

Unit 11 Section 3 Computer Lab

Part 1:

MARINE FOOD WEBS

Educational Outcomes: In a marine ecosystem, organisms interact with one another, and with the physical conditions and chemical substances of their surroundings. An ecosystem has both living (biotic) and non-living (abiotic) components plus a source of energy. Biotic components include producers, consumers, and decomposers whereas abiotic components constitute the physical and chemical properties of their surroundings (e.g., nutrients, water, currents). The energy source is primarily sunlight.

The simplest marine ecosystems begin with producers, most commonly photosynthesizing plants, algae, and bacteria. The four major groups of phytoplanktonic organisms are diatoms, coccolithophores, dinoflagellates, and bacteria. These primary producers are called autotrophs (meaning self-feeders) because they manufacture the food they need from the physical and chemical environment through photosynthesis (and chemosynthesis). Organisms (usually animals) that feed on autotrophs are called consumers or heterotrophs (meaning other-feeders). Heterotrophs may be herbivores, carnivores, or omnivores. Decomposers are bacteria that break down the remains of plants and animals, and recycle the remains back to inorganic nutrients.

A food chain is a sequence of feeding relationships among organisms (e.g., producers, consumers) that provides pathways along which energy and materials (biomass) move within an ecosystem. For example, in a marine food chain, phytoplankton is eaten by a herbivore, which in turn is eaten by a carnivore, which is then eaten by another carnivore and so on. Eventually decomposition recycles the remains back to primary production at the beginning of the food chain or web in the form of inorganic nutrients. Actually, such simple food chains rarely exist in the ocean and marine heterotrophs are more likely to feed on a variety of prey organisms. Most marine ecosystems consist of several levels of consumers including fish, marine mammals, and sea birds. Humans tend to feed at the highest levels in many marine ecosystems. The complex of feeding relationships (consisting of many intertwined food chains) within marine ecosystems is more realistically described as a food web and each level of production and consumption is called a trophic level. Marine animals rarely feed at only one trophic level.

Within food webs, energy is transferred in only one direction, from lower trophic levels to higher trophic levels (e.g., from producers to consumers) and this transfer is relatively inefficient. As an organism occupying one trophic level feeds on its prey, only a small portion of the energy stored in the tissues of the prey organism is passed to the next higher trophic level. We can visualize the energy distribution within a food web as a pyramid with producers forming a broad base containing most of the ecosystem's energy. Each successively higher trophic level contains considerably less energy (and biomass) than the one below it. Ecological efficiency is the percentage of energy that passes from one trophic level to the next. An ecological efficiency of 10% is typical of marine ecosystems. (Ecological efficiency is low because not all food is harvested, not all food that is ingested is digested, and cellular respiration is inefficient. See page 209 in your DataStreme Ocean text for additional explanation.)

In this part of the investigation, we examine how marine organisms depend on one another as sources of food energy. Because the flow of energy within marine food webs is difficult to measure directly, scientists follow the transfer of biomass from one trophic level to another as an indicator of energy flow. Biomass is the total mass (weight) of organic tissue present within a group of living organisms.

1. In a marine food web, the first (lowest) trophic level is occupied by [(autotrophs) (herbivores) (carnivores)] and the second trophic level is occupied by [(autotrophs)(herbivores) (carnivores)].
2. Energy is always transferred from [(autotrophs to heterotrophs) (heterotrophs to autotrophs)].
3. An ecological efficiency of 10% in a marine ecosystem means that [(10%) (80%) (90%)] of the energy consumed at one trophic level is not passed on to the next higher trophic level.
4. The lower the trophic levels at which an organism feeds, the [(greater)(less)] is the amount of biomass available. In order to have a sufficient food supply, blue whales (the largest living organisms on Earth) must feed at [(lower)(higher)] trophic levels.
5. Consider the following marine food chain: Copepods (minute crustaceans) eat phytoplankton. The copepods are then consumed by herring, which are ingested by mackerel, which in turn make a meal for a swordfish. A person in a restaurant orders the swordfish for dinner. Represent this simple food chain by completing the table below:

<i>Trophic Level</i>	<i>Organism</i>	<i>Type of Organism</i>

In this case, there are six trophic levels. In the first column, label the trophic levels as "first" at the bottom to "Sixth" at the top. In the middle column, enter the corresponding organism (phytoplankton etc.) occupying each trophic level. In the third column, identify the organism as an autotroph, heterotroph (herbivore, carnivore), or decomposer. Draw arrows between members of the food chain indicating the direction in which biomass and energy flow.

