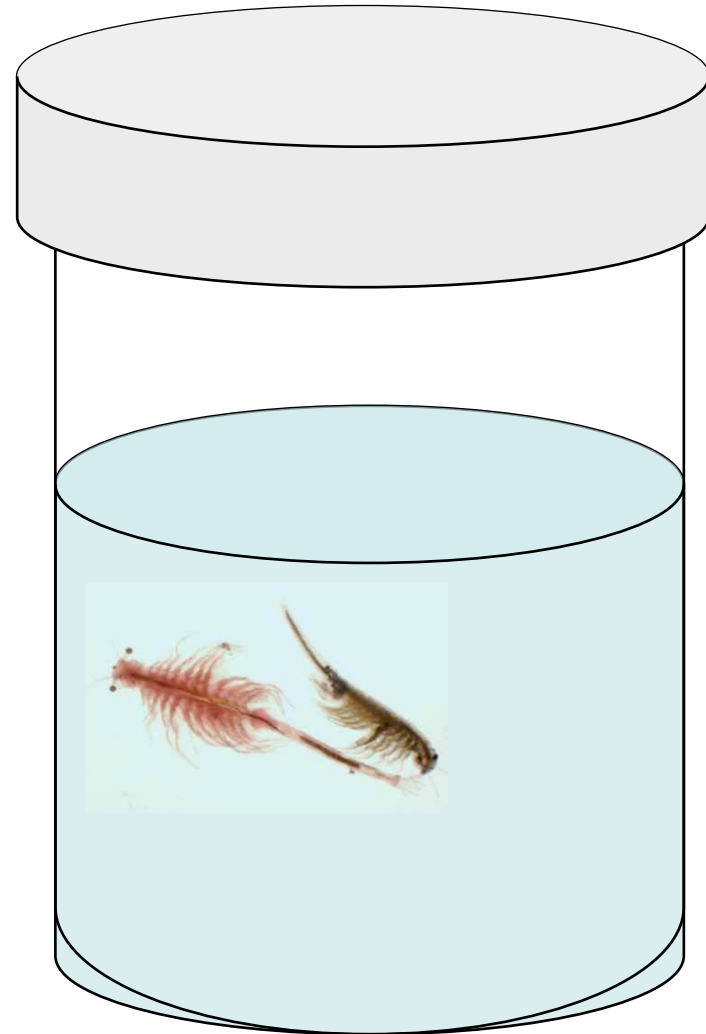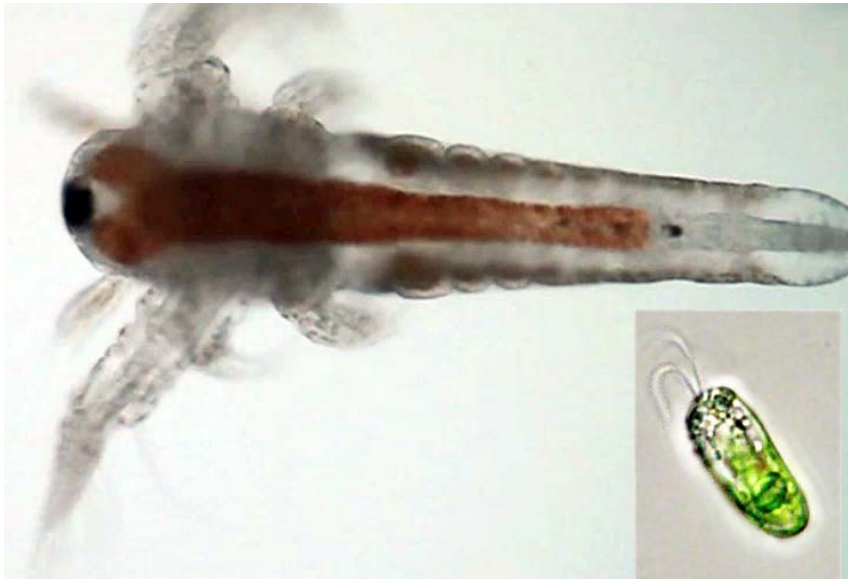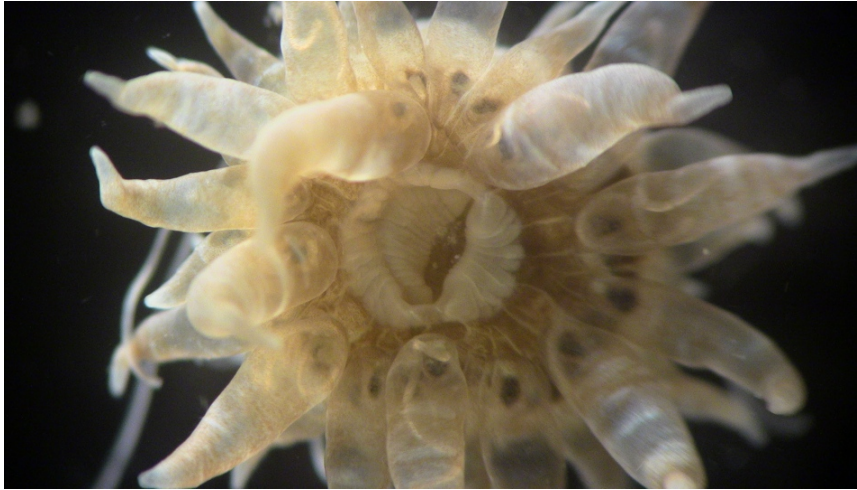# To Build an Ecosystem

by John R. Finnerty

Can we build our own self-contained ecosystems?
Why would we want to?

