs and rocky areas Diet: worms (feather duster, polychaete, Christmas Tree), urchin, smaller fish Predator: sharks, barracuda, jacks, lionfish Vulnerability: bacteria & disease, high temperatures, increase in pH, coral bleaching
	**Yellowtail Snapper**, *Ocyurus chrysurus* Habitat: reef enrironments Diet: seagrass, worms (feather duster, polychaete, Christmas Tree), urchin, smaller fish Predator: sharks, barracuda, jacks, lionfish (juveniles) Vulnerability: bacteria & disease, high temperatures, increase in pH, coral bleaching
	**Queen Triggerfish**, Balistes vetula Habitat: reef tops, coral rumble, grass beds Diet: sea urchins, smaller fish Predator: sharks, barracuda, jacks, lionfish (juveniles) Vulnerability: bacteria & disease, high temperatures, increase in pH, coral bleaching
	**Nassau Grouper** , *Epinephelus striatus* Habitat: shallow to mid range coral reefs, mangroves Diet: small fish, lionfish, lobsters, crabs, turtles, rays Predator: humans, sharks, fin fish Vulnerability: overfishing, small

Organism	Description
	**Great Barracuda,** *Sphyraena barracuda* Habitat: Coral Reef Diet: Parrot fish, wrasse, trigger fish, butterfly fish, damselfish, snapper Predator: Dolphins, Sharks Vulnerability: Loss of prey due to habitat loss
	**Scalloped Hammerhead Shark,** Sphyma lewinin Habitat: Cruise reefs, walls and shallows Diet: jacks, Barracuda, Grouper, Parrot fish, Triggerfish, snapper, Sea turtle, Urchins, Damselfish, *Lionfish (being trained to eat, but wont eat naturally) Predator: Humans (Boat Strikes and overfishing) Vulnerability: Loss of prey due to loss of habitat
	**Black Jacks,** Caranx lugubris Habitat: Deep water fish, walls, and steep drop-offs Diet: Parrot fish, triggerfish, butterfly fish, snapper, dameselfish Predator: Dolphin, Shark, Vulnerability: Loss of prey due to loss of habitat
	**Lionfish,** *Pterois radiate* Habitat: Natively from the Indo-Pacific, but found all along rocky areas Diet: Most juvenile reef fish, wrasse Predator: None Vulnerability: Loss of prey

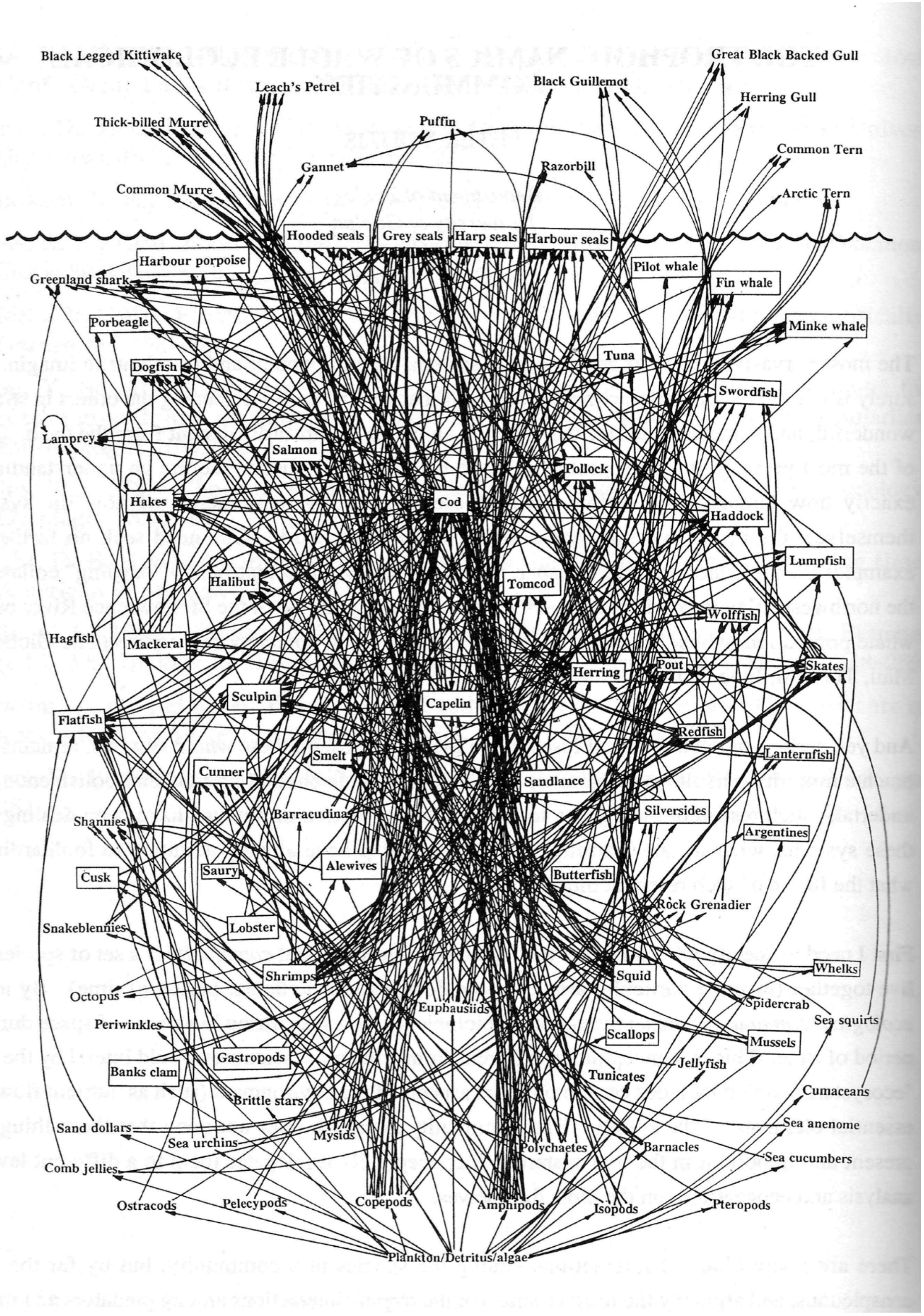
Organism	Description
	**Stoplight Parrot Fish,** *sperisoma viride* Habitat: Reef Environments Diet: algae from Coral Predator: Sharks, Grouper, Baracudda, Lionfish (eats juveniles) Vulnerability: Loss of Coral due to water temp increase, disease from bacteria due to water temperature increase.
	**Sting Ray** Habitat: Sandy, Sea grass areas Diet: Damselfish, most juvenile fish, Urchins, Crabs Predator: Sharks, Vulnerability: Fishery bicatch (unintentional), habitat loss
INVERTEBRATES	
	**Stinker Sponge,** *Ircinia felix* Habitat: shallow to mid-ridge reef Diet: filter feed phytoplankton, sediment filters Predator: turtles, nudey branch Vulnerability: sedimentation, bacteria & disease, high temperatures ,skeletal dissolution by increase in pH.
	**Christmas Tree Worms**, *Spirobranchus giagantus* Habitat: all areas of the reef Diet: filter feeders Predator: crabs, carnivorous fish Vulnerability: bacteria & disease, high temperatures, increase in pH, coral bleaching