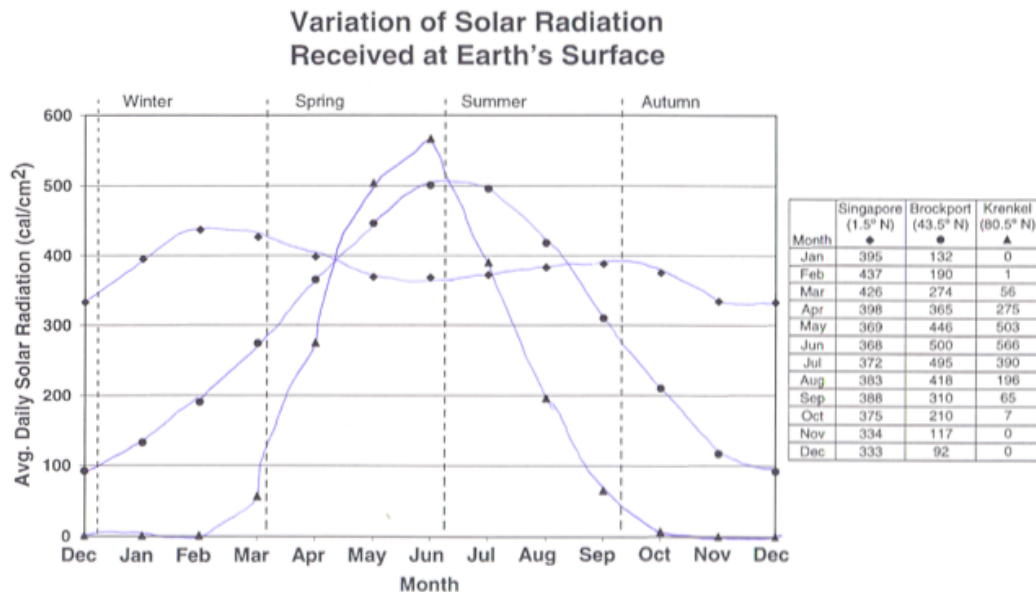
6. Assume an ecological efficiency of 10% in the simple food chain in item 5, If 10,000 metric tons of phytoplankton is present, the maximum possible biomass at the fourth trophic level would be about $[(10000)(100)(10)]$ metric tons.

7. In coastal upwelling zones, the ecological efficiency is somewhat higher than the average value for the ocean. Assume an ecological efficiency of 15% in a coastal upwelling zone, If the phytoplankton biomass is 200,000 kilograms, the maximum possible biomass at the seventh trophic level is about $[(200000)(15)(2.3)]$ kilograms.

8. A whale weighing 10 metric tons (positioned at the fourth trophic level of a marine food chain) feeds on krill and copepods occupying the third trophic level. Assuming a 10% ecological efficiency, the amount of phytoplankton biomass required to produce this whale would be $[(10,000)(100)(100)]$ metric tons.

In surface waters, (in addition to nutrient supply which is discussed elsewhere) the autotroph population varies with the availability of incoming solar radiation that powers photosynthesis. Because autotrophs form the base of most marine food chains, seasonal variations in incoming solar radiation also have implications for the populations of organisms occupying higher trophic levels.

Examine the accompanying figure below. As you recall, data points on the graph represent monthly averages of measurements of actual solar radiation received daily on horizontal planes at Earth's surface at equatorial (Singapore, 1.5 degrees N), midlatitude (Brockport, NY, 43.5 degrees N), and high latitude (Krenkel Observatory, Russia, 80.5 degrees N) locations. On the graph, the month of the year is plotted along the horizontal axis and average daily incident radiant energy (in calories per square cm per day) is plotted on the vertical axis. We are assuming that the values of radiation given for each of these three locations are representative of ocean locations at the same latitude.



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9. The Figure Below. Or, you may reproduce the curves again by drawing on the figure in this investigation smooth curved lines connecting the radiation values already plotted for each location. Draw each curve to the edges of the graph. December values are plotted twice to more clearly illustrate the annually repeating radiation cycles. Again note that at the Krenkel Observatory, radiation values are zero or nearly zero for five months.

