Session 9: Coevolution

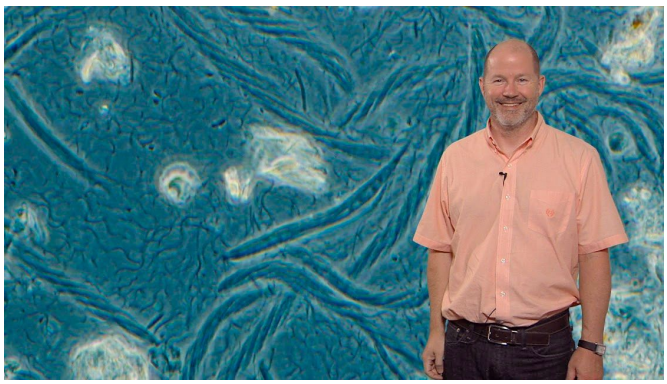
Overview:
Coevolution occurs when two (or more) species influence each other's evolution. In this session, we look at coevolution in several diverse systems. Dr. McFall-Ngai begins with an overview of different types of symbiosis, including the important interactions between hosts and their beneficial microbes. Dr. Estes studies the coevolution of sea otters, sea urchins and kelp. Using historic records, he has been able to show the impact of human over-hunting of otters on an entire ecosystem. In the last video, Dr. Baldwin describes the amazingly intertwined lives of the *Nicotiana attenuata* plant and the *Manduca sexta* moth. In a fascinating twist, defensive toxins produced by the plant to prevent predation by the *M. sexta* caterpillar, may in fact protect the caterpillar from predation by a spider.

First Video:
Speaker: Margaret McFall-Ngai
Living together: The symbiosis of host-microbial interactions

Please watch this video from time 00:00 to 10:09.

Optional Video: An example of Symbiosis Between Termites and their Gut Microbes
Speaker: Jared Leadbetter
Title: Termites and their symbiotic gut microbes

Please watch this video from time 9:07 to 37:07.



Questions for Part 1:

1. Which of the following is an example of symbiosis? Choose all of the answers that apply.
    a. Infection by malaria of humans.
    b. Microbes that live on human skin.
    c. A fish that lives on an anemone.
    d. Fungi that grow in the roots of plants.
    e. None of the above.

2. Choose all of the answers that apply. Symbiosis in which one species benefits is called:
    a. Mutualism**.**
    b. Competition.
    c. Amensalism.
    d. Commensalism.
    e. Mimicry.
    f. Parasitism.

3. Which of the following statements is true about the benefits of having bacteria in the gastrointestinal tract? Choose all of the answers that apply.
    a. Bacteria in the colon allow for the absorption of certain nutrients.
    b. Bacteria in the mouth help with food digestion.
    c. Bacteria can produce essential amino acids.
    d. Bacteria in the colon help the immune system fight pathogens.
    e. Bacteria are not beneficial as, at any opportunity, they will proliferate and attack the host.

For questions 4-5, determine if the statement is true or false. If the statement is false, change one word to make it true.

4. A mutualistic symbiosis improves the fitness of both species.

5. A fox and a chicken are likely to form a commensal relationship.

6. Define the three types of symbiosis and provide examples of each.

7. In order to study the symbiosis between mammals and their gut microbes, scientists have created bacteria-free mouse models. They discovered that the bacteria-free animals were more prone to infection due to a weaker immune system. Propose an explanation for these observations. Briefly explain how the evolution of the host-microbe relationship improves the fitness of both the bacteria and the host animal.

Second Video:
Speaker: James Estes
Title: Apex predators: Sea Otters and Kelp Forests

Please watch this video from time 1:05 to 26:50.

Questions for Part 2:

1. Which of the following statement(s) is/are true about the relationship between sea otters, sea urchins, and kelp? Choose all of the answers that apply.
    a. An abundance of otters leads to an abundance of kelp.
    b. An abundance of otters leads to an abundance of kelp and sea urchins.
    c. A decreased number of otters leads to an abundance of kelp.
    d. A decreased number of otters leads to an abundance of kelp and sea urchins.
    e. Otters have no effect on the abundance of kelp or sea urchins.

For questions 2-4, determine if the statement is true or false. If the statement is false, change one word to make it true.