❖ **Building artificial ecosystems or manipulating natural ecosystems allows us to investigate ecosystem function in simple, well controlled experiments.**

▪ This is important because we don't fully understand the factors that influence the stability of ecosystems. Our ignorance about ecosystem function is compounded by the fact that humans are impacting natural ecosystems to an unprecedented degree.

▪ Ecologists use "microcosms" and "mesocosms" to test the effects of specific variables on the dynamics of simple ecosystems. This approach can be used to test how ecosystem composition is affected by :
> **(1)** contamination by pollutants
> **(2)** enrichment by nutrients
> **(3)** addition of an invasive species
> **(4)** removal of a native species

❖ **Looking toward the future, we may want to colonize the moon, or Mars.** This will require the development of self-contained agricultural ecosystems capable of supporting a long term human occupation.

❖ **One caveat is important to keep in mind.** Our simple artificial ecosystems may not faithfully represent the behavior of natural ecosystems.

Can we build our own self-contained ecosystems?
BIOSPHERE 2: A very complex failure

In theory, it ought to be possible to build a semi-closed ecosystem that could support human life. Such a system would require sufficient sunlight to power photosynthesis, the proper mix of chemical building blocks, and the appropriate combination of microbes, plants, and animals (including humans). If the starting conditions were just right, the plants would consume carbon dioxide and water as they used photosynthesis to build biomass and generate oxygen. The humans and other animals would breath the oxygen and consume a renewable fraction of the plants' biomass. In turn, the animals would supply the plants with carbon dioxide (in the form of their exhalations) and nitrogenous compounds (in the form of their excretions) that would fertilize the plants' growth.

http://en.wikipedia.org/wiki/File:Wiki_bio2_sunset_001.jpg

In 1991, this theory was put to the test in the Santa Catalina Mountains of Arizona. when 4 women and 4 men entered "Biosphere 2" with the intent of becoming semi-permanent residents of this materially-closed ecosystem. Despite its size (> 3 acres) and complexity (it enclosed a rainforest, a mangrove forest, a coral reef, a savannah and an agricultural area), the agricultural output of the Biosphere 2 proved insufficient to support longterm human habitation, and the experiment was eventually abandoned.

Can we build our own self-contained ecosystems?
ECOSPHERE® : A very simple success

Biosphere 2 failed, in part, because it was so complex (though still simpler than many real life ecosystems). Simpler ecosystems involving only a small number of species may be easier to engineer because their behavior may be easier to predict.

Your goal in this lab is to learn about the factors that affect ecosystem stability in a simple enclosed system, and to develop a stable system of your own.

You may derive some important design lessons by considering **EcoSphere®** , a simple self-enclosed ecosystem sold as a novelty item. The following passage is excerpted from the company's web site : http://www.eco-sphere.com/home.htm.

"**The Original EcoSphere®** is the world's first totally enclosed ecosystem - a complete, self-contained and self-sustaining miniature world encased in glass. Our ecosystems demonstrate in a most simplistic way the interdependence of animal and plant life with Earth's most precious element - water."
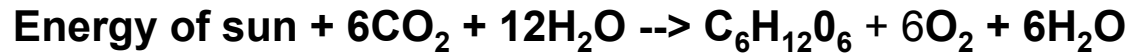
Challenges for building a self-contained ecosystem
I. Balancing gas exchange (O_2 and CO_2)

• Plants (producers) capture the energy of the sun in the covalent bonds of glucose via photosynthesis.

• Photosynthesis consumes carbon dioxide (CO_2) and releases oxygen (O_2).

PHOTOSYNTHESIS

**Energy of sun + $6CO_2$ + $12H_2O$ --> $C_6H_{12}O_6$ + $6O_2$ + $6H_2O$**

• All organisms liberate the energy bound up in biological macromolecules via cellular respiration. The energy captured by the cell in the process of respiration is stored in the high energy phosphate bond of ATP. Theoretically, 1 molecule of glucose could yield 36 molecules of ATP

• Respiration consumes oxygen (O_2), and releases carbon dioxide (CO_2)

CELLULAR RESPIRATION

$C_6H_{12}O_6$ + $6O_2$ --> $6CO_2$ + $6H_2O$ + energy

• So photosynthesis and respiration are complementary processes. Photosynthesis generates O_2 which is needed for respiration. Respiration generates CO_2, which is needed for photosynthesis.
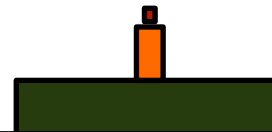
O_2

photosynthesis   respiration

CO_2
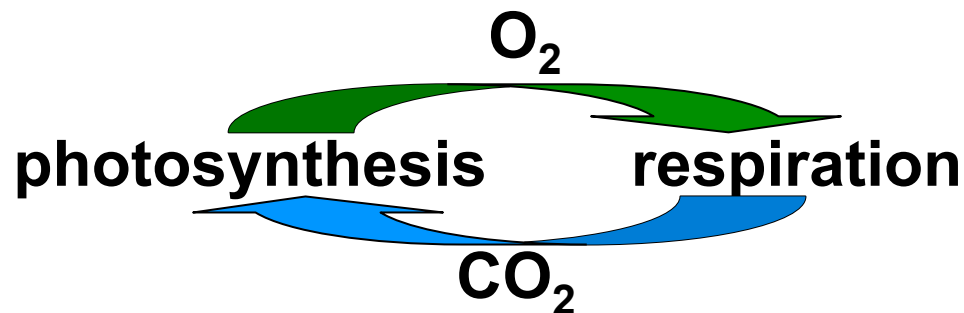
Challenges for building a self-contained ecosystem II. Energy flow in food chains

10% (**10 J**) captured by **secondary consumers**
10% (**100 J**) captured by **primary consumers**
1% (**1000 J**) captured by **primary producers**

100,000 joules (J) of energy produced by the **sun**

Each step in a food chain represents a significant loss of available energy.
In other words, each step involves significant **inefficiency**.
Inefficiency limits the length of a food chains.