10. According to the curves you have drawn, the average daily solar radiation varies the least over the period of a year at the [(equatorial)(midlatitude)(polar)] location and the most at the (equatorial)(midlatitude) (polar)] location.

11. Compare the annual range of solar radiation received at the three locations. As latitude increases, the annual range of daily solar radiation ((increases)(decreases)). This implies corresponding seasonal variations in the amount of solar radiation available for photosynthesis in the sunlit portion of the ocean. On this basis, we would expect the phytoplankton population to exhibit its greatest variation through the course of a year at (equatorial)(midlatitude)(polar)] latitudes.

12. Each year at higher latitudes, in response to increasing sunlight in spring and early summer, phytoplankton populations soar. This so-called "spring bloom" triggers a(n) ((increase)(decrease)) in populations of organisms occupying higher trophic levels (i.e., herbivores and carnivores) of marine food webs.

13. At higher latitudes in late summer and early autumn, we would expect a dramatic decline in [~(heterotroph)] populations followed by a precipitous drop in [(autotroph)(heterotroph)] populations.

Part 2:

MARINE FOOD WEBS

In the first part of this investigation fundamental concepts concerning mass and energy flows in marine food chains and food webs were examined. In this portion, we introduce one threatened ocean ecosystem that is characterized by the interdependency of organisms: coral reefs.

Coral reefs occur mostly in shallow tropical waters within 30 degrees latitude of Earth's equator. They are one of the most productive ecosystems on Earth providing habitats for a huge number of different species. Coral reefs provide many benefits, including fisheries, coastal protection, tourism, and medicines.

Corals are small animals living in colonies. Corals harvest nutrients and energy from the algae called *zooxanthellae*, which inhabit their cells by the thousands. The presence of pigments associated with the zooxanthellae gives the otherwise nearly colorless corals their striking appearance.

Coral reefs are the product of groups of organisms that produce calcium carbonate (CaCO₃). These coral animals build an external calcium carbonate structure that over the span of thousands of years can constitute an underwater city. Living coral consists of colonies of small polyps. Within their tissues are the zooxanthellae. While corals also feed on zooplankton, energy and oxygen are received from the zooxanthellae via photosynthesis. Zooxanthellae also promote the growth of the reef by aiding production of calcium carbonate. This is a mutually beneficial (symbiotic) relationship between the coral polyps and zooxanthellae. Symbiotic relationships occur among other organisms living on coral reefs.

Coral reefs are generally found offshore in waters having a narrow range of physical characteristics. Reef-building corals typically occur only in the tropics where waters are generally warm, clear, low in nutrients, and have stable temperature and salinity conditions. Ocean currents can reduce or expand the area where these reef conditions exist.

Coral reefs are among the most productive habitats, producing 2000 decagrams of carbon per square meter per year.

"The brilliant and beautiful topography of reefs provides superior refuge for hundreds of thousands of species, which utilize reef habitat for protection, living substrate, and food. Every nook, cranny, cavern, and overhang on a healthy coral reef is overflowing with different life forms and this immense biodiversity has earned coral reefs the nickname of "the rainforests of the sea." Aside from their awe-inspiring vertical relief, coral reefs are an oasis of nutrients and food in oligotrophic tropical waters. The high productivity of coral reefs is due to the primary production of millions of tiny photosynthetic organisms, which utilize energy from the sun to build necessary organic matter. This organic matter is the starting point of the complex, yet efficient, food web of coral reefs, which support the unique variety of species from tiny mollusks to large sharks." - Sorokin, Y.I. 1995. Coral Reef Ecology, Springer. New York, NY. (quoted on http://www.coral.noaa.gov/faq2.shtml#f1_1)

Coral reefs require a specific combination of physical conditions. They are:

- Intense solar radiation
- High dissolved oxygen: 5-7 milligrams per liter
- Low turbidity
- Low nutrients
- Consistent temperature: 18-30 °C
- Consistent salinity: 33-36 psu

Coral Bleaching

A serious threat to coral reefs is *coral bleaching*. The whitening of coral occurs when the zooxanthellae are expelled or killed, impairing the symbiotic relationship with the coral polyps. The loss of the food supplied by the zooxanthellae leads to coral death. Most of the color of coral systems is a result of the zooxanthellae so that their loss causes the remaining calcium carbonate shell to dominate the coral's appearance, making it look as though it were bleached. The exact causes of zooxanthellae death are not well understood.