Organism	Description
	**Bristleworm,** *Cirratulus cirratus* Habitat: On rocks and dead coral on sandy reef flats Diet: Algae, coral, smaller worms Predator: Fish, snails, crabs Vulnerability:, Temperature increase, disease, and bacteria
	**Marine Fireworm,** *Hermodice carunculata* Habitat: On rocks and dead coral on sandy reef flats Diet: Algae, coral, smaller worms Predator: Fish, snails, crabs Vulnerability:, Temperature increase, disease, and bacteria
	**Long-Spined Urchin,** *Diadema Antillarum* Habitat: Hide in sheltered locations during the day, come out during the night Diet: Algae and coral Predator: Sharks, Triggerfish, Grouper, stingray Vulnerability:, Temperature increase, disease, and bacteria
	**Reef Urchin**, Echinometra viridis Habitat: shallow reefs, Diet: algae Predator: triggerfish, stingrays, humans Vulnerability: bacteria & disease, high temperatures, increase in pH, coral bleaching

Organism	Description
	**Slate Pencil Urchin**, *Eucidaris tribuloides* Habitat: sea grass beds, reef rumbles, reefs Diet: algae Predator: triggerfish, stingrays, humans Vulnerability: bacteria & disease, high temperatures, increase in pH, coral bleaching
	**Tiger tail sea cucumber,** *Holothuria thomasi* Habitat: cracks or crevices in the coral reef Diet: decomposing matter, detritus Predator: grouper, lionfish (predate on juveniles), and humans Vulnerability: coral reef habitat loss, increase in temperature and pH
	**Painted elysia,** *Elysia picta* Habitat: coral reef and reef rubble Diet: sponges Predator: triggerfish, butterfly fish, Vulnerability: trigger fish, butterfly fish, and snapper
	**Green clinging crab,** *Mithrax sculptus* Habitat: shallow reefs and adjacent coral rubble, hide in cracks and crevices Diet: detritus, Christmas tree worms, juvenile fish Predator: grouper, barracuda cormorant Vulnerability: increase in pH, habitat loss due to coral reef bleaching

Organism	Description
	**Golden Coral Shrimp,** Stenopus scutellatus Habitat: All reef areas Diet: Parasites and micro biota, clean around holes in reef, near sponges and off of fish (cleaner stations) Predator: Grouper, Snapper, damselfish, Lionfish, triggerfish Vulnerability: Fish leaving due to habitat loss → loss of cleaner stations
BIRDS	
	**Cormorant,** *Phalacrocorax auritus* Habitat: coastal reef Diet: fish, crabs, and urchins Predator: osprey Vulnerability: food limitation due to loss of reef dwelling fishes
REPTILES	
	**Hawksbill Turtle** Habitat: Cruse, Reefs Diet: Shrimp, Crab, Sponges, squids, anemones, clams Predator: Sharks, Humans Vulnerability: Fishing, boat Strikes, Light pollution, Land use changes,
MAMMALS	
	**Bottlenose Dolphin,** *Tursiops truncatus* Habitat: Greater Atoll, Cay environments Diet: Parrot fish, triggerfish, butterfly fish, snapper, dameselfish, Predator: Humans Vulnerability: Loss of prey, boat impact, hunting

Simplified Atlantic Food Web (NOAA)



Part 3. Walk The Line

Description:

In this lesson students will have the opportunity to investigate a model coral reef system in the classroom. Students will assume the role of marine biologists, explore a "natural assemblage" of reef species, and collect data "in the field" using standard underwater sampling methods. This lesson will challenges students to learn and develop a *search image* for coral reef species, differentiate between indicators of healthy and unhealthy reefs, and accurately record scientific data in real time. By the end of this lesson students will have had first hand experience in sampling a model ecosystem and documenting their field observations. Quantitative information gathered by students in this lesson will be analyzed and discussed in Part 4 of this chapter and used to develop trophic dynamic models in Part 5.

Learning Objectives:

1) Use a model to quantify coral reef health using known indicator species (parrot fish and Diadema presence)
2) Collect data to provide evidence for the number and variety of marine biota in healthy and unhealthy reef.
3) Visually identify and count key coral reef species on a model coral reef
4) Develop a search image for critical reef health indicator species
5) Sample species richness and abundance using standard underwater transect methods
6) Collect and organize "field data" in real time using a data sheet
7) Prepare data for analysis in Part 4

Time Needed: 1- 2 class periods

Related Concepts/Prior Knowledge

- Species identification
- Data collection and organization
- Species abundance and species richness

Materials

- Double Sided Reef Species Cards (Side 1: healthy reef critters / Side 2: unhealthy reef critters)
- Reef boundary markers
- Two 3-meter lengths of string (transect measuring tapes)
- Optional: clipboards for student data sheets

Handouts

- Coral Reef Species Key
- Reef Transect Student Directions

Assessments

- Student buddy pair organization and preparedness for field "sampling" (i.e., familiarity with the data sheet and communication about field methods and expectations prior to entering the field).

Tips for Teaching this lesson/Safety

Set up of the model coral reef will require ample classroom floor space. If your classroom does not allow for this, the coral reef can be set up outside, in a gym, or in another large area on the school campus. In this exercise, students buddy pairs will interact with the model coral reef sequentially, one pair at a time. You are encouraged to develop a procedure for this exercise that works best for your group of students. For example, the class could be practicing species identification using flash cards in small groups while buddy pairs take turns coming up to the reef, collecting their transect line, placing their transect line on the reef, and sampling.

The key to bringing the coral reef model to life for students is to simulate real underwater sampling considerations in the classroom. Students should be instructed not to disturb reef species while near the coral reef, to be careful and calculated when sampling, and to be considerate of their fellow marine biologists while they are collecting data. When sampling real coral reefs in the field, scientists are careful not to scare fish or invertebrates with sudden movements, not to hit corals with their hands or dive fins, and to remain in fixed positions relative to the transect line while sampling (see Figure 2.6 below). Ultimately, the success of the sampling exercise depends on the accuracy and reproducibility of the group's sampling methods while in the field.

Before and during the model coral reef sampling exercise, student pairs should communicate and practice standard sampling methods, including (1) familiarization with the data sheet and target species *prior to* "sampling in the field", (2) orderly approach to the reef, (3) careful placement of the transect, and (4) methodical species counts during sampling. Scientists will often practice their sampling roles before entering the ocean (i.e., who will swim on the left vs. right side of the transect? Will both buddies simultaneously count all observed species or will each buddy target a particular group of species?), this lesson is a great opportunity for student pairs to discuss the same considerations.

Teacher Background

Healthy coral reefs are inherently complex and highly biodiverse ecosystems. The goal of developing a model coral reef in the classroom is to capture the richness, randomness, and interconnectedness of natural coral reefs. The classroom environment that you create during this lesson, both physical and conceptual, should strive to emulate natural reef complexity. In its simplest form your model reef will consist of a random mix of species cards distributed across an open floor, in a teacher-enriched form your coral reef can be made to emulate a real location (i.e., a reef in your country or a reef you have researched online) and be presented with site-relevant information about the prevailing weather, local coastal conditions, and anthropogenic influence. The addition of site-specific Information in this activity will not only make the experience more real but can introduce variables relevant to student assessment of overall reef health later in this chapter.

Prior to the sampling of your model coral reef, teachers are encouraged to lead a class discussion about the value of coral ecosystems. The simple visual model you have created in your classroom represents a system capable of taking up and storing global carbon, providing shelter and critical nursery habitat for thousands of associated species, and functioning as a food source for both humans and animals. While spread out on the classroom floor, Reef Species Cards can be used to review the roles of key species in the model coral reef system and stimulate a conversation about their individual vulnerabilities to change and the downstream food web effects of their removal.

The sampling methods utilized in this lesson are based on a three-pronged assessment tool researchers have developed to assess the health of coral reefs called the *Coral Reef Health Index* (CHI). CHI uses three metrics to determine the health of a reef and provides conservation biologists and environmental policy makers with a relative health rating important to future protection, use, or recovery of the coral reef resource. In its full form, three coral reef variables are measured using the CHI methodology, including (1) fish species richness and abundance, (2) benthic species richness and abundance, and (3) microbe richness and abundance. Data are collected along a 30-meter transect situated randomly on a coral reef. In summary, the characteristics of the fish, benthic, and microbial species assemblage are an effective proxy for the productivity and viability of a coral reef community.