A reasonable approximation is that photosynthetic organisms capture only about 1% of the available solar energy, and only ~10% of the available energy is transferred from one level in the food chain (trophic level) to the next. Because of the loss of available energy at each step, food chains typically include only 3-5 levels.

[The joule (J) is a more modern unit of energy than the calorie. 1 calorie = 4.184 joules. The calories we refer to when counting the energy content of food are actually kilocalories. So 1 of these "food calories" is equivalent to 4,184 joules.]

Challenges for building a self-contained ecosystem II. Energy flow in food chains

• Part of the reason that only 10% of energy is transferred between trophic levels is that each level in the food chain is expending energy during respiration and losing energy in its waste.

Plant material eaten by caterpillar

200 J

100 J

67 J

Feces

Cellular respiration

33 J

Growth
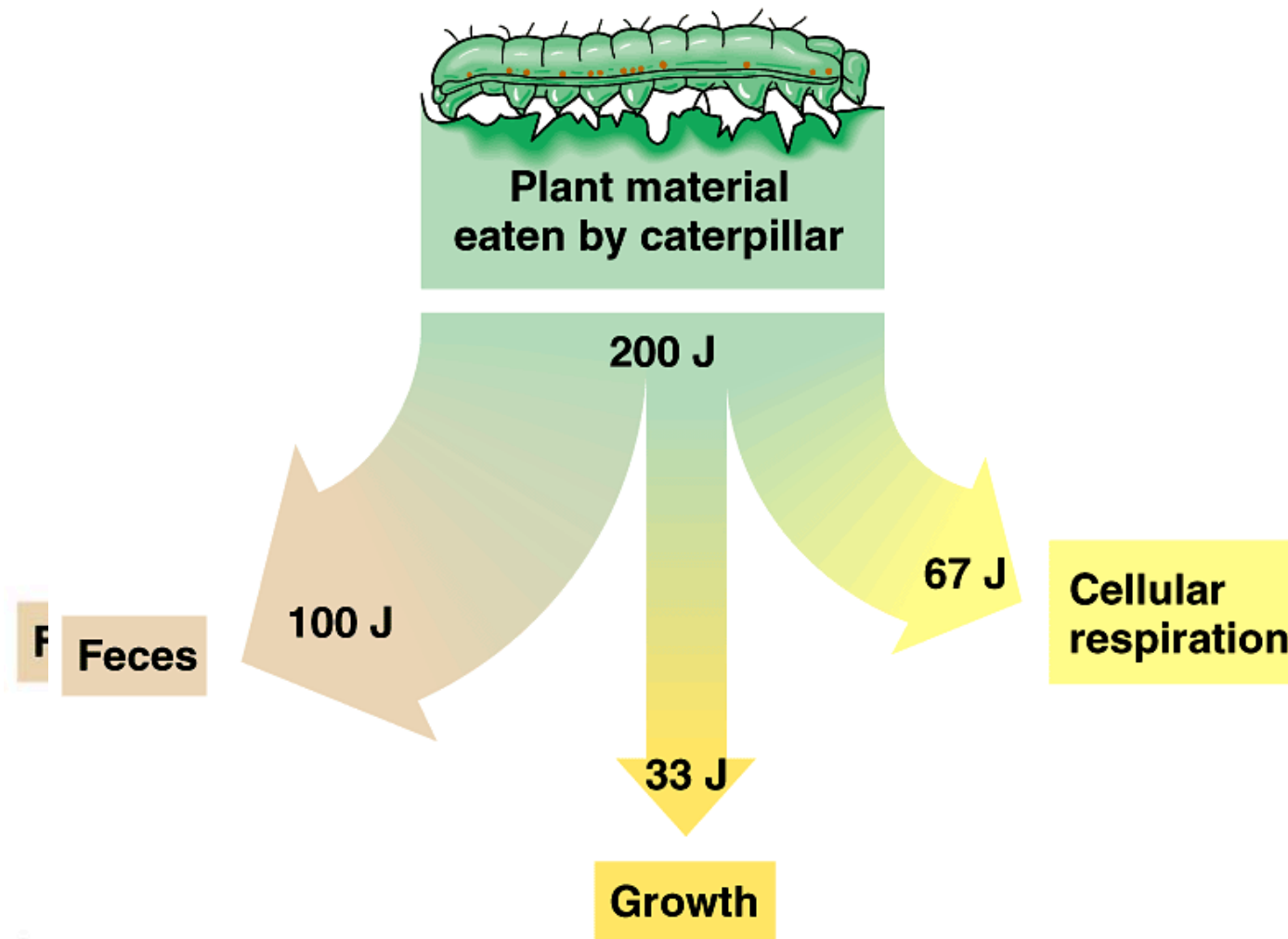
What Trophic Level do Humans Occupy?
[a great exam question]