Research on coral bleaching suggests that sea surface temperature is a major catalyst or at least indicator of coral stress. Coral may be stressed by other environmental factors or some combination such as high temperatures along with elevated nutrient levels, which causes algal growth and an increase in turbidity. For more information on coral health and NOAA monitoring of corals worldwide, go to <http://www.coral.noaa.gov/>.

NOAA's "Tropical Ocean Coral Bleaching Indices" website reports near real time information on thermal stress that induces coral bleaching for 24 selected reef sites around the globe. Basic to the indices is the use of the NOAA satellite-derived **Degree Heating Week (DHW)**, a unit of measurement designed to gauge the accumulated thermal stress that coral reefs experience over a twelve-week period. *One DHW is defined as one week of sea surface temperature that is 1 Celsius degree above the expected summer maximum*. Hence, 2 DHWs can indicate one week of 2 Celsius degrees above the expected summer maximum or two weeks at one degree above the expected summertime maximum. DHWs of 10+ are associated with severe bleaching and often mortality. (The DHW unit is analogous to heating and cooling degree-days that have been used for decades to monitor energy demand and use for space heating and cooling in the U.S.)

NOAA also receives onsite reports from around the world on directly observed bleaching episodes. As an illustration, the following report was filed in April 2003:

Bleaching in Southern Kenya

Report from: Tim McClanahan
The Wildlife Conservation Society
Coral Reef Conservation Project
Mombasa, Kenya

Date: 14 April 2003

"Coral bleaching has been observed in southern Kenya over the past week. The taxa most affected are Pocillopora, and massive Porites and many other taxa have paled. There is some mortality of these two taxa, but also high variation in their color ranging from normal dark colors to white.

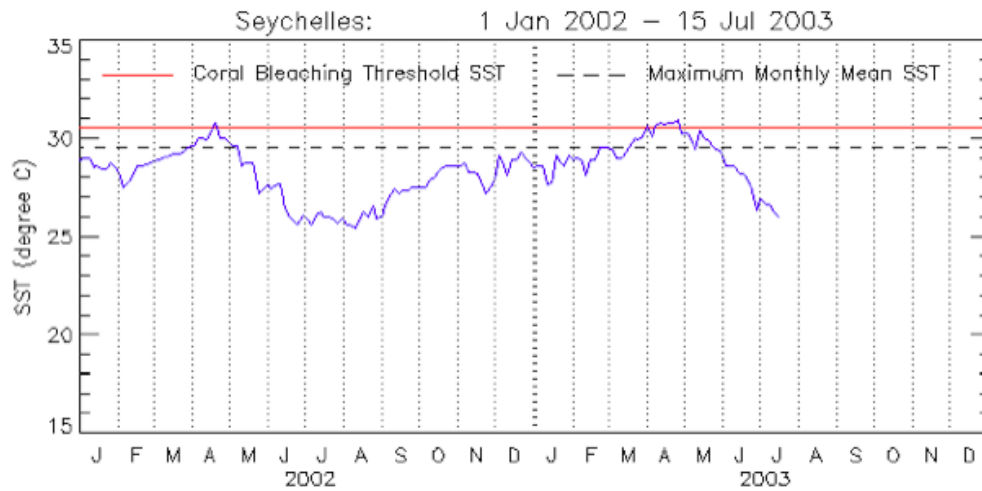
"This bleaching is unusual based on past observations. For example, some taxa that usually bleach, such as Acropora and Stylopora, are not abundant due to high mortality in 1998 and the few colonies present are not bleaching.

"Water temperatures are currently around 29-31 °C in some areas, but this bleaching is unusual in that the degree heating weeks is <4 as this warm season has, overall, been cool. The bleaching is followed by a period of calm doldrums that usually precede the monsoonal rains.

Bleaching in this region in 1987, 1994, and 1998 were observed earlier from late February to Mid March and this late bleaching has not been reported before and may be associated with a delay in the onset of the rains. In these previous years bleaching in Kenya has preceded more extensive bleaching in the northern hemisphere summer and these observations may be a good forewarning of bleaching this year."