2. Kelp produces chemicals that help prevent predation by sea otters.

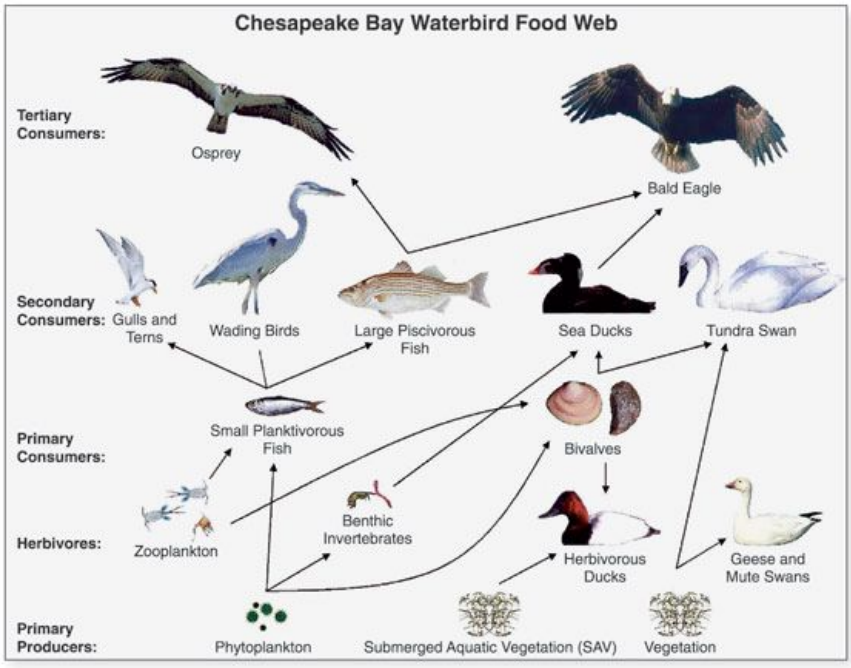
3. The presence of sea otters can affect the evolution of abalones.

4. In the presence of sea otters, kelp is likely to evolve metabolites to decrease predation by herbivores.

5. The presence of sea otters can have an effect on other species, even on species that do not directly interact with sea otters.
    a. Briefly explain why this is true.

    b. The presence or absence of sea otters can also affect the levels of atmospheric CO_2. How is this possible? What are the possible evolutionary implications? Briefly explain.

6. Shown below is the trophic cascade of the Chesapeake Bay waterbird food web.

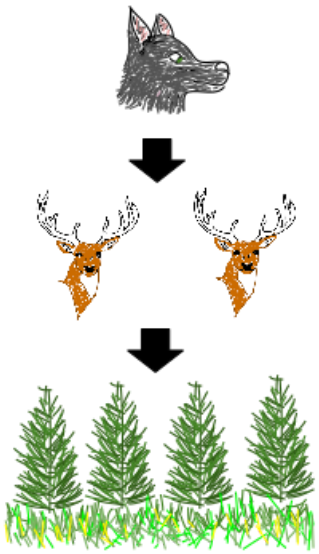


a. In this food web, which of the species is an example of a foundation species? Why?

b. If a disease were to decrease the number of herbivorous ducks from this food web
   i. what would be the direct effect on other species in this trophic cascade?

   ii. what would be the indirect effect on other species in this trophic cascade?

7. Shown below is the trophic cascade between wolves, elk, and vegetation in a forest.



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a. How would you expect the environment to change if the wolf population decreased? Briefly explain.

b. Lyme disease is a big problem in parts of the US. Lyme bacteria are transmitted to humans by ticks which pick up the bacteria when feeding on infected animals, often mice, and then bite humans. Using the food web diagram below (assume these are the only interactions in this ecosystem), describe the effect of a decrease in the wolf population on the prevalence of Lyme disease.

Third Video:
Speaker: Ian Baldwin
Title: *Nicotiana attenuata's* Responses to Attack from a Nicotine-tolerant Herbivore

Questions for Part 3:

1. Which of the following statements are true? Choose all of the answers that apply.
    a. The *Manduca sexta* moth is the best pollinator for *Nicotiana attenuata*.
    b. *Manduca sexta* cannot process nicotine, therefore it avoids the *Nicotiana attenuata*.
    c. The *Manduca sexta* caterpillar can process nicotine and can therefore eat the *Nicotiana attenuata*.
    d. None of the above.

2. Kelp releases a metabolite that is toxic to predators. This is an example of
    a. An indirect defense.
    b. A direct defense.
    c. Symbiosis.
    d. Mutualism.
    e. None of the above.

3. Choose all of the answers that apply. The relationship between the *Nicotiana attenuata* and *Manduca sexta* is an example of
    a. Mutualism.
    b. Parasitism.
    c. Commensalism.
    d. None of the above.

4. Choose all of the answers that apply. When a rabbit is the main predator of the *Nicotiana attenuata* the plant
    a. Increases its indirect defenses.
    b. Increases the levels of nicotine in the leaves.
    c. Decreases the levels of nicotine in the leaves.
    d. The *Nicotiana attenuata* cannot sense predation by the rabbit.
    e. None of the above.