In this lesson, teachers and students will utilize a simplified form of CHI that focuses on the assessment of two key coral reef indicator species, parrot fish and *Diadema* sea urchins. These two groups are particularly important to the diversity and stability of corals and a simple assessment of their presence and absence enables marine biologists to rapidly determine general reef health. Parrot fish are corallivorous and through their consumption of corals create space for new corals to grow (increasing species diversity) and as a byproduct of their feeding produce coral rubble valuable to the maintenance of the reef's nonliving coral rock foundation. *Diadema* sea urchins are herbivores and through their consumption of algae they free corals from their competition with algae (direct competition for space, food, and sunlight) and thus help to maintain coral abundance. The presence of these groups leads to a diverse and abundant coral assemblage, the absence of these groups leads to a decrease in species diversity, reef deterioration, and algal abundance.

Resources (Books, Webs, Media)

- Coral Health Index pdf: (http://science2action.org/files/s2a/chi-lowresolution.pdf)
- Parrotfish Critical To Coral Reefs: Permanent Damage Likely Unless Urgent Action Taken, Scientists Warn, *Science Daily*: http://www.sciencedaily.com/releases/2007/10/071031112907.htm
- The long-spined *sea urchin*, *Diadema*, as a keystone coral reef species: http://www.coastal.edu/media/administration/honorsprogram/pdf/Jessica Keller.pdf
- Methods for the ecological monitoring of coral reefs: http://data.iucn.org/dbtw-wpd/edocs/2004-023.pdf
- Carolina Biological for specimens
- Coral Reef Field Guides (helpful but not required)

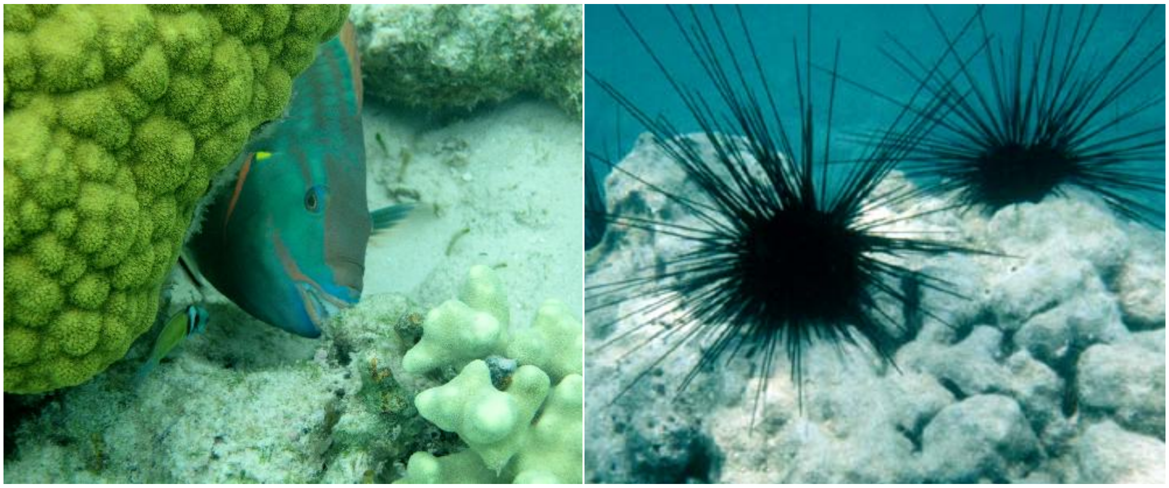


Figure 2.5. (A) Parrot fish eating corals and (B) *Diadema* sea urchins consuming an algal mat on dead coral structures. Images courtesy of Kennesaw State University.

Schedule

Day One	
Activity	50 min
Day Two (If needed)	
Continue Activity	50 min

Day One

ACTIVITY

Time: One-two class periods

Materials: Double-sided Reef Species Cards (Side 1: healthy reef species / Side 2: unhealthy reef species), Reef boundary markers, Two 3-meter lengths of rope or string (transect measuring tapes), Transect data processing worksheet, Reef food-web activity worksheet and rubric

Teachers will set-up the model reef ecosystem on the classroom floor and explain the reef transect sampling protocol. Students buddy pairs will take turns coming up to the model reef two at a time with the teacher to complete the transect sampling exercise.

> **Note:** Once all students have completed the "healthy reef transect", flip the cards over and have them complete a second transect on the "unhealthy reef". *This exercise can be divided into two separate class periods, one for each lesson, if necessary.

Set up: For this activity, students will be walking through a model coral reef and collecting data on the coral reef species they observe as they proceed. The model reef will consist of a random assortment of species cards spread out on the floor a circle roughly 5-7 meters in diameter.

In pairs, students take turns approaching the reef and are responsible for placing their own 3m transects (rope or string) across the reef environment. Encourage students to be random in the selection of their sampling location, an optional discussion on random sampling and sampling bias can accompany this step.

Buddy pairs will then sample their transect by proceeding along the transect line, shoulder-to-shoulder in fixed left and right positions relative to the transect, and identify and count all fish and invertebrates *occurring within 0.5 m of their side of the transect line* (see Fig. 2.6). If an organism card is beyond their 0.5 m "swath" it should not be counted.

When the buddy pairs add their data together, after sampling the transect, the result is a 3 m^2 sample (i.e., 3 m x 1 m, or transect length x transect width) of the larger model coral reef.

> **Note:** Depending on student age and size, shoulder width is often a good proxy for estimating 0.5 m while proceeding down the transect line.

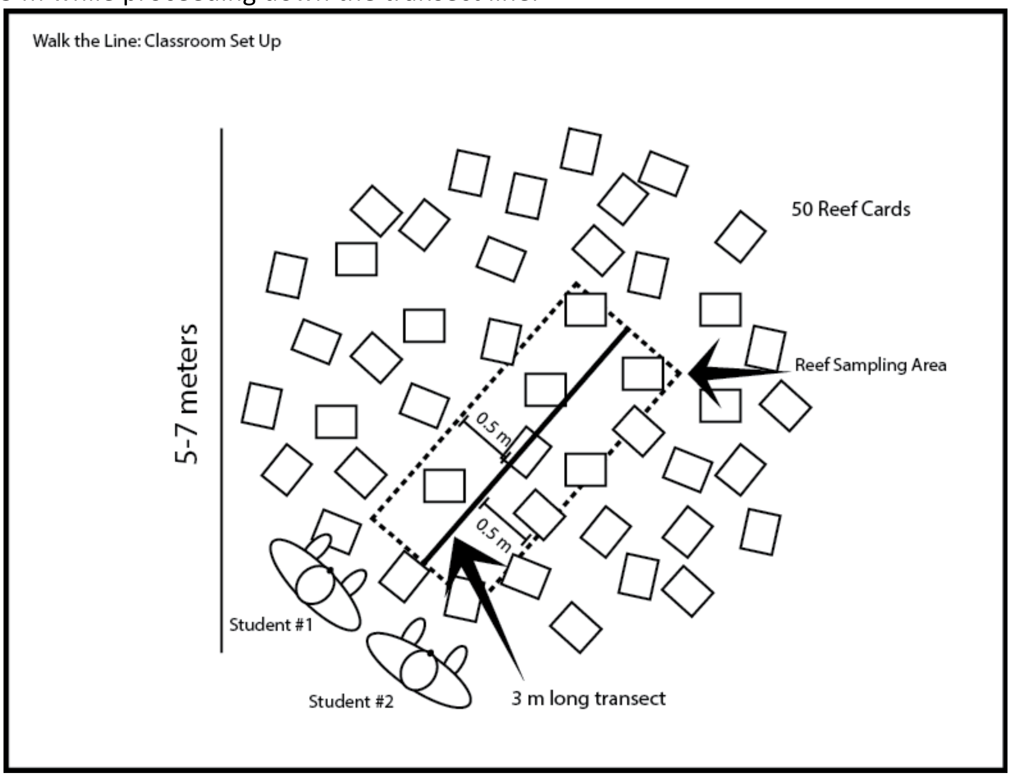


Figure 2.6

Each student in the buddy pair will gather their own raw data from their side of the transect. Following completion of the transect walk, buddy pairs will be responsible for compiling their data within their pair (addition) and within their original group of four (average). The original groups of four will then enter their data into a table on class whiteboard.