The Tropical Ocean Coral Bleaching Index time series for the Seychelles Islands, 4 degrees S, 55 degrees E, nearby in the western Indian Ocean off Kenya is shown below. The jagged line is the satellite derived sea surface temperature (SST) in °C in the vicinity of the islands. The temperature scale is along the vertical left axis. The time scale of the months of 2002 and 2003 is plotted along the horizontal axis across the bottom. The dashed horizontal line shows the expected summertime maximum monthly mean sea surface temperature for the Seychelles vicinity. The solid horizontal line is the coral bleaching threshold temperature, defined as one Celsius degree above the expected summertime maximum monthly mean temperature. Based on weekly SST measurements of one degree above threshold, one DHW unit has accumulated.

SST Time Series -- Seychelles



14. According to the chart, the expected "summertime" or warm season maximum monthly mean sea surface temperature (dashed line) for the Seychelles is _____ °C.

15. While this is a "summer" maximum value, given the tropical location of the Seychelles (4 degrees S latitude), would you expect much variation in monthly SST? [**yes**] (**no**)
16. The coral bleaching threshold SST for the Seychelles is _____ °C. While this is only one degree above the summertime maximum monthly mean SST, SST above this value would significantly impact coral habitats if present long enough to accumulate 10+ Degree Heating Weeks (DHWs) over a 12-week period.
17. The Kenya report indicated that coral bleaching was occurring. At the same time, the highest temperature recorded during April 2003 in the Seychelles was about [**26**] (**29**) (**31**) °C.
18. This temperature [**did**] (**did not**) exceed the indicated threshold temperature.
19. This threshold temperature value was exceeded [**for only a few days**] (**for most of the month**). The number of HDWs did not exceed 10 implying temperature was not the sole factor in the bleaching.
20. In April 2002, the highest SST recorded in the Seychelles was about [**26**] (**29**) (**31**) °C. This temperature was higher than the indicated coral bleaching threshold temperature.
21. The threshold temperature value was exceeded in April 2002 [**only briefly**] (**through most of the month**).
22. The report from Kenya above indicated that bleaching may have been associated with the delayed onset of the monsoon rains. Delayed rainfall would likely be associated with [**additional evaporation**] (**reduced input of freshwater**) (**increase in surface layer salinity**) (**all of these factors**). Salinity consistency was suggested above as a critical factor in the survival of coral reefs.
23. Go to the *DataStreme Ocean Website*, scroll down to the "Biological" section, and click on "Tropical Coral Bleaching Indices" web page. Print a copy of the table that appears. Examine the data providing near real time information on thermal stress that may cause coral bleaching. This information is based on data provided by the National Environmental Satellite, Data, and Information Service (NESDIS) for 24 selected reef sites around the globe. The latest conditions are reported for _____ (date).
24. Scroll down to the listing of 24 reef sites. A red triangular icon signals that some degree of thermal stress is present at a reef site. A **Bleaching Watch** is indicated when the current SST is greater than the maximum monthly mean SST. A **Bleaching Warning** is issued when the current SST reaches 1 Celsius degree above the maximum monthly mean SST. At this point, DHW begin accumulating. An accumulation of 4 DHW triggers a **Bleaching Alert Level 1** with bleaching expected within a few weeks of the alert. Accumulation of 8 DHW triggers a **Bleaching Alert Level 2** at which point widespread bleaching and some coral mortality is likely. In the Pacific Ocean, the red triangular icon appears at the following location(s):
25. Virgin Islands US is a location in the Atlantic Ocean where the degree of thermal stress has warranted issuance of a [**Bleaching Watch**] (**Bleaching Alert Level 1**). Click on "Current DHW" to view map showing DHW distribution in the region including the reef site accumulated over the prior 12 weeks. Note areas, if any, where DHW values are greater than 10 (orange to purple colors). These are locations where any existing coral reefs may be undergoing severe bleaching, and possibly mortality.
26. Use your browser's return button and click on "Virgin Islands US" for a location map (18 N, 65 W). Then click on "SST Time Series" under "Coral Reef Site Information" above the map. The top two graphs plot the SST in °C for the period _____ (date) to _____ (date).
27. According to the top graph, during 2006 to date the SST [**did**] (**did not**) exceed the coral Bleaching Threshold SST.
28. From the two graphs, the most stressful SST period for corals at this site is generally [**February-March**] (**September-October**).