For questions 5-8, determine if the statement is true or false. If the statement is false, change one word to make it true.

5. *Manduca sexta* evolved to preferentially pollinate *Nicotiana attenuata* because it increases the fitness of the *M. sexta* caterpillar.

6. The *Manduca sexta* caterpillar uses nicotine for energy.

7. *Nicotiana attenuata* is able to control the level of nicotine it produces and it will produce lower levels when is being preyed upon by an animal that cannot process nicotine.

8. *Nicotiana attenuata* recognizes when is being eaten by the caterpillar. This initiates a signaling cascade in the plant which activates defense mechanisms.

9. The relationship between *Manduca sexta* and *Nicotiana attenuata* is mostly beneficial.
    a. Briefly explain how the relationship between these two species increases the fitness of the *Manduca sexta*?

b. Briefly explain how the relationship between these two species increase the fitness of the *Nicotiana attenuata*?

10. Scientists classify the relationship between the *Manduca sexta* and the *Nicotiana attenuata* as co-evolution. Briefly explain the evolutionary pressures that shaped this relationship.

11. What two types of defense mechanisms are observed in plants? Provide examples in *Nicotiana attenuata*.

Answers for Session 9:

Questions for Part 1:

1. Which of the following is an example of symbiosis? Choose all of the answers that apply.
    a. **Infection by malaria of humans.**
    b. **Microbes that live on human skin.**
    c. **A fish that lives on an anemone.**
    d. **Fungi that grow in the roots of plants.**
    e. None of the above.

2. Choose all of the answers that apply. Symbiosis in which one species benefits is called:
    a. Mutualism**.**
    b. Competition.
    c. Amensalism.
    d. **Commensalism**.
    e. Mimicry.
    f. Parasitism.

3. Which of the following statements is true about the benefits of having bacteria in the gastrointestinal tract? Choose all of the answers that apply.
    a. **Bacteria in the colon allow for the absorption of certain nutrients.**
    b. Bacteria in the mouth help with food digestion.
    c. **Bacteria can produce essential amino acids.**
    d. **Bacteria in the colon help the immune system fight pathogens.**
    e. Bacteria are not beneficial as, at any opportunity, they will proliferate and attack the host.

For questions 4-5, determine if the statement is true or false. If the statement is false, change one word to make it true.

4. A mutualistic symbiosis improves the fitness of both species.
    True.

5. A fox and a chicken are likely to form a commensal relationship.
    False. ~~Commensal~~; predator-prey

6. Define the three types of symbiosis and provide examples of each.
    a. **Parasitism: a parasitic organism lives in or on a host organism. The parasite benefits (often by feeding on the host) and the host is harmed (but not usually killed). Some examples include tapeworms and other intestinal worms, *Wolbachia*, Trypanosomes, etc.**
    b. **Mutualism: both interacting species benefit. Examples include clownfish and anemones, and pollinators with flowers.**

c. **Commensalism: one species benefits, while the other is not affected. Examples are barnacles on whales and cattle egrets on cattle.**

7. In order to study the symbiosis between mammals and their gut microbes, scientists have created bacteria-free mouse models. They discovered that the bacteria-free animals were more prone to infection due to a weaker immune system. Propose an explanation for these observations. Briefly explain how the evolution of the host-microbe relationship improves the fitness of both the bacteria and the host animal.

   The bacteria likely promote development of the host immune system. Specifically, they train the host immune system to recognize and attack pathogenic gut bacteria. This benefits the host by reducing infections by harmful bacteria and thus improving host fitness. It also benefits the beneficial gut bacteria because these bacteria will not have to compete with the harmful bacteria for the resources provided by the host (such as food). This is an example of mutualism since both the host and the bacteria benefit from the interaction.

Questions for Part 2:

1. Which of the following statement(s) is/are true about the relationship between sea otters, sea urchins, and kelp? Choose all of the answers that apply.
   a. **An abundance of otters leads to an abundance of kelp.**
   b. An abundance of otters leads to an abundance of kelp and sea urchins.
   c. A decreased number of otters leads to an abundance of kelp.
   d. A decreased number of otters leads to an abundance of kelp and sea urchins.
   e. Otters have no effect on the abundance of kelp or sea urchins.

For questions 2-4, determine if the statement is true or false. If the statement is false, change one word to make it true.