Although students are highly encouraged to learn coral reef species and their identification, data collection in this exercise can be simplified to "parrot fish vs. other fish" counts, where all non-parrot fish are clumped into "other fish" and tallied. Similarly, benthic invertebrates can be simplified to "*Diadema* vs. other invertebrates" counts, where all non-*Diadema* invertebrates are clumped into "other invertebrates" and tallied.

The learning gap between positive species identification and general field description can be gapped with a quick sketch of the organism as the student passes during sampling. This rough sketch can be used as reference to "look up the animal after leaving the water". Student buddy pair raw data using common names for coral reef species might look something like the following:

SAMPLE DATA COLLECTION

Student Buddy Pair 1
Transect #1 Healthy Reef

"Left" Diver

Healthy Reef	
Parrot Fish	Other Fish
1. spotlight parrotfish 2. spotlight parrotfish	1. bluehead wrasse 2. dusky damselfish 3. black jack 4. queen triggerfish 5. bluehead wrasse
Parrot Total: 2	Other Fish Total: 5
Diadema	Other Urchins
1. Diadema 2. Diadema 3. Diadema 4. Diadema	1. bristleworm 2. slate pencil urchin 3. painted elysia 4. golden coral shrimp
Diadema Total: 4	Other Invertebrates Total: 4

"Right" Diver

Healthy Reef	
Parrot Fish	Other Fish
1. spotlight parrotfish	1. dusky damselfish 2. yellowtail snapper 3. foureye butterfly 4. queen triggerfish
Parrot Total: 1	Other Fish Total: 4
Diadema	Other Urchins
1. Diadema 2. Diadema 3. Diadema	1. green clinging crab 2. reef urchin 3. marine fireworm 4. bristleworm 5. slate pencil urchin 6. tiger tail sea cucumber
Diadema Total: 3	Other Invertebrates Total: 6

Totals for Student Buddy Pair #1 would be:

Parrot fish: 3 individuals per 3 m^2
Other fish: 9 individuals per 3 m^2

Diadema: 7 individuals per 3 m^2
Other invertebrates: 10 individuals per 3 m^2

These values can then be averaged with the other buddy pair in the student's group of four and entered into the class data table.

At the end of their time on the reef student buddy pairs will have counted species in both healthy and unhealthy reef systems using the following standard data table design. As students finish collecting their raw data, teachers can encourage teams of four to begin thinking about the relative species richness (total number of species per unit area) and species abundance (total number of individuals per each species per unit area) that they observed. Patterns in healthy vs. unhealthy reef species assemblages will undoubtedly begin to emerge at this level.

Healthy Reef	
Parrot Fish	Other Fish

Healthy Reef	
Diadema	Other Urchins

Unhealthy Reef	
Parrot Fish	Other Fish

Unhealthy Reef	
Diadema	Other Urchins

During the Activity: The teacher will guide each group through this process.

Before you call students up, have them partner up and have their data sheet and pencil. The teacher will need to have the two 3 meter transects (string or rope).

> **Note:** Teachers may want to call up a volunteer buddy pair to model the sampling procedure for the class before real data is collected.

When ready:

1. Have students line up in pairs.
2. Give the first student buddy pair one of the transect lines and ask them to carefully lay it out anywhere on the reef (some species cards will be truly overlapped in doing so). Give the second transect line to the second pair of students waiting.
3. The first student buddy pair will then walk shoulder-to-shoulder on either side of the transect identifying and counting all species occurring within 0.5 m of their side of the transect and recording their data. IF a species card lies under the transect line itself it should be counted by the student that it is closer to, NOT both students.
4. When the buddy pair gets to the end of the transect the students will carefully collect the transect line and give it to the next group waiting. The students should then move away from the reef, review and tally their counts (species identifications could be verified at this stage), record their buddy pair data on the class chart (See below), and return to the back of the line.
5. Repeat this process with the next pair of students. Each new student buddy pair will choose where to lay their transect.

6. Once all the student pairs have gone, flip the cards over (have students help) and repeat the process for the unhealthy reef.

Note: You may need a second day to complete this.

Students will record this information on a class data sheet that will be ***drawn on the front board***. When complete, students will copy the class data onto the Class Data sheets. (Appendix p. …)

	Healthy Reef		**Unhealthy Reef**	
Group #	**Parrot Fish**	**Other Fish**	**Parrot Fish**	**Other Fish**
1				
2				
3				
4				
5				

	Healthy Reef		**Unhealthy Reef**	
Group #	**Diadema**	**Other Urchin**	**Diadema**	**Other Urchin**
1				
2				
3				
4				
5				

Note: Although species cards will be located on the floor, be sure to inform students that not all coral reef-associated organisms occupy the seafloor. Many fish species occupy the water column above corals or the interstitial spaces within the coral matrix. Many benthic invertebrates do occupy the seafloor but given the structural complexity of healthy coral reefs they often occur on the top of coral features and are in fact far from the seafloor itself. Your challenge as a teacher is to remind students that if they were actually swimming through a coral reef they would actually be observing a 3-D space and not a flat 2-D space.

Figure 2.7. Underwater transect sampling protocol using both a transect tape and a 1 meter visual reference bar. Image courtesy of reef.org.

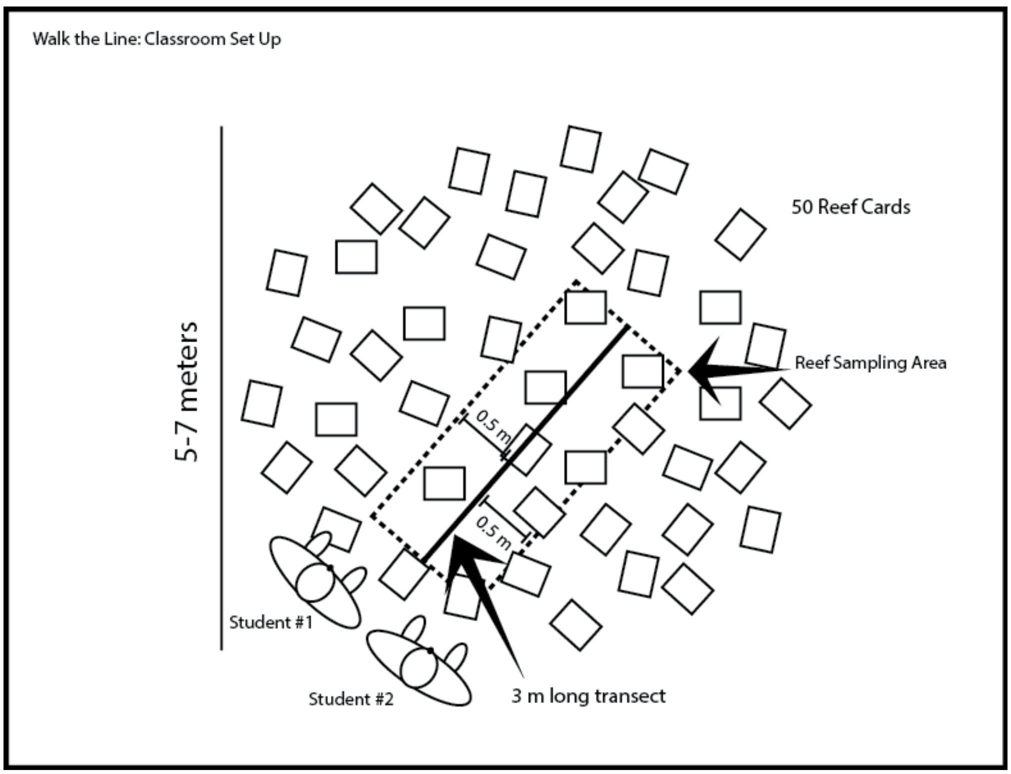
Name:____________________________ Class:_______________ Date:____________

Part 3. Walk The Line: Transect Data Collection Worksheet

Directions. You will be walking on a model coral reef counting the number of indicator species along the way. A circular reef environment roughly 5 -7 meters in diameter will be set up on the floor where you will randomly choose to place your 3 meter transects. While you are in the reef area, each student is responsible for collecting data about biota that falls ONLY in the 0.5m on their respective sides of the transect tape (see Figure 1). All other biota on the reef will not be considered.

At the end of their time on the reef add their numbers together for a total creature count along the transect and add them to the class chart that you teacher will place at the front of the class.

Figure 1



Record your count in the data tables for their time “on the reef” about the number of fish you see, and count them as either Parrot Fish or not. The other data point will be looking at bottom feeders, which will either be counted as Diadema or not. You will repeat this process for the Unhealthy Reef that your teacher will create by flipping over the cards.

Healthy Reef	
Parrot Fish	**Other Fish**

Healthy Reef	
Diadema	**Other Urchins**

Wait for you teacher to flip all the reef cards over to show you the unhealthy reef then repeat the data collection process. You may lay your transect line anywhere you like.

Unhealthy Reef	
Parrot Fish	**Other Fish**

Unhealthy Reef	
Diadema	**Other Urchins**

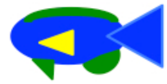
Name:______________________________ Class:________________ Date:_____________

Part 3. Walk The Line: Reef Transect Class Data

Benthic Sampling: Urchin Indicator Species

Group	Healthy Coral Reef		Unhealthy Coral Reef	
	Diadema Urchin	Other Urchin	Diadema Urchin	Other Urchin
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Pelagic Sampling: Fish Indicator Species



Group	Healthy Coral Reef		Unhealthy Coral Reef	
	Parrot Fish	Other Fish	Parrot Fish	Other Fish
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Part 4. Making Sense of Data

Description: Students will use their own data, as well as the data from their classmates to calculate summary statistics to try and assess the validity of the scientific tools they have employed while applying grade-level math skills. Students can then quantify the actual data from the whole simulated coral reef, which of course would not be feasible for actual sampling, and discover how well their sampling reflects this true measurement.

Learning Objectives:

1) Conduct basic summary statistics to describe data and estimate how well sampling characterizes the larger scale of interest, in this case the mock coral reef.
2) Analyze and interpret data on the distribution of biota to provide evidence of coral reef health.
3) Use mathematical representations to support explanations of how the presence of certain biota may indicate the overall health of a coral reef.

Time Needed: 1-2 class periods

Related Concepts/Prior Knowledge

- Mean, median, mode
- Volume, area

Materials

- pencils
- calculators

Handouts

- Coral Reef Species Key
- Reef Transect Data from Part 3
- Reef Transect Data Analysis Worksheet

Assessments

-Evaluate based on completeness of worksheet (data, calculations, answer completion.)

Tips for Teaching this lesson/Safety

-If your students are not equipped for the math in this activity, model how to complete the calculations or complete them as a class.

Teacher Background

For studies of large-scale processes, such as population size, habitat characterization, water chemistry, or fluxes of nutrients between system pools, scientists must employ statistical techniques to provide confidence in a their sub-sample values and then to scale data to more meaningful, system-scale estimates. This lesson will teach students to work with sub-sample data and calculate some basic statistics. They will also employ a simple scaling model, using volume of water, to apply their data to the entire "population" in this simulation. Since we are working with an artificial reef with a known population size, students will be able to validate their estimate. Comparisons of estimates with known values can provide material for stimulating discussion about sampling error and experimental design.

In the first part of this lesson, students will compile the data that each pair collected from sampling a small portion of the “reef.” In a typical study, the mean of all these subsamples would be used as the quantified result with some description of the variability of the data, usually standard deviation or standard error. In nature, variability is often real and random. However, sampling design can introduce bias and this should be minimized wherever possible. For example, collection of Diadema abundance data could be influenced by subtle differences in environment among transects, by the time of day or visibility when sampling, by the skill of the observer, or any number of other factors. A good experimental design eliminates as much variability as possible, while considering the practicality and cost of sampling methods. Although students will not be asked to calculate these more complex statistics in this exercise, discussion of the variability in data among pairs and of the differences among the mean, median, and range may fuel critical thinking.

Next, students will use geometry skills to calculate the volume of their transect and the volume of the whole reef. By assuming that the sampling method is accurate and that the sub-sample is representative of the whole reef, a model for estimating the population of the reef may be established by setting up a proportion. Teachers are encouraged to discuss the merits of this estimation technique with students. This simulation provides an opportunity to directly compare estimates to the actual value. In most studies, this is not possible. One interesting extension would be to have students scale up their individual group mean and compare this to the scaled up estimate of the class mean. If the group estimate differs only slightly from the class mean, this could result in a much larger difference after scaling. Given that this model is used so widely for many important estimates, students should understand the importance of accurate estimation and sound experimental design.

Resources (Books, Webs, Media)

- Coral Reef Field Guides (helpful but not required)
- Coral Health Index pdf

Schedule

Day One

Activity 50 min

DAY ONE

Activity

Time: 1-2 class periods
Materials: Individual and class transect data from Part 3, pencils, calculators, Coral Reef Species Guide

Display the transect data collected by each group of students to the class. Data should have the general form of the following example:

Pelagic Sampling: Fish	
Parrot Fish	**Other Fish**
Group 1 Value	*Group 1 Value*

Benthic Sampling: Urchins	
Diadema Urchin	**Other Urchin**
Group 1 Value	*Group 1 Value*

Group 2 Value	*Group 2 Value*		*Group 2 Value*	*Group 2 Value*
Group 3 Value	*Group 3 Value*		*Group 3 Value*	*Group 3 Value*
Group 4 Value	*Group 4 Value*		*Group 4 Value*	*Group 4 Value*
Group 5 Value	*Group 5 Value*		*Group 5 Value*	*Group 5 Value*
Group 6 Value	*Group 6 Value*		*Group 6 Value*	*Group 6 Value*

Students will fill in their own group's data in their assigned group number row and copy down their classmates' values to complete the table. For each of the four sampling metrics in each type of reef (healthy and unhealthy), students will calculate the mean, median, and range of the data. These values will be entered into the worksheet (Question 1).