Humans can occupy different trophic levels, and different amounts of energy are available to us at each level. The more energy that is available, the larger the human population that could be supported. [Energy content is not the only consideration though. We need protein to build tissues, and some good sources of energy, such as corn, are actually poor protein sources.]
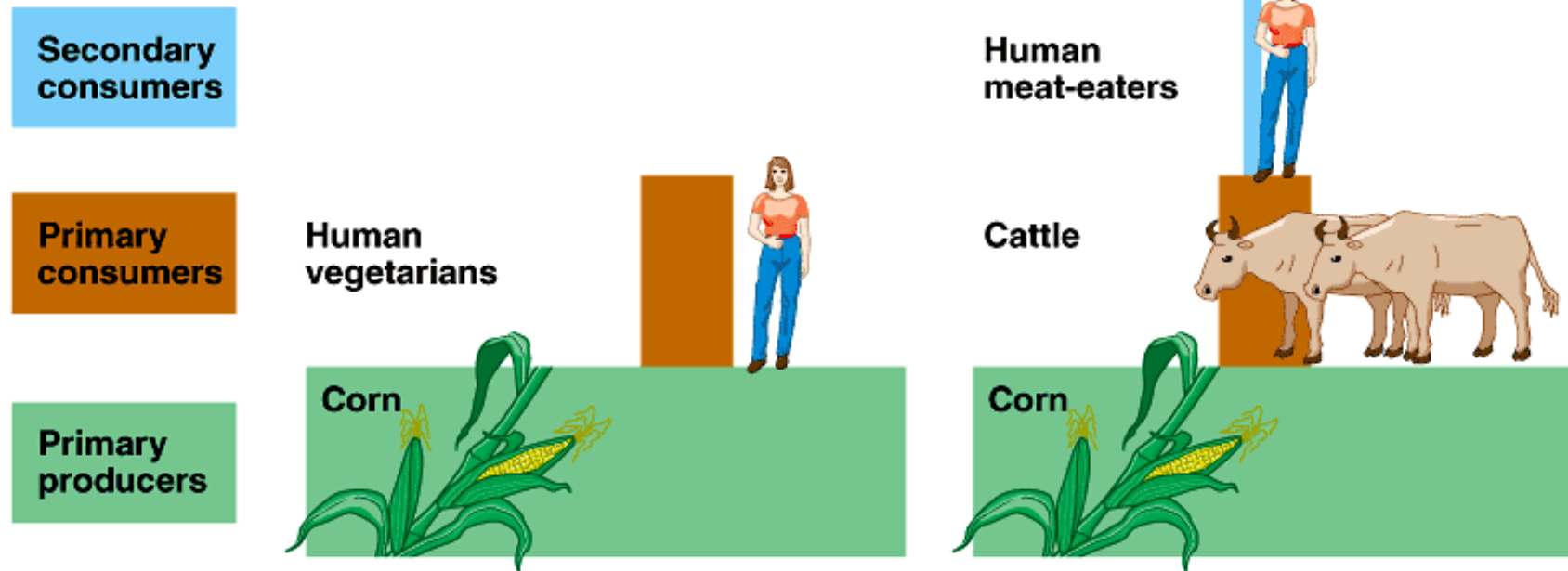
Copyright © Pearson Education, Inc., publishing as Benjamin Cummings.

Challenges for building a self-contained ecosystem
II. Energy flow in food chains

Consider the energy loss at each step in the following well characterized example involving plants in a meadow (consumers), mice (grazers), and weasels (predators) (Golley 1960).

Plants (**producers**) are able to capture about 1% of the available solar energy using pigments in their leaves such as chlorophyl and beta carotene.

> ➤Plants use about 15% of the captured energy during respiration. So, about 85% of the energy is assimilated in the plants' tissues (available to be eaten by a grazer).

http://www.erowid.org/

Mice (**primary consumers** or **grazers**) eat about 2% of the available plant tissue.

> ➤The mice use about 68% of the energy they consume during respiration. So, about 32% of the energy is assimilated into their tissues (available to be eaten by predators).

Weasels (**secondary consumers** or **predators**) eat about 31% of the mice.