2. Kelp produces chemicals that help prevent predation by sea otters.
   False; ~~Sea otters~~ sea urchins (or other herbivores that eat kelp)

3. The presence of sea otters can affect the evolution of abalones.
   True.

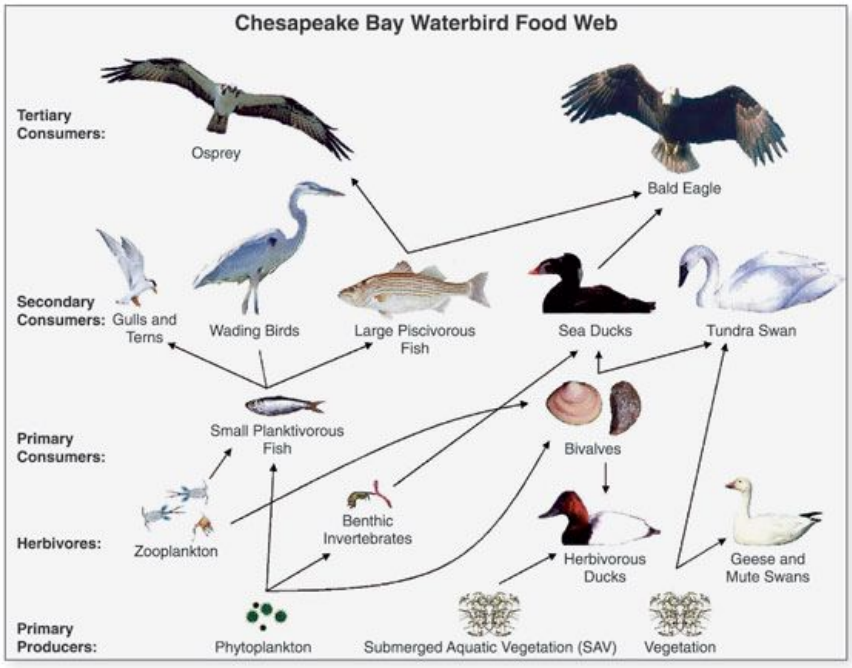
4. In the presence of sea otters, kelp is likely to evolve metabolites to decrease predation by herbivores.
   False; ~~presence~~ absence.

5. The presence of sea otters can have an effect on other species, even on species that do not directly interact with sea otters.
   a. Briefly explain why this is true.
      Sea otters feed on sea urchins and sea urchins feed on kelp. Thus more otters means fewer urchins and more kelp (and vice versa). Kelp is a

foundation species (multiple species depend on kelp for food) and small changes in the abundance of kelp impacts many species in the ecosystem.

b. The presence or absence of sea otters can also affect the levels of atmospheric CO_2. How is this possible? What are the possible evolutionary implications? Briefly explain.
In the presence of sea otters, the abundance of kelp increases. Kelp undergoes photosynthesis. It uses the energy of the sun and atmospheric CO_2 to generate biomass and O_2. This decreases the level of atmospheric CO_2 by sequestering CO_2 in the kelp. An ecosystem with sea otters can drawn down about 10% of the CO_2 in the overlying atmosphere as compared to a system without otters. Since CO_2 is an greenhouse gas, decreasing atmospheric CO_2 levels is important for slowing the rise in global temperatures that has been occurring since the industrial revolution. Global warming may lead to extinction of species (e.g. polar bears) which are dependent on a cold climate and to the migration of other species into new regions.

6. Shown below is the trophic cascade of the Chesapeake Bay waterbird food web.

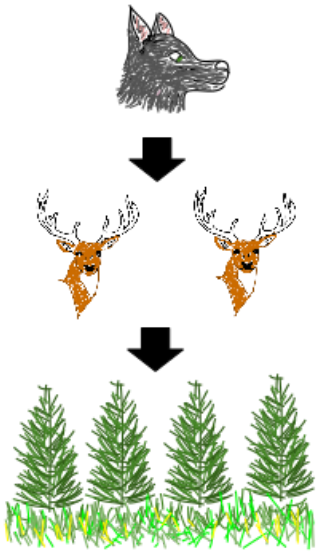


a. In this food web, which of the species is an example of a foundation species? Why?
Phytoplankton. It is a foundation species because multiple species depends on it for food.

b. If a disease were to decrease the number of herbivorous ducks from this food web
    i. what would be the direct effect on other species in this trophic cascade?
    If the number of herbivorous ducks were to decrease, the number of bivalves, and SAV should increase.

    ii. what would be the indirect effect on other species in this trophic cascade?
    The increase in bivalves will affect directly and indirectly the abundance of different animals. For example, zooplankton populations may decrease leading to a reduction in the number of planktivorous fish, and that may decrease the populations of animals that eat these fish. It is also possible that sea ducks and swans will feed more on bivalves, but the relative number of ducks and swans may not increase dramatically since they have other food sources.