As we have seen in this investigation, rising sea surface temperatures can trigger coral bleaching. Warming may be associated with short-term variations in ocean-atmosphere conditions such as those accompanying El Niño or La Niña. When the period of high SST is of relatively short duration, bleaching may be temporary and coral may recover. On the other hand, warming of the sea surface may signal a longer-term change in climate so that episodes of coral bleaching may become more frequent and longer lasting. In that case, recovery is much less likely.

Optional: Want to learn details about the biology of coral reefs, and more? Go to NOAA National Ocean Service's education website on corals, featuring an online tutorial: <http://www.oceanservice.noaa.gov/education/corals/welcome.html>. That same website has a "Corals Roadmap" link which directs you to specific data offerings within NOS and NOAA. Included in the corals

roadmap is a link to CoRIS - NOAA's Coral Reef Information System (<http://coris.noaa.gov>).

Part 3:

OCEAN LIFE

Educational Outcomes: In this investigation we examine net primary production by photosynthesis at a single site in the North Atlantic Ocean through the traditional technique of obtaining water samples at various depths, incubating them for a period of time along with a sample kept in the dark at the same depth, and then measuring the amount of nutrients taken up. Thereby, scientists make direct observations of primary production. In this investigation, we also consider the global distribution of primary production obtained via a numerical model and remote sensing. It should be noted that some organisms, mostly specialized bacteria, can convert inorganic nutrients to organic compounds without the presence of sunlight through chemosynthesis. Their production is not considered in this activity, but is discussed elsewhere.

Phytoplankton are responsible for approximately 40% of Earth's total annual photosynthetic (primary) production. Light and nutrients are the primary factors regulating the growth of phytoplankton populations. As phytoplankton populations increase, they continually strip inorganic nutrients (e.g., nitrogen and phosphorus compounds) from the surface waters. Some of the primary production finds its way to the deep sea, partly due to the sinking of dead cells and fecal matter. Most of the organic carbon reaching the deep sea is ultimately assimilated by bacteria, which regenerate it back into inorganic forms. These processes of carbon transfer in the ocean are part of the biological pump. The biological pump, consisting of phytoplankton cells, their animal predators, and the bacteria that assimilate their waste is an important part of the ocean's role in the global carbon cycle. (For more on the biological pump, refer to pages 215-217 in your DataStreme Ocean textbook.)

Primary production is reported in gross and net values. Gross primary production is the amount of carbon fixed by photosynthesis (i.e., synthesized from inorganic substances) in the uppermost sun-lit layer of the ocean. But cellular respiration releases some of the energy stored in these carbon-containing compounds in a form that is used by organisms for such processes as growth, maintenance, and reproduction. Both plants and animals respire continually. Net primary production is the amount of organic matter produced during photosynthesis that exceeds the amount consumed in the process of cellular respiration.

The source of data in Figure 1 is a series of measurements taken from regularly scheduled ocean cruises to the Bermuda Biological Station for Research's Hydrostation "S" located 15 nautical miles southeast of Bermuda. The series is from one of the longest sets of oceanographic data available for such observations. The Bermuda site is at approximately 32 degrees N, 64 degrees W in the North Atlantic.

1. Within the ocean [(photosynthesis)(cellular respiration)] occurs at all depths. Net primary production takes place [(only in the photic zone)(below the photic zone)].

2. Variations in net primary production are primarily due to changes in [(sunlight)(nutrient supply)(either of these factors)].

Traditionally, ocean scientists have gathered data on primary production by using ship casts to collect water samples at various depths. Samples are then incubated at the original depth (or more typically nowadays, in incubation bottles on deck with various mesh screens to simulate the % light at the depth of collection) for a period of time to determine the uptake of ^{14}C , carbon dioxide (or radioactive nitrogen or phosphorus in the nutrients nitrate or phosphate) by the organism. (On deck screened bottles are done so that the ship does not have to stay on station for the typical 6 hours it takes to do the incubations.) In the data that follow, three samples were incubated with water containing dissolved carbon dioxide that included radioactive carbon-14 isotope (tracer). Another sample from the same depth was kept in the dark at that level (more conveniently in a dark bottle on deck) for the same time period to measure respiration. (The amount of carbon fixed is measured by how much of the radioactive tracer was taken up in the photosynthesis and calculated as $\text{gm C/m}^3/\text{day}$.) Net primary production was determined by taking the mean of the three incubated light samples and subtracting the sample kept in the absence of light.