Benthic Sampling: Urchin Indicator Species (Class Totals)

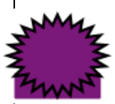
Healthy Coral Reef			**Unhealthy Coral Reef**	
Diadema Urchin	**Other Urchin**		**Diadema Urchin**	**Other Urchin**
Mean:	*Mean:*		*Mean:*	*Mean:*
Median:	*Median:*		*Median:*	*Median:*
Range:	*Range:*		*Range:*	*Range:*

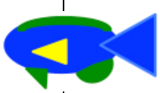
Pelagic Sampling: Fish Indicator Species (Class Totals)

Healthy Coral Reef			**Unhealthy Coral Reef**	
Parrot Fish	**Other Fish**		**Parrot Fish**	**Other Fish**
Mean:	*Mean:*		*Mean:*	*Mean:*
Median:	*Median:*		*Median:*	*Median:*
Range:	*Range:*		*Range:*	*Range:*

After calculating the mean, students should compare the summary statistics for the healthy reef to the unhealthy reef to determine if there are differences (Question 2). Some differences in range might arise due to the different relative abundance of indicator species in the healthy and unhealthy reefs.

Next, students will compare their group's value to the mean and report the difference from the mean. They will be asked to explain any variation (Question 3.).





	Group Data	Class Mean	Difference (Group Data – Class Mean)
Benthic Sampling:			
Diadema Urchins			
Other Urchins			
Pelagic Sampling:			
Parrot Fish			
Other Fish			

Next, students will convert the mean sampling count into a value of urchins per unit area of benthos or fish per unit volume of water. This will require that they calculate the area and "volume" sampled in their transect. Although the actual simulated transect is actually flat, we are representing a volume of water 2m deep (Question 4).

Benthic Sampling: Urchin Indicator Species

Urchins are benthic species, meaning they occupy the sea floor. Urchin sampling is conducted on a ground area, measured in m^2. To calculate a value for urchins per m^2, calculate the area of your transect:

Length of transect: ______________ *m*

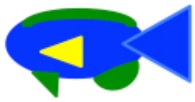
Width of transect: ______________ *m*

Area of transect: ______________ *m^2*

Healthy Coral Reef	
Mean Diadema Urchin per m^2	**Mean Other Urchin per m^2**

Unhealthy Coral Reef	
Mean Diadema Urchin per m^2	**Mean Other Urchin per m^2**

Pelagic Sampling: Fish Indicator Species



Fish occupy a volume of water in the water column as they swim around looking for food. Therefore, fish sampling in the water is actually measured in m^3. The space they occupy includes a length, width, and height. In our mock coral reef transect, all of the fish sampled occupied the water column to a depth of 2m. To calculate a value for fish per m^3, calculate the volume of water in your transect:

Height of transect: ______________ *m*

Length of transect: ______________ *m*

Width of transect: ______________ *m*

Volume of transect: ______________ *m^3*

Healthy Coral Reef	
Mean Parrot Fish per m^3	**Mean Other Fish per m^3**

Unhealthy Coral Reef	
Mean Parrot Fish per m^3	**Mean Other Fish per m^3**

Once students have calculated this value and assigned the proper units, they will be asked to develop a method to test how representative their data is. The teacher can assign one or two students to take measurements of the diameter of the mock coral reef (which should be 5-7 meters) and the class will use this to calculate total reef area (Question 5).

Diameter of Reef:* ___________*m ***Area of Reef = (Diameter ÷ 2)^2 x π =***

_______________*m^2*

Total Diadema Urchins in Healthy Coral Reef = ________________________

Total Diadema Urchins in Unhealthy Coral Reef = ________________________

Now calculate the total volume of water in the 2m deep simulated coral reef:

Depth (Height) of Reef:* ___________*m

Volume of Water in Reef = Depth x Area =* _______________*m^3

Total Parrot Fish in Healthy Coral Reef = ________________________

Assign two more volunteers to pick up all the cards in the reef and distribute them roughly evenly among groups. The groups will count the four metrics represented by the their cards and the teacher can record each groups count on the board. Calculate the sums as a class and have students record these values on their worksheets (Question 6).

Actual Total of Diadema Urchins in Simulated Reef: __________________

Actual Total of Parrot Fish in Simulated Reef: __________________

Students will then compare the actual reef values dived by the reef volume or area to their group value and the mean value that they calculated earlier in the lesson.

Discussion questions will guide students to think about how well their sample characterizes the actual reef and analyze the healthy versus unhealthy reef. Dynamics of healthy versus unhealthy reefs will be expanded in the next part of the lesson.

Name:______________________________ Class:________________ Date:_____________

Part 4: Making Sense of Data

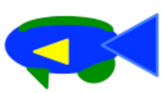
Reef Transect Simulation: Data Analysis

Objective: Using the data collected from your transect and by your classmates, calculate the number of indicator species that would likely be encountered in a given area of a healthy or unhealthy coral reef.

1. To begin analyzing our data, calculate the mean, median, and range of **class observations** in each category. Enter your results in the table below:

Benthic Sampling: Urchin Indicator Species (Class Data)

Healthy Coral Reef		Unhealthy Coral Reef	
Diadema Urchin	**Other Urchin**	**Diadema Urchin**	**Other Urchin**
Mean:	*Mean:*	*Mean:*	*Mean:*
Median:	*Median:*	*Median:*	*Median:*
Range:	*Range:*	*Range:*	*Range:*



Pelagic Sampling: Fish Indicator Species (Class Data)

Healthy Coral Reef		Unhealthy Coral Reef	
Parrot Fish	**Other Fish**	**Parrot Fish**	**Other Fish**
Mean:	*Mean:*	*Mean:*	*Mean:*
Median:	*Median:*	*Median:*	*Median:*
Range:	*Range:*	*Range:*	*Range:*

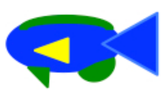
2. Do the mean, median, and range differ between the healthy and unhealthy coral reefs? What might explain the similarity or difference in these values?

____

____

____

3. What is the difference between the value your group recorded and the class mean?



	Group Data	**Class Mean**	**Difference** (Group Data – Class Mean)
Benthic Sampling:			
Diadema Urchins			
Other Urchins			
Pelagic Sampling:			
Parrot Fish			
Other Fish			

Does your group's data tend to overestimate, underestimate, or accurately estimate the populations of urchins and fish, relative to the class mean. Explain.

____

____

4. Using the class transect sampling means, calculate the number of urchins or fish that are likely to occupy a given area of healthy or unhealthy coral reef. Show your work.

Benthic Sampling: Urchin Indicator Species

Urchins are benthic species, meaning they occupy the sea floor. Urchin sampling is conducted on a ground area, measured in m^2. To calculate a value for urchins per m^2, calculate the area of your transect:

Length of transect: ______________ m

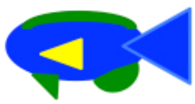
Width of transect: ______________ m

Area of transect: ______________ m^2

Healthy Coral Reef	
Mean Diadema Urchin per m^2	Mean Other Urchin per m^2

Unhealthy Coral Reef	
Mean Diadema Urchin per m^2	Mean Other Urchin per m^2

Pelagic Sampling: Fish Indicator Species



Fish occupy a volume of water in the water column as they swim around looking for food. Therefore, fish sampling in the water is actually measured in m^3. The space they occupy includes a length, width, and height. In our mock coral reef transect, all of the fish sampled occupied the water column to a depth of 2m. To calculate a value for fish per m^3, calculate the volume of water in your transect:

Height of transect: ____________ m

Length of transect: ____________ m

Width of transect: ____________ m

Volume of transect: ____________ m^3

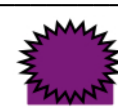
Healthy Coral Reef	
Mean Parrot Fish per m^3	Mean Other Fish per m^3

Unhealthy Coral Reef	
Mean Parrot Fish per m^3	Mean Other Fish per m^3

5. With values for urchins per m^2 and fish per m^3, we can now scale up and estimate how many of our indicator species of urchins (Diadema) and fish (Parrot fish) are present on the whole simulated reef. We just need to know the area and volume of the reef. Your teacher will select a representative to measure the diameter of the simulated coral reef, use this value to calculate area:

Diameter of Reef: ___________m Area of Reef = (Diameter ÷ 2)^2 x π = _______________m^2

Total Diadema Urchins in Healthy Coral Reef = ________________________



Total Diadema Urchins in Unhealthy Coral Reef = ________________________

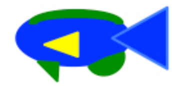
Now calculate the total volume of water in the 2m deep simulated coral reef:

Depth (Height) of Reef: ___________m

Volume of Water in Reef = Depth x Area = _______________m^3

Total Parrot Fish in Healthy Coral Reef = ________________________

Total Parrot Fish in Unhealthy Coral Reef = ________________________



6. What do you observe about the presence of indicator species in healthy versus unhealthy reefs? What factors can explain the patterns that you observe in your data?

____

____

____

____

____

7. Scientists often use a small area, like our transect, for sampling a larger area. Using data from this small scale sample, scientists draw conclusions about the large area, like a whole coral reef. In practice, this is necessary because it would be impossible to sample an entire coral reef effectively in nature. However, here in our classroom we can sample our whole coral reef to see how well our sampling data agrees with the populations of indicator species that are actually present. As a class, calculate the total number of Diadema Urchins and Parrot Fish in the entire simulated reef.

Actual Total of Diadema Urchins in Simulated Reef: ___________________

Actual Total of Parrot Fish in Simulated Reef: ___________________

How do these values compare to the values that we calculated in Question 5?

Do you feel confident that sampling transects is a good measure of the broader reef?

What factors might contribute to error in our sampling? How could we improve our sampling method?

Part 5. Make a Model

Description: In this activity, students will create a diagram of a reef transect that they would expect to find in five different environmental scenarios (healthy reef, reef damage by overfishing, drop in pH, invasive species and increase in temperature) then provide reasoning for the species they chose for each transect based on evidence collected in earlier activities.

Learning Objectives:

1) Develop a model to describe the distribution of coral reef biota in healthy versus unhealthy reef systems.
2) Construct an explanation that gives rationale to patterns of interactions among organisms across coral reefs.

Time Needed: One class period

Related Concepts/Prior Knowledge

- Coral reef health indicators
- Invasive species

Materials

- Handouts
- Colored pencils

Handouts

- Model Reed Transect Worksheets (A, B & C)

Assessments

- Evaluate each transect for it's completeness (B) and how the student justified each collection of species (C).

Tips for Teaching this lesson/Safety

- Instead of having students draw the images for each transect, you could create a sheet of small images to copy and ask students to cut out and paste onto the transects.

Teacher Background

- Refer to all previous background readings in addition to the references below.

Resources (Books, Webs, Media)

- Coral Reef Field Guides (helpful but not required)
- Coral Health Index pdf
- http://www.toniparras.com/stories/Healthy_Reef_24_complete-1.pdf
-

Schedule

Day One

Activity	50 min

DAY ONE
Activity **Time: One class period.** **Materials:** Model Reef Transect Worksheets , colored pencils. Handout copies of Part 5. Model Reef Detectives. Tell the class that they are going to create a diagram of coral reef transect they would expect to find in five different environmental scenarios; a healthy reef; a reef damaged by low pH; a reef damaged by increasing temperature; a reef damaged by invasive species; and a reef damaged by overfishing. In Part 1 they will draw images of organisms onto each transect in corresponding abundance. In Part 2 they will explain their reasoning for how they constructed each transect. *(See the example on the student page.) This can followed up with a class discussion of results and student reasoning for their selection of organisms for each transect.

Name:______________________________ Class:_______________ Date:____________

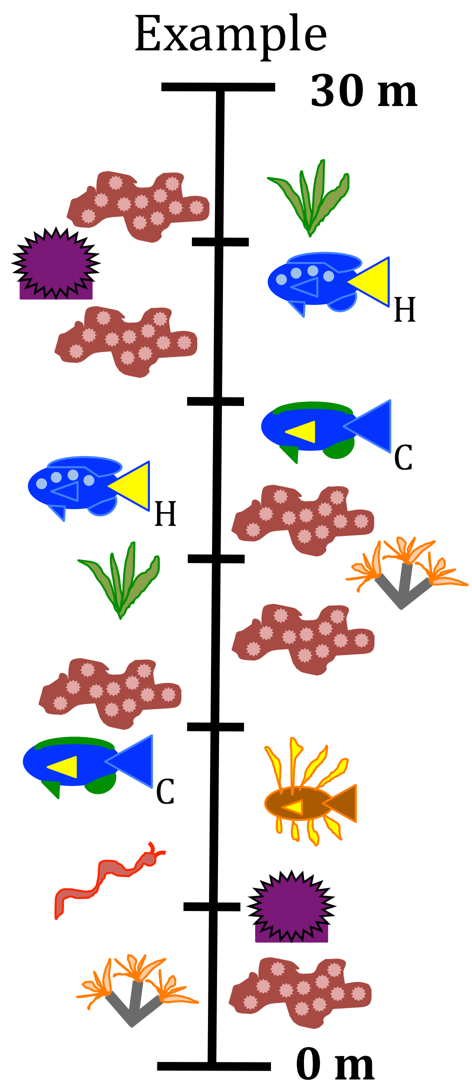
Part 5. Model reef transects

Based on the Coral Reed Food Web Activity you are now aware of the type of organisms that inhabit reef ecosystems and how these organism fit into interacting trophic levels. You should also be familiar with marine transect sampling techniques which you applied during your Reef Transect Simulation activity.

Directions:

1. In Part 1 use your knowledge of reef ecosystems and their vulnerabilities to ***create a diagram of the transect you would expect to find*** in each of the five environmental scenarios listed on the next page.
2. Place the images of healthy and unhealthy organisms onto each transect to demonstrate the presence/absence and abundance of organisms in each reef environment.
3. Consider the following for each organism as you construct the transect:
    a. specific vulnerabilities*
    b. optimum habitat conditions*
    c. trophic interactions*

    ***Note:** *Refer to the Coral Reef Species Key to find this information.*
4. In Part 2, explain your reasoning for how you constructed each transect.



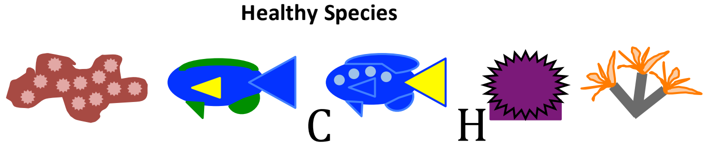
Healthy reef organisms include

- coral
- corallivorous fish (C)
- herbivorous fish (H)
- *Diadema* urchins,
- calcareous *Polychaete* worms.
-

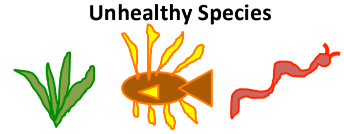
Unhealthy' reef organisms include:

- algae
- invasive species (like the Lion Fish)
- mobile *Polychaete* worms

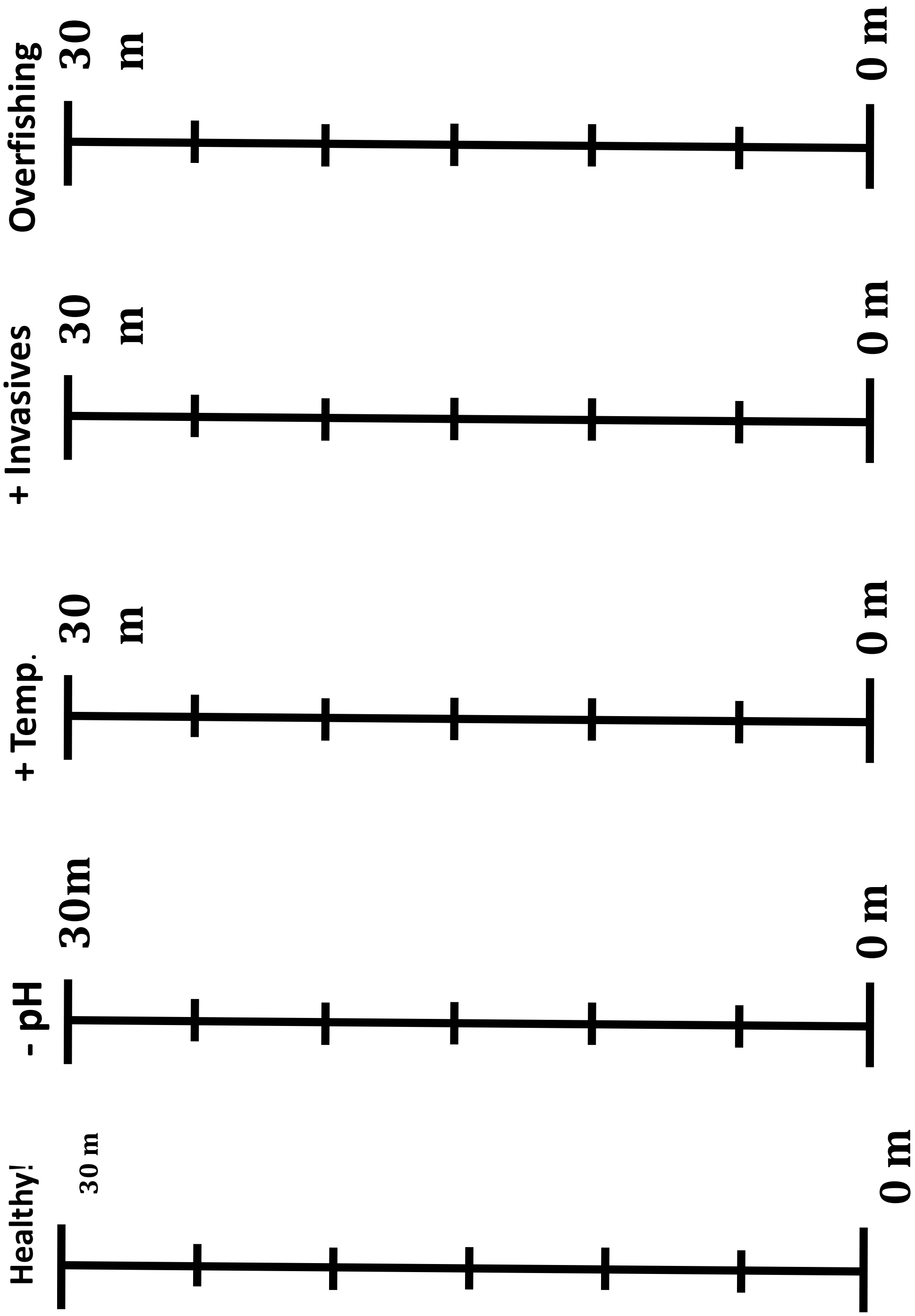
Healthy Species



Unhealthy Species



Part 1. Place the images of healthy and unhealthy organisms onto each transect to demonstrate the presence/absence and abundance of organisms in each reef environment.



Part 2. Please justify the decisions you made when constructing your virtual transects.

1. How and why do different environmental scenarios (temperature change, pH change, etc.) shift reef ecosystem dynamics away from the conditions found on healthy reefs?
2. How does this shift affect trophic interactions on the reef?
3. How did you determine presence/absence and abundance of each organism?

Transect Type: Decrease in pH.

Transect Type: Increase in Temperature

Transect Type: Invasive Species

Transect Type: Overfishing

Part 6. Reef Detectives

Description: As a final activity students return to the healthy/unhealthy reef images from Part 1 and review their initial ideas about what may have damaged the reef. Using the data from the other activities, they are to make a claim based on evidence and supported by scientific reasoning as to what they think caused the damage. Note that some students' ideas may not change from their initial observations. Once all students have completed their claims, the teacher then reveals what caused the damage to each reef.

Learning Objectives:

1) Analyze and interpret data to provide evidence for the effects of damage to a coral reef and on distribution of organisms and populations of organisms in a coral reef.

Time Needed: 1 class period

Related Concepts/Prior Knowledge
- Indicators of coral reef health
- Effect of damaging factors to a coral reef (overfishing, invasive species, increased temperature, decrease in pH)

Materials
- One set of color reef images for each group of students and/or projector to project each image

Handouts
- Disturbed Reef Modeling Worksheet

Assessments
- Student will make a claim about each image and should back their claim up with evidence and reasoning.

Tips for Teaching this lesson/Safety
- Once students have completed their own assessments, have them turn to a partner and share their ideas. For a final share, project each image to the class and have a group discussion of what they think happened.

Teacher Background:

Refer to coral health readings below with special attention to the *Coral Health Index*

Resources (Books, Webs, Media):
- Coral Health Index pdf (http://science2action.org/files/s2a/chi-lowresolution.pdf)
- Reefs At Risk, A Map-Based Indicator of the Threats to the World's Coral Reefs (http://pdf.wri.org/reefs.pdf)

- Healthy Reefs for Healthy People, A Guide to Indicators of Reef Health and Social Well-being in the Mesoamerican Reef Region
  http://www.toniparras.com/stories/Healthy_Reef_24_complete-1.pdf

3. The Coral health Monitoring Program, NOAA (http://www.coral.noaa.gov/
4. Coral Reef Field Guides (helpful but not required)

Schedule

Day One

Activity 50 min

DAY ONE
Activity **Time: One class period.** **Materials:** Healthy/Unhealthy Reef Cards (One set per group of 3-4 students), Coral Reef Species Key Sheet In this activity students will return to the 5 images of coral reefs. They will record and share their observations, this time aiming for more accuracy in their assessment of what has caused the reefs to change. Once complete, hand back their original ideas and ask them compare what they think now versus what their initial ideas were. The images include: IMAGE #1: Healthy Reef IMAGE #2: Reef damaged by overfishing IMAGE #3: Reef damaged by lowered pH IMAGE #4: Reef damaged by invasive species IMAGE #5: Reef damaged by high temperature. Hand out the Coral Reef Image Comparison Worksheet and have them read and complete part one as a group or individually. Once complete, have groups share their observations with the class. Optional: If you are unable to make color copies you could project each image one at a time and have the class make observations. These could be recorded on chart paper or in their journals/worksheet.

Name:______________________________ Class:________________ Date:_____________

Part 6. Reef Detectives? Revisiting Coral Reef Images

Not that you have had a chance to explore a coral reef system and see the harm that can happen when not managed properly, use your knowledge to see determine what has caused the reefs in these images to change.

Directions: You are to take on the role of a marine scientist and make observations of coral reef images. First, observe the image of a health coral reef. What evidence can you see that would lead you to believe this reef is healthy? Record your observations then compare this image to the four images of damaged reefs that follow. In the space below each image jot down your observations and questions as you compare and contrast the images. In the last box, record how you ideas have changed since Part 1.

Healthy Reef

Observations/Evidence:

Damaged Reef #1	
Observations/Evidence	What might have happened?
Similarities/differences to other images	How have your ideas about this image changed?

Damaged Reef #2	
Observations/Evidence	What might have happened?
Similarities/differences to other images	How have your ideas about this image changed?

Damaged Reef #3	
Observations/Evidence	What might have happened?
Similarities/differences to other images	How have your ideas about this image changed?

Damaged Reef #4	
Observations/Evidence	What might have happened?
Similarities/differences to other images	How have your ideas about this image changed?