7. Shown below is the trophic cascade between wolves, elk, and vegetation in a forest.



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a. How would you expect the environment to change if the wolf population decreased? Briefly explain.
The elk population would increase and the number of young trees would decrease. Eventually the forest would have fewer trees and this could impact other organisms in the forest ecosystem.

b. Lyme disease is a big problem in parts of the US. Lyme bacteria are transmitted to humans by ticks which pick up the bacteria when feeding on infected animals, often mice, and then bite humans. Using the food web diagram below (assume these are the only interactions in this ecosystem), describe the effect of a decrease in the wolf population on the prevalence of Lyme disease.

If the population of wolves decreases, the prevalence of Lyme disease will increase. Fewer wolves will lead to an increase in coyotes, which will lead to a decrease in red foxes, and an increase in the population of small mammals such as mice. More mice (a reservoir for Lyme bacteria) will mean more infected ticks to transmit the disease to humans.

Questions for Part 3:

1. Which of the following statements are true? Choose all of the answers that apply.
   - **a. The *Manduca sexta* moth is the best pollinator for *Nicotiana attenuata*.**
   - b. *Manduca sexta* cannot process nicotine, therefore it avoids the *Nicotiana attenuata*.
   - c. **The *Manduca sexta* caterpillar can process nicotine and can therefore eat the *Nicotiana attenuata*.**
   - d. None of the above.

2. Kelp releases a metabolite that is toxic to predators. This is an example of
   - a. An indirect defense.
   - **b. A direct defense.**
   - c. Symbiosis.
   - d. Mutualism.
   - e. None of the above.

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5. *Manduca sexta* evolved to preferentially pollinate *Nicotiana attenuata* because it increases the fitness of the *M. sexta* caterpillar.
    True.

6. The *Manduca sexta* caterpillar uses nicotine for energy.
    False; ~~energy~~ protection

7. *Nicotiana attenuata* is able to control the level of nicotine it produces and it will produce lower levels when is being preyed upon by an animal that cannot process nicotine.
    False. ~~lower~~ higher OR ~~cannot~~ can

8. *Nicotiana attenuata* recognizes when is being eaten by the caterpillar. This initiates a signaling cascade in the plant which activates defense mechanisms.
    True.

9. The relationship between *Manduca sexta* and *Nicotiana attenuata* is mostly beneficial.
    a. Briefly explain how the relationship between these two species increases the fitness of the *Manduca sexta*?
    The plant is a source of food for the moth's caterpillar. By eating nicotine, the caterpillar acquire defenses against predators.

    b. Briefly explain how the relationship between these two species increase the fitness of the *Nicotiana attenuata*?
    The *Manduca sexta* is a great pollinator because it increases the chances of cross pollination and mixing of gametes between plants. Mixing gametes is beneficial because it will make the population of plants more heterogenous and will increase the chances of survival (evolutionary advantages of sexual reproduction).

10. Scientists classify the relationship between the *Manduca sexta* and the *Nicotiana attenuata* as co-evolution. Briefly explain the evolutionary pressures that shaped this relationship.
    The pressures acting on *N. attenuata* are a balancing act, or battle, between the benefits of using the *Manduca sexta* moth as a very effective pollinator and the damage caused by *M. sexta* caterpillar predation. *M. sexta* caterpillars, on the other hand, balance the pressure of eating a toxic plant which slows their growth and interferes with their nervous system function, with the benefit of being able to use nicotine as a defense against predators.

11. What two types of defense mechanisms are observed in plants? Provide examples in *Nicotiana attenuata*.
    a. **Direct defenses - Release of toxic metabolites (such as nicotine) that prevent predation; release of compounds that decrease the predator's ability to digest the plant (protease or amylase inhibitors, abrasives that destroy animal's teeth)**
    b. **Indirect defenses - Produce compounds that attract species that attack the herbivore that is eating the plant. For example, beetles that eat the *M. sexta* caterpillar are attracted by compounds released by damaged *N. attenuata* leaves or lizards and ants that are attracted to the caterpillar frass which has a distinct smell due to plant compounds it has ingested.**
    c. **Tolerance - Predation by *M. sexta* caterpillars triggers *N. attenuata* to store nutrients in their roots. This allows them to flower later in the season when *M. sexta* caterpillars have pupated or morphed to moths and are no longer feeding on plant leaves.**
    d. **Avoidance - Attracting different pollinators. Usually *N. attenuata* flowers at night and is pollinated by *M. sexta.* By flowering during the day instead, *N. attenuata* attracts hummingbirds as pollinators.**