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Data on primary production have been gathered for many years by the Bermuda Biological Station for Research at its Hydrostation "S". (Additional measurements of temperature, salinity, dissolved oxygen, and fluorescence were obtained by CTD techniques.) Figure 1

was constructed based on values obtained from cruises to the casting site in 2000. The data are believed to be representative of values measured in other years. Depicted in the figure is the net primary production determined at depths of 1 meter (solid line

with diamond symbols), 40 meters (dashed line with boxes), 100 meters (dash-dot line with triangles), and 140 meters (dotted line with circles). Productivity is given in milligrams of carbon uptake per cubic meter of water per day. Although actual cruise dates varied slightly each month, the data are plotted on a monthly basis.

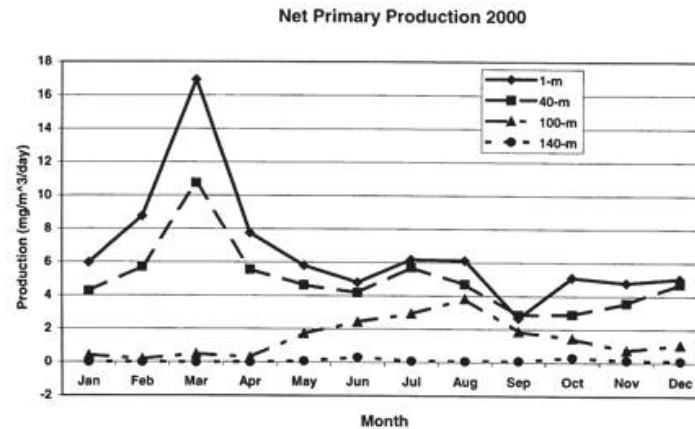


Figure I. Net primary production in Year 2000 at depths of 1,40,100, and 140 meters.

3. Based on the Year 2000 data, the primary productivity in near-surface waters at Bermuda (1 m and 40 m) reaches a maximum in [(December) (March) (June), (September)]. At greater depths (100 m and 140 m), production [(is) (is not)] at a maximum at the same time of year.

4. Bermuda is located in the Sargasso Sea within the North Atlantic subtropical gyre. Waters have relatively low total productivity. The generally warm and saline surface waters typically are stratified all year so that upwelling and vertical mixing are not factors in net primary production. The reason for the spring maximum in production is likely [(increasing solar radiation)(mixing due to tropical cyclones)] at that time of year.

5. The subsequent (to June) decline in net primary production at both 1 m and 40 m is likely due to declining [(solar radiation)(nutrient supply)].

6. A limiting factor in photosynthesis by phytoplankton is the amount of sunlight. Solar radiation is attenuated by seawater. Depending on the clarity of the water, sunlight penetrates to depths of 100 to 200 m in the open ocean. Primary production is limited to this so-called photic zone. From Figure I it is reasonable to assume that the base of the photic zone (where net primary production is zero) near Bermuda is above a water depth of [(40) (100) (140)] meters. In general, as water depth increases, the amount of sunlight available for photosynthesis [(increases) (decreases)]. The amount of primary production also generally [(increases) (decreases)] with increasing water depth.

7. Productivity at 100 meters reaches a maximum in [February) (May) (August) (November)]. Of the two factors listed here, the increase of productivity at this time of year is likely due to increased [(sunlight) (nutrients raining down from above)].

More information on the Bermuda Biological Station for Research plus access to data series can be found at: <http://www.bbsr.edu>.

Part 4:

OCEAN LIFE

The first part of this investigation examined factors that influence variations in net primary production with depth at a single location in the North Atlantic Ocean. The focus of this part of the investigation is related to the other end of the ocean food web and the sustainability of commercial fisheries.

Net primary production is an important consideration in the sustainability of commercial fisheries in that it specifies the supply of food energy at the base of marine food webs. Ultimately, net primary production governs the food energy supply for

commercial fish that occupy the higher trophic levels. Net primary production is one of the factors that influences limits on fish harvests set by fisheries managers in order to prevent overfishing and the collapse of the fishery. *Overfishing* is defined as harvesting a fish species at a rate that exceeds the maximum harvest that would still allow the population to be replaced by reproduction.

For example, several rockfish populations on the continental shelf of the U.S. West Coast have been steadily declining over the past 40 years due to excess harvesting. In recent years, the well-being of some of these rockfish stocks declined to the level that the Pacific Fisheries Management Council (PFMC) decided to close the entire groundfish fishery along the West Coast as of 1 January 2003. The purpose of the closure was to allow populations to recover. Subsequently, limited fishing was allowed. The PFMC manages 65 rockfish species, 12 flatfish species, 6 roundfish species, and 6 species of sharks and skates. (For more information on PFMC, go to <http://www.pcouncil.org/groundfish/gfback.html>.)

We can investigate the problems with the West Coast groundfish fishery by going to NOAA's National Marine Fisheries Service (NMFS) and its Fisheries Statistics & Economics Division, which tracks the populations of commercial fish and shellfish landed by U.S. fishers. Part of the NMFS mission is dedicated to the stewardship of living marine resources through science-based conservation and management, and the promotion of healthy ecosystems.

We will examine the recent historical fishing catches of two important commercial species. Go to <http://www.st.nmfs.gov/st1/commercial/index.html>. At the top of the left column under "Commercial Fishery Landings," click on "Annual Landings" and then "Species Locator." (A security box may appear. If so, click on "Continue.") Near the bottom of the page at "Enter common species name:" click on "Search." Now click on the down arrow next to the "Pick from these results:" window. Use the scroll bar to the right of the list that appears to move down the through the listing of 715 species tracked by the National Marine Fisheries Service to "ROCKFISH, BOCACCIO". (Bocaccio is one of the West Coast rockfish species.) Click on "Return." Under "YEAR RANGE," select FROM: 1985 and TO: 2004 and under "GEOGRAPHICAL AREA, STATE/AREA" select California. Scroll down and click on "Submit Query."

8. This procedure yields a table of commercial landings of bocaccio from 1985 through 2004 in terms of metric tons, pounds, and dollar value. Print the table. According to statistics in the table, in terms of both weight and dollar value of landings, harvesting of the bocaccio fishery in California peaked in _____ (year).
9. That peak year, the total weight of landings of bocaccio was _____ metric tons.
10. Also during the peak year, the dollar value of landings of bocaccio was _____.
11. From its peak harvest year through 2003, the bocaccio harvest generally [***(declined)***] [***(was unchanged)***] [***(increased)***]. Some recovery was noted in 2004.
12. Go back and use the "Species Locator" again to follow the same procedure for another West Coast rockfish species, yelloweye rockfish (ROCKFISH, YELLOWEYE on list). Select the period 1985-2004 and California. Then click on "Submit Query." According to the table, commercial landings of the yelloweye rockfish peaked in the year _____.
13. In 2004, the weight of landings of yelloweye rockfish in California had declined to [***(less than 1%)***] [***(about 10%)***] [***(about half)***] of what it was in the peak year.
14. Compare the annual landings data for bocaccio and yelloweye rockfish displayed in the tables. If the declines in harvest of these two rockfish species in recent decades are representative of the status of the West Coast groundfish fishery, the Pacific Fisheries Management Council's decision in 2003 to close the fishery appears [***(to be)***] [***(not to be)***] justified.

One approach to protecting marine habitats, preserving biodiversity, and preventing fished populations from overexploitation is the establishment of *marine reserves*, a type of marine protected area where extraction and alteration of all living and nonliving marine resources are banned. Worldwide, more than 20 nations have designated marine reserves but this amounts to less than one-hundredth of 1% of the ocean's total area. In the U.S., the Marine Sanctuary Program of NOAA's National Ocean Service involves about 47,000 square km (18,000 square nautical mi) but only a small percentage of that area is fully protected from exploitation. An example is the Western Sambo Ecological Reserve (http://www.fknms.nos.noaa.gov/research_monitoring/western_sambo.html) within the Florida Keys National Marine Sanctuary (<http://www.fknms.nos.noaa.gov/>). All fishing and collecting of biological resources are prohibited in that ecological reserve.

Go to NOAA's National Marine Sanctuary Program website, at <http://www.sanctuaries.nos.noaa.gov/> and scroll down to the map showing the locations of the National Marine Sanctuaries. Take some time to explore the nation's marine sanctuaries by visiting some of the sanctuary web sites accessed by clicking on their names around the globe.

15. The national marine sanctuary I would most like to visit is _____.