> ➤The weasels use about 93% of the energy they they have consumed during respiration. So, about 7% of the energy is assimilated in their tissues (available to be eaten by some other predator).
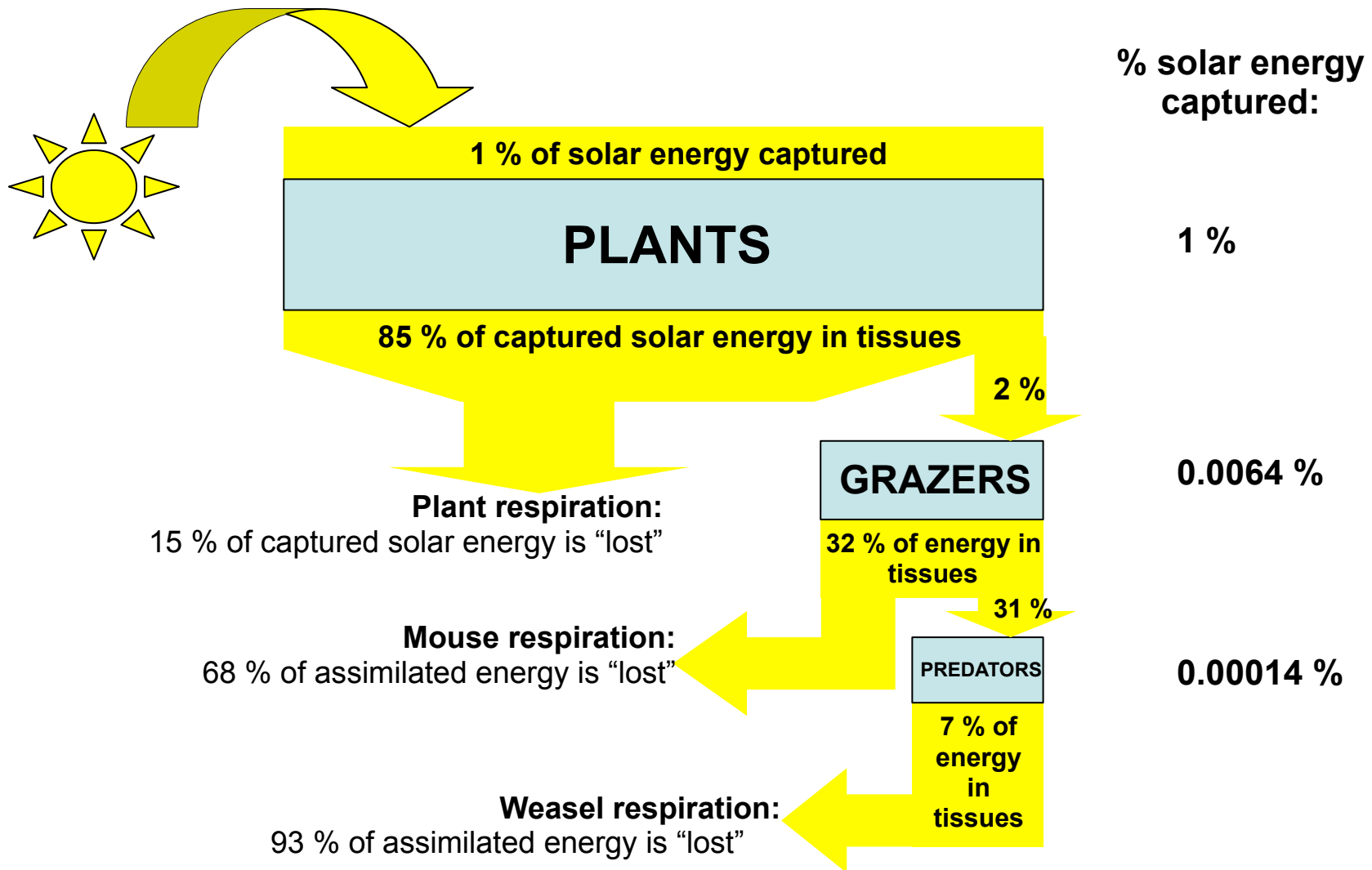
http://www.stockpix.com

• When you factor in how few plants are eaten by grazers, and how few mice are actually captured by the weasels, then far less than 10% of the available energy actually moves between these particular species which occupy different trophic levels. (Although, the mice may be eating other food items including insects, and the weasels may be eating other prey items in addition to mice.)

% solar energy captured:

1 % of solar energy captured

PLANTS

1 %

85 % of captured solar energy in tissues

2 %

GRAZERS

0.0064 %

Plant respiration:
15 % of captured solar energy is "lost"

32 % of energy in tissues

31 %

Mouse respiration:
68 % of assimilated energy is "lost"

PREDATORS

0.00014 %

7 % of energy in tissues

Weasel respiration:
93 % of assimilated energy is "lost"

IV-10

Challenges for building a self-contained ecosystem
III. Indirect species interactions in food chains

PRODUCER

Kelp

http://drjoe.biology.ecu.edu/ch07/predat.htm

GRAZER

Purple sea urchin

http://drjoe.biology.ecu.edu/ch07/predat.htm

PREDATOR

Sea otter

http://mypage.direct.ca/r/rhsu/otters.html

➢ **One species can affect the abundance of another species even if it has no direct interaction with that species.** For example, predators can affect the abundance of producers by reducing the abundance of consumers that eat the producers.

➢ Kelp is a multi-cellular marine algae that creates large "forests" that are vital habitat for a variety of other creatures including small fish, large fish, and invertebrates.

➢ Sea urchins are voracious grazers on kelp. They can eat a kelp forest down to the bare rock if they are very abundant. Sea urchins are preyed upon by sea otters.

➢ By keeping the population of urchins in check, otters actually help to preserve the kelp forest, thereby maintaining the biodiversity of the kelp forest community. So, the sea otter affects kelp indirectly through its effects on grazer populations. Humans can indirectly harm kelp forest communities by depleting the number of sea otters.

The simple food chain you will be working with:
Sea anemones, "sea monkeys," and marine algae
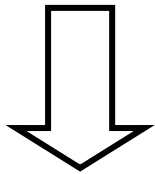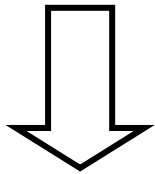
PRODUCER

Marine algae—One or more species of flagellated marine algae will constitute the primary producers in the food chain. The genera that may be used in a given microcosm are *Dunaliella, Platymonas, Stephanoptera*, and/or *Tetraselmis*.

Platymonas

GRAZER

**Artemia**—The brine shrimp *Artemia*, marketed to kids as "Sea Monkeys", is a small marine crustacean that grazes on planktonic algae.

PREDATOR

Sea anemones — sea anemones are animals that generally remain attached to the sea floor or burrow in soft sediments. They are predators that capture prey by stinging them with stinging cells located on their tentacles.

12

The MARINE ALGAE / primary producers

Dunaliella (done-al-ee-ell-a) is a single-celled green alga that lives in marine environments. It has " two similar flagella inserted at the apex of the cell." The cell contains many "cup-shaped green chloroplasts," which accounts for its green color. It occurs in salt marshes or other sites of high salinity. It requires bright light and an optimal temperature of 22°C.
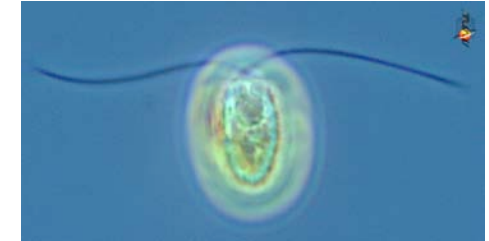
Source: TheAstrobiology Institute, MarineBiological Laboratory, Woods Hole, MA. [http://microscope.mbl.edu/reflections/baypaul/microscope/general/page_01.htm]

Platymonas is a single-celled green alga that lives in marine environments. It has four flagella. It requires bright light and an optimal temperature of 22°C.
Source: TheAstrobiology Institute, MarineBiological Laboratory, Woods Hole, MA. [http://microscope.mbl.edu/reflections/baypaul/microscope/general/page_01.htm]
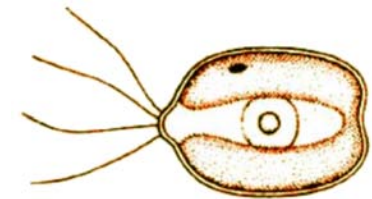
Tetraselmis is a single-celled green alga in inshore marine environments such as tidepools. Members of this genus are important experimental organisms for cell biology and plant physiology. It will undergo asexual reproduction by fission. Before doing so, it loses its flagellum and falls to the sediment. It is also an important food organism for juvenile fish and shellfish.
Source: http://www.bch.umontreal.ca/protists/tets/introduction.html

Stephanoptera is pyriform (pear-shaped) flagellated single-celled green algae. Like the other green algae in this lab, it thrives in relatively warm marine waters under bright light, and it has been used as a food source for cultured marine invertebrates. Source: http://www.carolina.com

ARTEMIA: the primary consumer

- *Artemia salina*, the brine shrimp, is a crustacean, a relative of crabs and lobsters.

- Brine shrimp hatch from dessication-resistant eggs that are encased in a tough outer shell. The encased egg is called a **cyst**. The cysts are harvested and dried commercially and sold to aquarists because after hatching, the brine shrimp make excellent fish food.

- After hatching, *Artemia* develops into a larva called a **nauplius**.

- In a few days, the nauplius develops into the adult shrimp which is about half an inch long, with prominent eyes and many swimming legs.

- *Artemia* adults feed by "grazing" on marine algae.

Artemia cysts hatching

http://www.advancedaquarist.com/issues/dec2002/breeder.htm
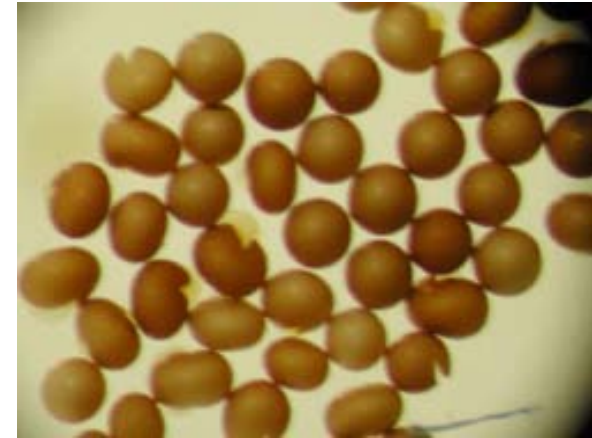
Artemia adults

Harvesting *Artemia* cysts

http://www.zoology.uwa.edu.au/staff/rblack/31102001.html

Artemia **nauplius**

Sea Anemones: the predator

• The striped sea anemone, *Haliplanella*, and the brown sea anemone, *Aiptasia*, are members of a very simple and very ancient evolutionary lineage of animals called the Cnidaria.

• Other cnidarians include *Hydra*, corals, and jellyfishes.

• Both species will eat *Artemia* and other larval crustaceans.

• Both species can reproduce by sexual or asexual means.

"striped sea anemone"
Haliplanella luciae
http://www.mbl.edu/marine_org/marine_org.php?func=detail&0myID=BX76
http://www.njscuba.net/biology/sw_plant-like.html

"brown sea anemone"
Aiptasia pallida

General Instructions

- Your ecosystems will be assembled in glass screw-top bottles.

- To each bottle, add the following
    - 20 ml of artificial sea water
    - 2 ml of an algal culture
        - **Treatments 1-4 [March 21] <u>OR</u> 8-13 [March 28]**: 2 ml of *Platymonas*
        - **Treatments 1-4 [March 23] <u>OR</u> 8-13 [March 30]**: 2 ml *Tetraselmis*
        - **Treatment 5 [March 21]**: 2 ml of *Dunaliella*
        - **Treatment 5 [March 23]**: 2 ml *Stephanoptera*
        - **Treatment 6 & 7 [March 21]**: *Platymonas/Dunaliella* (1 ml each)
        - **Treatment 6 & 7 [March 23]**: *Tetraselmis/Stephanoptera* (1 ml each)

- Estimate the number of algae present in a 1 ml or 1/2 ml aliquot of algal culture. To estimate the number of algae in 1 ml of culture, you should count the number present in a very small amount of diluted culture (1:10 dilution or 1:100 dilution). For example, if you count 10 algae in 1/10th of a ml of a 1:10 dilution, then 1 ml of undiluted culture would contain 1000 algae.

- The exact instructions for each treatment (how much of which alga and how many *Artemia*) are listed in the tables that follow.

- Attempt to put the correct number of *Artemia* into each treatment. Use the small glass pipets to capture a few *Artemia* and try to dispense them one at a time in to each treatment.

- Label each tube with your lab section (e.g., L1), the treatment #, and the initials of someone in your lab group. Two or three sets of lab partners (4 or 6 people) may collaborate on one set of six or seven treatments (each person should assemble all the ingredients [sea anemone, shrimp & algae] for at least one treatment).

- You will share data, but each pair of lab partners must submit their own lab report. **IV-16**

How many individual algae are there in 1 ml of culture?

- **Alga #1** *Circle one: Platymonas or Tetraselmis*

- **Alga #2;** *Circle one: Dunaliella or Stephanoptera*

EXPERIMENT 1a. Optimal Ratio of Producer / Grazer [March 21only]

Hypothesis: There is an optimal ratio between the population of primary producers (algae) and the population of grazers (brine shrimp) at which the ecosystem will exhibit the greatest stability.

Experiment: While holding the density of algae constant, vary the number of brine shrimp (from 2-16) added to a small self-contained ecosystem. After two weeks, record any changes in the population of algae and the population of shrimp.

	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Starting conditions (quantity of each species)	**2 ml** Alga (*Platymonas*) # individual alga:	**2 ml** Alga (*Platymonas*) # individual alga:	**2 ml** Alga (*Platymonas*) # individual alga:	**2 ml** Alga (*Platymonas*) # individual alga:
Length of incubation	**14 days**	**14 days**	**14 days**	**14 days**
Final conditions	# *Platymonas* _____ # *Artemia*)	# *Platymonas* _____ # *Artemia*)	# *Platymonas* _____ # *Artemia*)	# *Platymonas* _____ # *Artemia*)
Percentage change (±%)	*Platymonas* _____ *Artemia* _____	*Platymonas* _____ *Artemia* _____	*Platymonas* _____ *Artemia* _____	*Platymonas* _____ *Artemia* _____

Names:

EXPERIMENT 2a. Differences in the Algal Community [March 21only]

Hypothesis: Differences in the composition of the community of primary producers will lead to differences in the stability of the ecosystem.

Experiment: While holding the density of *Artemia* constant, vary the species of algae that are added to the ecosystem.

	Treatment 5	Treatment 6	Treatment 7
Starting conditions (quantity of each species)	**2 ml** Alga (*Dunaliella*) *# Dunaliella*:_____	**2 ml** Alga (1 ml *Dunaliella*) (1 ml *Platymonas*) *# Dunaliella*:_____ *# Platymonas*:_____	**2 ml** Alga (1 ml *Dunaliella*) (1 ml *Platymonas*) *# Dunaliella*:_____ *# Platymonas*:_____
Length of incubation	**14 days**	**14 days**	**14 days**
Final conditions	*# Dunaliella* _____ *# Artemia*	*# Dunaliella* _____ *# Platymonas* _____ *# Artemia* _____	*# Dunaliella* _____ *# Platymonas* _____ *# Artemia* **0**
Percentage change (±%)	*Dunaliella* _____ *Artemia* _____	*Dunaliella* _____ *Platymonas* _____ *Artemia* _____	*Dunaliella* _____ *Platymonas* _____ *Artemia* **n/a**

Names:

IV-19

EXPERIMENT 1b. Optimal Ratio of Producer / Grazer [March 23 only]

Hypothesis: There is an optimal ratio between the population of primary producers (algae) and the population of grazers (brine shrimp) at which the ecosystem will exhibit the greatest stability.

Experiment: While holding the density of algae constant, vary the number of brine shrimp (from 2-16) added to a small self-contained ecosystem. After two weeks, record any changes in the population of algae and the population of shrimp.

	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Starting conditions (quantity of each species)	**2 ml** Alga (*Tetraselmis*) # individual alga:	**2 ml** Alga (*Tetraselmis*) # individual alga:	**2 ml** Alga (*Tetraselmis*) # individual alga:	**2 ml** Alga (*Tetraselmis*) # individual alga:
Length of incubation	**14 days**	**14 days**	**14 days**	**14 days**
Final conditions	# *Tetraselmis* _____ # *Artemia*	# *Tetraselmis* _____ # *Artemia*	# *Tetraselmis* _____ # *Artemia*	# *Tetraselmis* _____ # *Artemia*
Percentage change (±%)	*Tetraselmis* _____ *Artemia* _____	*Tetraselmis* _____ *Artemia* _____	*Tetraselmis* _____ *Artemia* _____	*Tetraselmis* _____ *Artemia* _____

Names:

EXPERIMENT 2b. Differences in the Algal Community [March 23 only]

Hypothesis: Differences in the composition of the community of primary producers will lead to differences in the stability of the ecosystem.

Experiment: While holding the density of *Artemia* constant, vary the species of algae that are added to the ecosystem.

	Treatment 5	**Treatment 6**	**Treatment 7**
Starting conditions (quantity of each species)	**2 ml** Alga (*Stephanoptera*) # *Stephanoptera* :_____	**2 ml** Alga (1 ml *Stephanoptera*) (1 ml *Tetraselmis*) # *Stephanoptera* :_____ # *Tetraselmis* :_____	**2 ml** Alga (1 ml *Stephanoptera*) (1 ml *Tetraselmis*) # *Stephanoptera* :_____ # *Tetraselmis* :_____
Length of incubation	**14 days**	**14 days**	**14 days**
Final conditions	# *Stephanoptera* _____ # *Artemia* _____	# *Stephanoptera* _____ # *Tetraselmis* _____ # *Artemia* _____	# *Stephanoptera* _____ # *Tetraselmis* _____ # *Artemia* **0**
Percentage change (±%)	*Stephanoptera* _____ *Artemia* _____	*Stephanoptera* _____ *Tetraselmis* _____ *Artemia* _____	*Stephanoptera* _____ *Tetraselmis* _____ *Artemia* **n/a**

Names:

IV-21

EXPERIMENT 3a. The Effect of a Predator [March 28only]

Hypothesis: The presence of the predator (sea anemone) will decrease the abundance of grazers and increase the abundance of producers (relative to an ecosystem without predators). This may de-stabilize the ecosystem if the grazer becomes extinct, but it may also stabilize the ecosystem if the grazer does not become extinct and is prevented from causing the extinction of the algae.

Experiment: Compare pairs of otherwise equivalent ecosystems with and without predators.

	Treatment 8	Treatment 9	Treatment 10	Treatment 11
Starting conditions (quantity of each species)	**2 ml** Alga (*Platymonas*) # individual alga: *Artemia:* **4** Anemone: **0**	**2 ml** Alga (*Platymonas*) # individual alga: *Artemia:* **4** Anemone: **1**	**2 ml** Alga (*Platymonas*) # individual alga: *Artemia:* **8** Anemone: **0**	**2 ml** Alga (*Platymonas*) # individual alga: *Artemia:* **8** Anemone: **1**
Length of incubation	**14 days**	**14 days**	**14 days**	**14 days**
Final conditions	Alga (*Platymonas*) ___ Shrimp (*Artemia*) ___	Alga (*Platymonas*) ___ Shrimp (*Artemia*) ___	Alga (*Platymonas*) ___ Shrimp (*Artemia*) ___	Alga (*Platymonas*) ___ Shrimp (*Artemia*) ___
Percentage change (±%)	Alga (*Platymonas*) ___ Shrimp (*Artemia*) ___ Anemone **n/a**	Alga (*Platymonas*) ___ Shrimp (*Artemia*) ___ Anemone ___	Alga (*Platymonas*) ___ Shrimp (*Artemia*) ___ Anemone **n/a**	Alga (*Platymonas*) ___ Shrimp (*Artemia*) ___ Anemone ___

Names:

IV-22

EXPERIMENT 3a. The Effect of a Predator (continued) [March 28 only]

	Treatment 12	Treatment 13
Starting conditions (quantity of each species)	**2 ml** Alga (*Platymonas*) # individual alga: *Artemia:* **16** Anemone: **0**	**2 ml** Alga (*Platymonas*) # individual alga: *Artemia:* **16** Anemone: **1**
Length of incubation	**14 days**	**14 days**
Final conditions	Alga (*Platymonas*) ____ Shrimp (*Artemia*) ____	Alga (*Platymonas*) ____ Shrimp (*Artemia*) ____
Percentage change (±%)	Alga (*Platymonas*) ____ Shrimp (*Artemia*) ____ Anemone **n/a**	Alga (*Platymonas*) ____ Shrimp (*Artemia*) ____ Anemone ____

Names:

IV-23

EXPERIMENT 3b. The Effect of a Predator [March 30 only]

Hypothesis: The presence of the predator (sea anemone) will decrease the abundance of grazers and increase the abundance of producers (relative to an ecosystem without predators). This may de-stabilize the ecosystem if the grazer becomes extinct, but it may also stabilize the ecosystem if the grazer does not become extinct and is prevented from causing the extinction of the algae.

Experiment: Compare pairs of otherwise equivalent ecosystems with and without predators.

	Treatment 8	Treatment 9	Treatment 10	Treatment 11
Starting conditions (quantity of each species)	**2 ml** Alga (*Tetraselmis*) # individual alga: *Artemia:* **4** Anemone: **0**	**2 ml** Alga (*Tetraselmis*) # individual alga: *Artemia:* **4** Anemone: **1**	**2 ml** Alga (*Tetraselmis*) # individual alga: *Artemia:* **8** Anemone: **0**	**2 ml** Alga (*Tetraselmis*) # individual alga: *Artemia:* **8** Anemone: **1**
Length of incubation	**14 days**	**14 days**	**14 days**	**14 days**
Final conditions	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___
Percentage change (±%)	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___ Anemone **n/a**	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___ Anemone ___	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___ Anemone **n/a**	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___ Anemone ___

Names:

EXPERIMENT 3b. The Effect of a Predator (continued) [March 30 only]

	Treatment 12	Treatment 13
Starting conditions (quantity of each species)	**2 ml** Alga (*Tetraselmis*) # individual alga: *Artemia:* **16** Anemone: **0**	**2 ml** Alga (*Tetraselmis*) # individual alga: *Artemia:* **16** Anemone: **1**
Length of incubation	**14 days**	**14 days**
Final conditions	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___
Percentage change (±%)	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___ Anemone **n/a**	Alga (*Tetraselmis*) ___ Shrimp (*Artemia*) ___ Anemone ___

Names: