BIOL 3340 Ecology Study Guide for Exam 2

Source: the lecture slides (text, figures and slide notes). No textbook.

Each heading is one Study Lab objective. [L13 s08] = Lecture 13, slide 8.

(teal italics) = plain meaning of the word before it. ⚠ **Do not mix up = a look-alike pair to keep apart.** **Amber dotted words** = names printed on the figure beside them.

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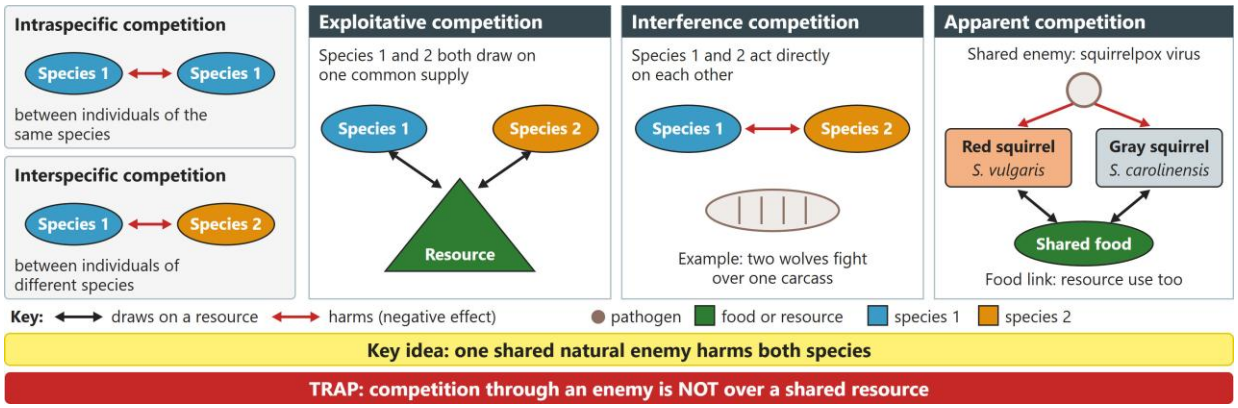
Click a line to jump to it. The PDF side panel (bookmarks) has the same parts.

Lecture 10: Competition and Facilitation

L10.1 Species interactions and types of competition

⚠ **Do not mix up: Apparent competition is NOT a shared resource: it is a shared natural enemy.** [L10 s10]

Species interactions *(how species affect each other)*: interactions among populations, usually of different species, in the same area. [L10 s05]



Intraspecific, interspecific, exploitative, interference and apparent competition side by side [L10 s09]

On the figure: Intraspecific competition · Interspecific competition · Exploitative competition · Interference competition · Apparent competition · squirrelpox virus

Intraspecific competition *(within one species)*: between individuals of the same species. [L10 s07]
Interspecific competition *(between species)*: between individuals of different species. [L10 s07]
Interspecific competition is the main focus, but individuals within a species compete strongly. [L10 s07]
Types of competition: interference, exploitation, apparent; also amensalism *(one species harmed, other unaffected)* and allelopathy. [L10 s60, L10 s06]
Exploitative competition: species **1** and species **2** both draw on the same shared resource. [L10 s08, L10 s09]
Interference competition: species **1** and species **2** act directly on each other. [L10 s08, L10 s09]
Apparent competition: involves a shared natural enemy. [L10 s10]
It is different from exploitative and interference competition. [L10 s10]
Squirrels: red squirrel (S. vulgaris) and gray squirrel (S. carolinensis) share the **squirrelpox virus**. [L10 s10]
The two squirrels also share a food resource, which is exploitative competition. [L10 s10]
Review question: why is apparent competition different than competition? [L10 s11]

Answer: apparent competition runs through a shared natural enemy, not shared resources or direct contact. [L10 s10, L10 s11]

Species interactions and their signs

Interaction	Species A	Species B
Competition	-	-
Amensalism	-	**0**
Predation, herbivory, parasitism	+	-
Mutualism	+	+
Commensalism	+	**0**
Neutralism	**0**	**0**

Table source: [L10 s06]

Three types of competition

Type	Diagram	Example
Exploitative	Two arrows from the species to one shared resource	Overlapping root systems
Interference	One arrow directly between species **1** and species **2**	Two wolves snarling over a carcass
Apparent	Both species linked to a shared natural enemy	Red and gray squirrels, squirrelpox virus

Table source: [L10 s08, L10 s09, L10 s10]

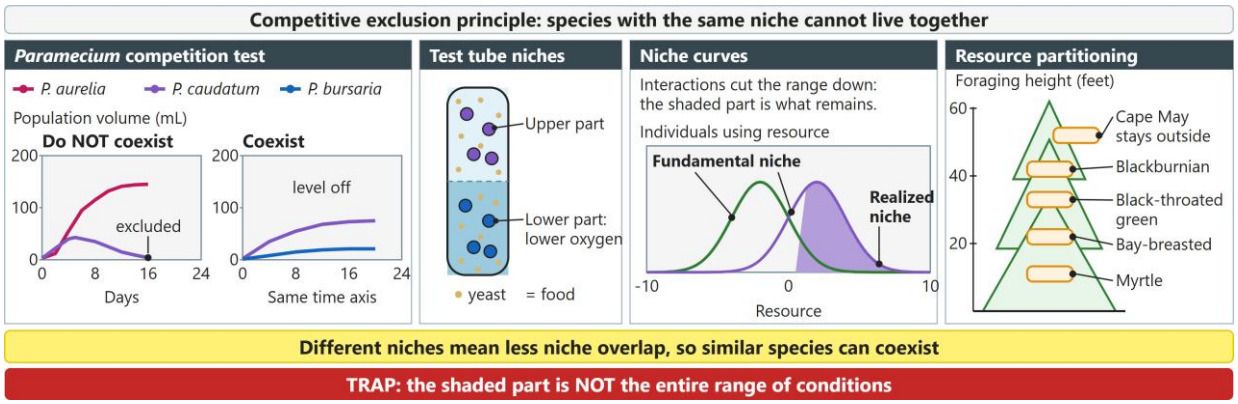
L10.2 Competitive exclusion, niches and resource partitioning

⚠ **Do not mix up: Realized niche is NOT the full possible range: that is the fundamental niche.** [L10 s17, L10 s18]

Competitive exclusion principle: species with exactly the same requirements cannot live together. [L10 s13]

Cannot live together means cannot use the same resources in the same place (the same niche). [L10 s13]

This is thought to be true of any species forced to compete: microbes, mammals, plants. [L10 s13]



Paramecium results, test tube niches, niche curves and warbler heights in one view [L10 s18]

On the figure: Paramecium · P. bursaria · P. caudatum · Fundamental niche · Realized niche · Resource partitioning · Blackburnian

Paramecium test: species grown alone, then in pairs; population volume (mL) tracked over days. [L10 s14]

Why the difference? Different resource use can prevent competitive exclusion. [L10 s14, L10 s15]

P. bursaria uses yeast in the lower part of the test tubes, where oxygen is lower. [L10 s15]

P. caudatum uses yeast in the upper part of the test tubes. [L10 s15]

These different niches are proposed to keep P. caudatum from excluding P. bursaria. [L10 s15]

Eltonian niche: the role of an organism in an ecosystem. [L10 s16]

Niche: the range of conditions within the environment where an organism can exist. [L10 s16]

The course primarily uses this second definition of niche. [L10 s16]

Fundamental niche *(every condition where it could live)*: the entire range of conditions a species could exist in. [L10 s17]

Most species do not exist across that entire range. [L10 s17]

Realized niche *(the part it actually uses)*: **only** part of that range. [L10 s18]

Competition, predation, parasitism or some other interaction cuts the range down. [L10 s18]

Resource partitioning *(splitting resources)*: differentiation of niches in space and time that lets similar species coexist. [L10 s19]

Warblers in spruce trees: five warbler species in New England. [L10 s19, L10 s20]

Four of the species used different heights and portions of the tree. [L10 s19]

Each probably fed on a different range of insects. [L10 s19]

The Cape May warbler attacked flying insects more than the **Blackburnian** did. [L10 s19]

The Cape May warbler also tended to remain on the outside of the trees. [L10 s19, L10 s20]

Result: reduced niche overlap, which promotes coexistence. [L10 s19, L10 s20]

Each warbler prefers a different height and portion of the tree, which reduces competition. [L10 s20]

Allopatric *(living apart)*: each finch alone, fuliginosa on **Los Hermanos**, fortis on **Daphne Major**. [L10 s21]

Sympatric *(living together)*: both finch species on the same islands, San Cristobal and **Santa Maria**. [L10 s21]

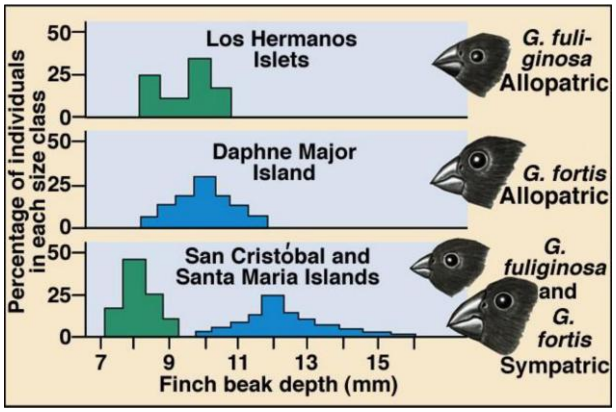
Galapagos finches: the Small Ground-Finch (Geospiza fuliginosa) and Medium Ground-Finch (Geospiza fortis). [L10 s22]

Character displacement *(traits shift apart)*: the trait measured is **beak depth**. [L10 s21]

Allopatric: the two beak depth ranges overlap. [L10 s21]

Sympatric: the two beak depth ranges shift apart, so beaks differ more. [L10 s21]

Niche: the resources a species uses and its interactions with other species define it. [L10 s23]



Beak depth of two finches alone and together: sympatric beaks shift apart [L10 s21]

On the figure: Allopatric · Sympatric · beak depth · Los Hermanos · Daphne Major · Santa Maria

Species a, b and c show large overlaps on the first niche dimension. [L10 s23]

Overlaps are smaller on the second niche dimension. [L10 s23]

With two dimensions together, the actual overlap (hatched area) is small. [L10 s23]

Paramecium competition results

Grown	Result
Each alone	All three level off
P. bursaria with P. caudatum	Coexist: both level off
P. aurelia with P. caudatum	Do **NOT** coexist: P. caudatum dies out

Table source: [L10 s14]

L10.3 Testing for competition: barnacles and caddisflies

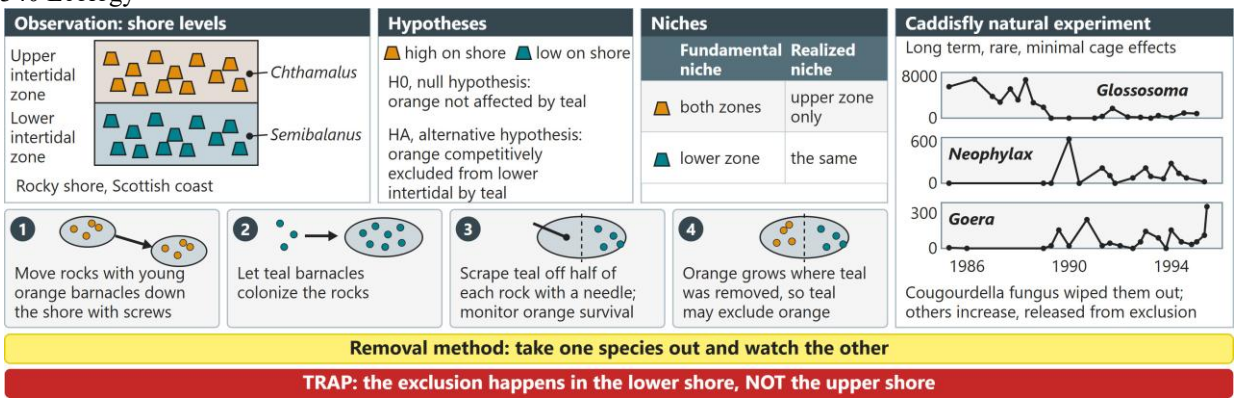
⚠ **Do not mix up: Semibalanus excludes Chthamalus from the LOWER zone, not the upper zone.** [L10 s27, L10 s28, L10 s29]

Competition can be an evolutionary force, strong enough to cause non-overlapping distributions between species. [L10 s24]

How can we test for competition and competitive exclusion experimentally? [L10 s25]

Removal method: temporarily remove one species and examine the effect on the other. [L10 s26]

This is one of the best tools for studying competition between two species. [L10 s26]



Barnacle removal steps, niches of the two barnacles, and the caddisfly long term record [L10 s29]

On the figure: Chthamalus · Semibalanus · Glossosoma · Removal method · Fundamental niche · Realized niche · H0

Barnacle experiment: a classic removal study of competition between two barnacle species. [L10 s26]

Observation: the two barnacle species occur at different levels of the rocky intertidal zone. [L10 s27]

Chthamalus stellatus *(upper shore barnacle)* occurs in the upper areas of the zone. [L10 s27]

Semibalanus balanoides *(lower shore barnacle)* is more abundant in the lower zone. [L10 s27]

Question: does competition restrict the ranges of these two barnacle species? [L10 s27, L10 s28]

H0 *(null hypothesis)*: Chthamalus are not affected by the presence of Semibalanus. [L10 s28]

HA *(alternative hypothesis)*: Chthamalus are competitively excluded from lower intertidal by Semibalanus. [L10 s28]

Setting: rocky shores of the Scottish coast, where the two species do not coexist. [L10 s29]

Result: Semibalanus may exclude Chthamalus from certain habitats. [L10 s29]

Chthamalus: fundamental niche covers both zones, realized niche **only** the upper zone. [L10 s29]

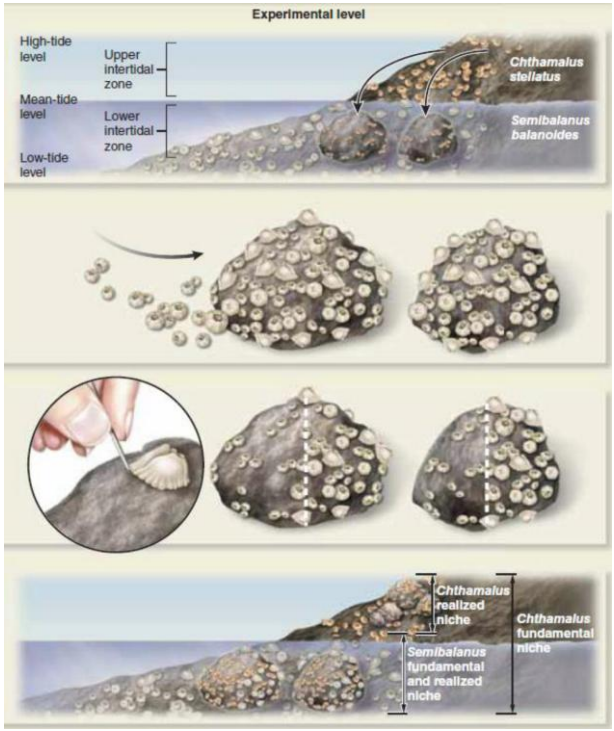
Semibalanus: fundamental and realized niche are the same, the lower zone. [L10 s29]

Glossosoma caddisflies: fungal pathogens (Cougourdella sp.) wiped them out in Michigan streams. [L10 s30]

This is a long-term natural experiment, a rare example with minimal cage effects. [L10 s30]

After Glossosoma was eliminated, other herbivorous insect species **increased** in density. [L10 s30]

They were released from exclusion via competition. [L10 s30]



Barnacle zones on the shore with realized and fundamental niche ranges [L10 s29]

On the figure: Chthamalus stellatus · Semibalanus balanoides · realized niche · fundamental niche

Barnacle removal experiment

Step	What was done
1	Remove rocks with young Chthamalus from upper zone, screw them down in lower zone
2	Allow Semibalanus to colonize the rocks
3	Remove Semibalanus from half of each rock with a needle, return rocks to lower zone, monitor Chthamalus survival on both sides
4	Chthamalus grows on the side where Semibalanus was removed

Table source: [L10 s29]

L10.4 Lotka-Volterra and R* models

⚠ **Do not mix up: Alpha is the effect of species 2 on species 1, NOT species 1 on species 2.** [L10 s34]

Lotka-Volterra competition model: based on the logistic equation of population growth. [L10 s31]

r1 is the per capita growth rate of species **1**; r2 is that of species **2.** [L10 s32]

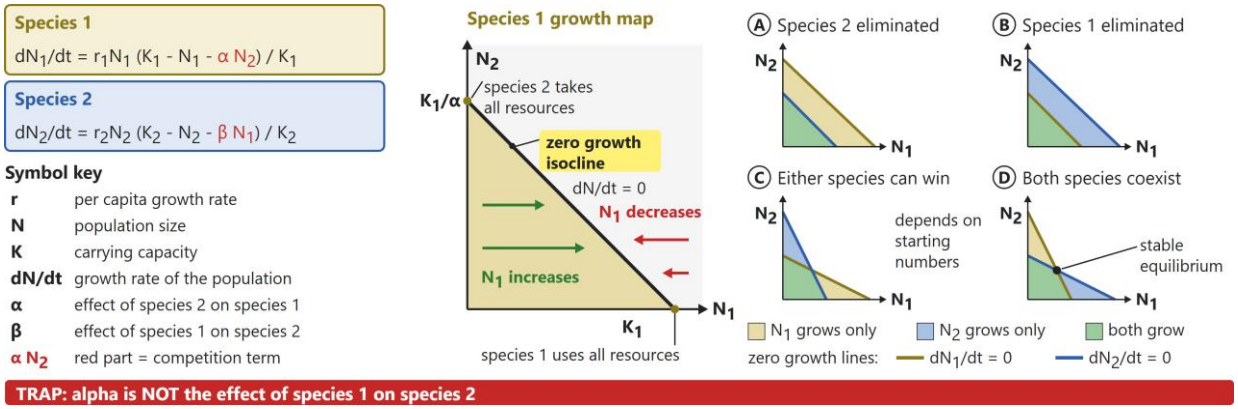
Start with the logistic equation for each species: dN1/dt = r1N1 (K1 - N1) / K1. [L10 s33]

Then add a competition term for each species effect on the other. [L10 s33]

Species **1**: dN1/dt = r1N1 (K1 - N1 - α N2) / K1. [L10 s34]

Species **2**: dN2/dt = r2N2 (K2 - N2 - β N1) / K2. [L10 s34]

These equations describe how the abundance of both species changes together. [L10 s34]



Competition equations, zero growth isocline with arrows, and the four outcomes [L10 s37]

On the figure: Zero growth isocline · Species 1 · Species 2 · K1/α · alpha

Zero growth isocline *(line where growth stops)*: the diagonal line where dN/dt = **0.** [L10 s35]

Axes: **species 1** size (x), **species 2** size (y); line runs **K1/α** to K1. [L10 s35]

Shaded area: species **1 increases** (arrows point right) and settles on the diagonal. [L10 s35]

Unshaded area: species **1 decreases** (arrows point left) until it reaches the diagonal. [L10 s35]

At K1 on the x axis, species **1** uses all resources and no N2 is present. [L10 s35]

At K1/α on the y axis, species **2** takes all resources; none remain for species **1.** [L10 s35]

Each species competes more strongly against its own species at high density. [L10 s36, L10 s37]

So each species limits itself more than it limits the other species. [L10 s36, L10 s37]

Colors: tan = N1 **increases only**, blue = N2 **increases only**, green = both **increase**. [L10 s36, L10 s37]

Dotted lines show vector addition *(adding the two solid arrows)* of the two solid line vectors. [L10 s37]

Tilman R star model *(resource level model)*: Tilman criticized the Lotka-Volterra model. [L10 s38]

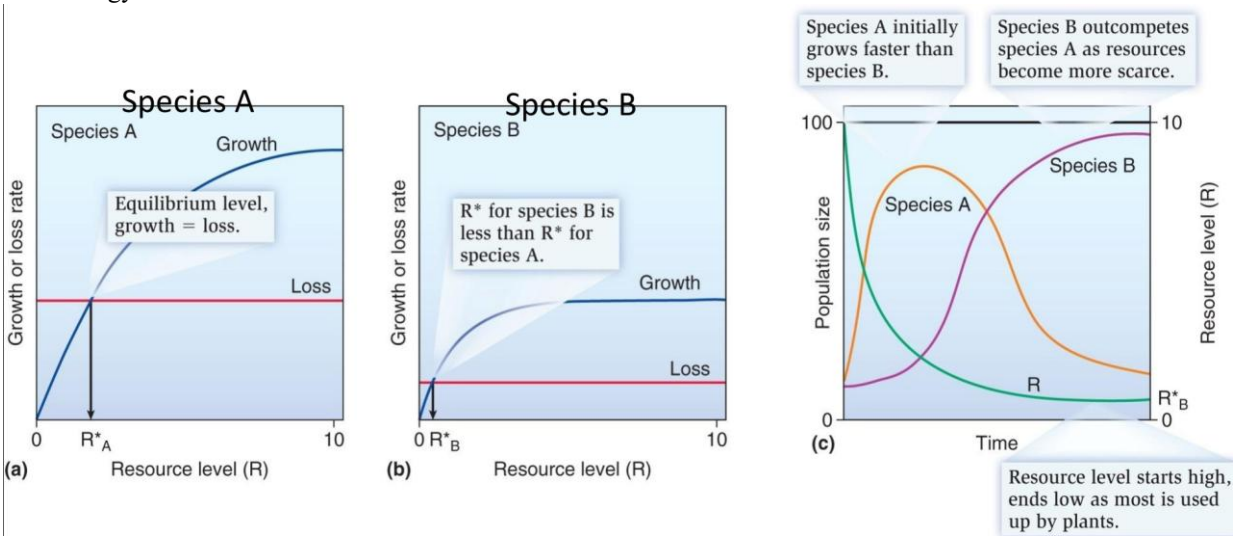
We need to know the mechanism by which competition occurs. [L10 s38]

Knowing the mechanism enables better predictions of the outcome. [L10 s38]

R star: the resource level where gains by growth equal losses to predators or disease. [L10 s38]

At R*, population size neither **increases** nor **decreases**. [L10 s38]

R* predicts the outcome of competition from resource use. [L10 s38]



Growth against loss for species A and B, and population and resource over time [L10 s39]

On the figure: Species A · Species B · resource level · Time

Species A: R* is where its rising growth curve meets the flat loss line. [L10 s39]

Species B: growth is slower than A, and R* for B is below R* for A. [L10 s39]

Over **time** species A first grows faster, peaks, then declines. [L10 s39]

Species B outcompetes species A as resources become scarce. [L10 s39]

Lower R star wins: species B has the lower R*, so it displaces species A. [L10 s39]

Species B drives the **resource level** down to R* of B. [L10 s39]

Resource level starts high and ends low, as most is used up by plants. [L10 s39]

Two resources: imagine a second resource where R* is lower for species A than B. [L10 s39]

They coexist if some habitat has more of resource **1** and some more of resource **2.** [L10 s39]

What the model teaches: competition is predicted to lead to local extinction of one species. [L10 s40]

Local extinction fails to occur if intraspecific competition is greater than interspecific competition. [L10 s40]

That means each species limits its own growth rate more than it limits the other species. [L10 s40]

Studies of R* show coexistence can occur when species require differing levels of the same resource. [L10 s40]

Summary: Lotka-Volterra models and the R* concept help explain species coexistence. [L10 s60]

Symbols in the model

Symbol	Meaning
r	per-capita rate of population growth
N	population size
K	carrying capacity
Subscripts 1, 2	refer to species **1** or species **2**
α (alpha)	per capita competitive effect of species **2** on species **1**
β (beta)	per capita competitive effect of species **1** on species **2**

Table source: [L10 s31, L10 s32, L10 s34]

Parts of the logistic equation

Part	Meaning
N1	population size
r1	per capita growth rate
dN1/dt	growth rate of the population

Table source: [L10 s33]

Four consequences of the model

Outcome	Result
A	Species **2** is eliminated
B	Species **1** is eliminated
C	Either species can win; it depends on the starting numbers
D	Both species coexist at a stable equilibrium

Table source: [L10 s37]

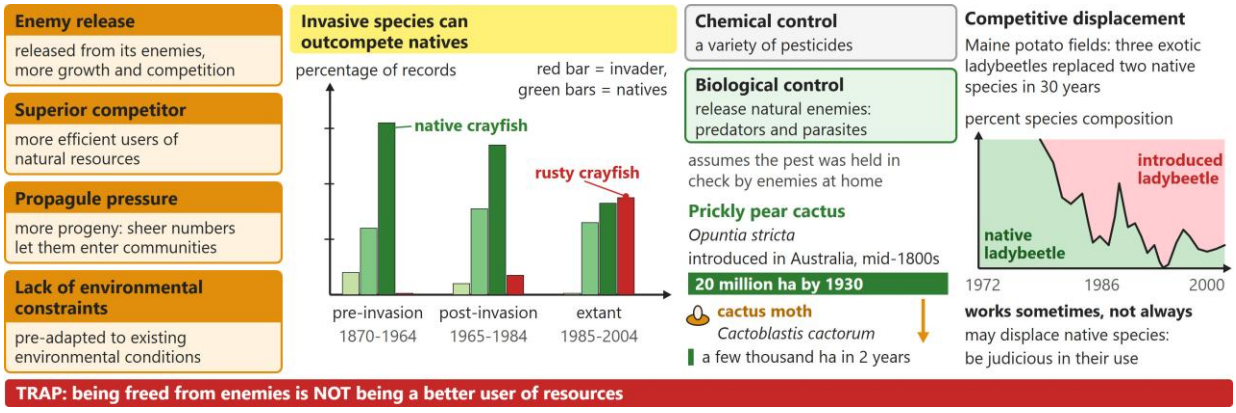
Two competition models

Model	Key idea	Prediction
Lotka-Volterra	Competition terms α and β added to logistic growth	Four outcomes, including coexistence
R* (Tilman)	Mechanism of competition, based on resource use	Species with the lower R* wins

Table source: [L10 s31, L10 s34, L10 s37, L10 s38, L10 s39]

L10.5 Invasive species and biological control

⚠ **Do not mix up: Enemy release is NOT efficient resource use: that is the superior competitor hypothesis.** [L10 s42]



Invasiveness hypotheses, crayfish records, biological control and ladybeetle displacement [L10 s41]

On the figure: Enemy release · Superior competitor · rusty crayfish · native crayfish · Biological control · Prickly pear cactus · Cactus moth · Competitive displacement

Invasive species can outcompete natives: an example is the **rusty crayfish** in Wisconsin. [L10 s41]
Competition from the rusty crayfish (red bar) reduced **native crayfish** abundance. [L10 s41]
Rusty crayfish records rose across three time periods while native O. virilis records fell. [L10 s41]
Four hypotheses are currently being tested to account for invasiveness. [L10 s42]
Enemy release also leads to evolution of **increased** competitive ability. [L10 s42]
These four hypotheses have rarely been tested concurrently. [L10 s42]
Summary: lack of natural enemies lets introduced species outcompete natives. [L10 s60]
Pest control is of paramount importance to agriculture, with two main methods. [L10 s43]
The enemies released are often those believed to control the pest in its native country. [L10 s43]
Biological control assumes the enemy release hypothesis is correct. [L10 s43]
Otherwise there is no reason to bring an enemy from the native country. [L10 s43]
Prickly pear cactus (Opuntia stricta) was introduced in Australia in the mid-**1800**s. [L10 s44]
Populations eventually established in the wild. [L10 s44]
It covered **20** million ha by **1930.** [L10 s44]
Cactus moth (Cactoblastis cactorum) was introduced; spread was hypothesized to come from lack of natural enemies. [L10 s45]
Opuntia cover dropped to **only** a few thousand ha in **only 2 years**. [L10 s45]
Competitive displacement: in Maine potato fields, three exotic ladybeetles replaced two native species in **30 years**. [L10 s46]
Biological control species sometimes (but not always) control the pest species. [L10 s46]

Introduced control agents may outcompete natives, so we must be judicious in their use. [L10 s46]

Four invasiveness hypotheses

Hypothesis	What it suggests
Enemy release	Invasives are released from natural enemies and devote more resources to growth and competition
Superior competitor	Invasives are more efficient users of natural resources than natives or non-invasives
Propagule pressure	Invasives produce more progeny than some natives, and sheer numbers let them enter communities
Lack of environmental constraints	Some invaders are pre-adapted to existing environmental conditions

Table source: [L10 s42]

Two methods of pest control

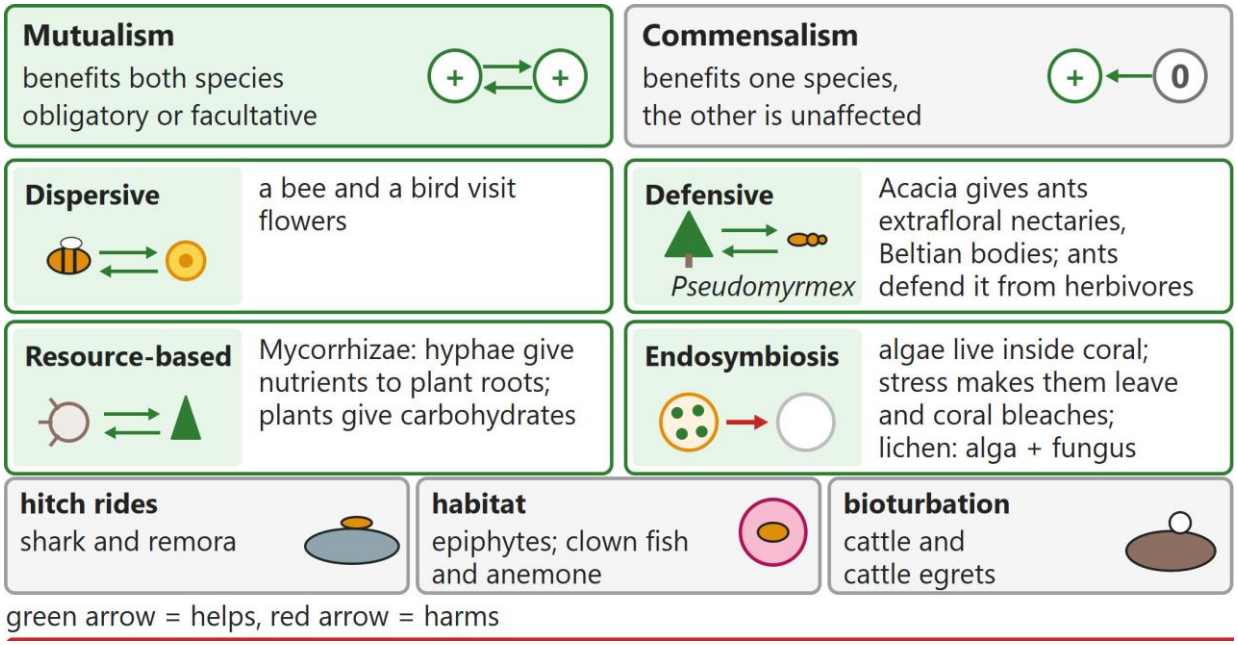
Method	How it works
Chemical control	A variety of pesticides is used
Biological control	Natural enemies such as predators and parasites are released against pests

Table source: [L10 s43]

L10.6 Facilitation: mutualism and commensalism

⚠ **Do not mix up: Commensalism is NOT mutualism: in commensalism one species benefits and the other is unaffected.** [L10 s48]

Facilitation *(one species helping another)*: the heading that covers mutualism and commensalism. [L10 s48, L10 s49]



Mutualism and commensalism signs with the kinds of mutualism and commensalism [L10 s06]

On the figure: Mutualism · Commensalism · dispersive · defensive · resource-based · endosymbiosis · remora · bioturbation

Mutualism: association between two species that benefits both species. [L10 s48]

Mutualism can be **obligatory** *(required)* or **facultative** *(optional)*. [L10 s48]

Commensalism: association between two species that benefits one species, while the other is unaffected. [L10 s48]

Signs: mutualism is + and +, commensalism is + and **0.** [L10 s06, L10 s48]

Mutualism may be **dispersive**, **defensive**, **resource-based**, or **endosymbiosis** *(partner living inside the other)*. [L10 s49]

Acacia and ants: acacia trees provide extrafloral nectaries *(nectar glands outside the flower)* to Pseudomyrmex ants. [L10 s50]

Acacia also provides protein-rich food nodules called **Beltian bodies.** [L10 s50]

In exchange, the ants defend the acacia tree from herbivores. [L10 s50]

Mycorrhizae *(root fungi)* form critical mutualisms with plants. [L10 s51]

Mycorrhizae are more efficient at obtaining nutrients. [L10 s51]

Hyphae *(fungal threads)* invade plant roots and receive carbohydrates from the plants. [L10 s51]

In exchange, the hyphae give nutrients to the plants. [L10 s51]

Coral bleaching: coral and **algae** depend on each other to survive. [L10 s52]

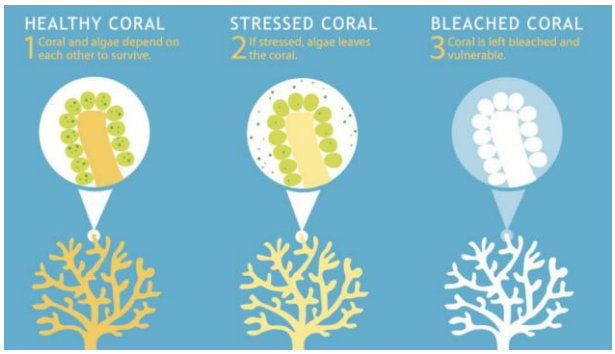
The algae are zooxanthellae *(tiny algae in coral tissue)*, the coral's primary food source, and give it color. [L10 s52]

Stress from **increased** ocean temperature or pollution makes the algae leave the coral tissue. [L10 s52]

Without algae the coral loses its main food, turns white, and is more prone to disease. [L10 s52]

Lichens: a mutualism between a photosynthetic organism and fungi. [L10 s53]

Commensalism examples include organisms that hitch rides, such as sharks and **remora** *(fish that ride on sharks)*. [L10 s54]



Healthy, stressed and bleached coral: algae leave and the coral turns white [L10 s52]

On the figure: coral · algae

Some use other organisms for habitat without damaging them: **epiphytes** *(plants growing on other plants)*, clown fish and anemone. [L10 s54]

Bioturbation *(organisms stirring soil or sediment)*: cattle and cattle egrets. [L10 s54]

Types of mutualism

Mutualism type	Example
Dispersive	A bee on a flower and a bird on a flower head
Defensive	Acacia trees and Pseudomyrmex ants
Resource-based	Mycorrhizae and plants
Endosymbiosis	Coral and algae; lichens

Table source: [L10 s49, L10 s50, L10 s51, L10 s52, L10 s53]

Coral bleaching steps

Step	Coral state	What happens
1	Healthy coral	Coral and algae depend on each other to survive
2	Stressed coral	If stressed, the algae leave the coral
3	Bleached coral	Coral is left bleached and vulnerable

Table source: [L10 s52]

Commensalism examples

Commensalism kind	Example
Hitch rides	Sharks and remora
Habitat use without damage	Epiphytes; clown fish and anemone
Bioturbation	Cattle and cattle egrets

Table source: [L10 s54]

L10.7 Facilitation in stressful environments

⚠ Do not mix up: Neighbors do NOT mainly hurt high elevation plants: removing them lowered flowers and survival. [L10 s57, L10 s58, L10 s59]

Plant mutualisms are more common in stressful environmental conditions, according to the evidence. [L10 s55]

Hypothesis: plants at higher elevations benefit more from neighboring plants. [L10 s55]

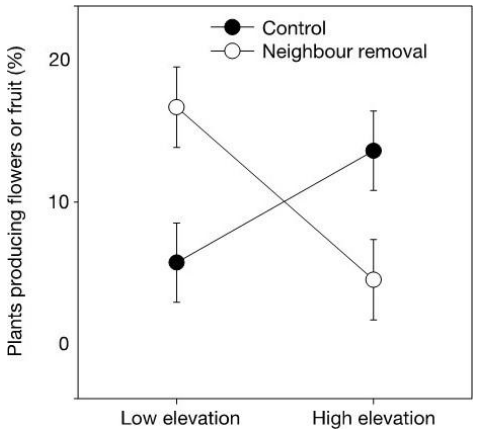
The reason is **facilitation** *(neighbors helping each other)*. [L10 s55]

Neighbors help by providing shade, protection from disturbance like wind, and herbivore protection. [L10 s55]

Global experiment: neighboring plants were removed at high and **low elevation** plots. [L10 s56]

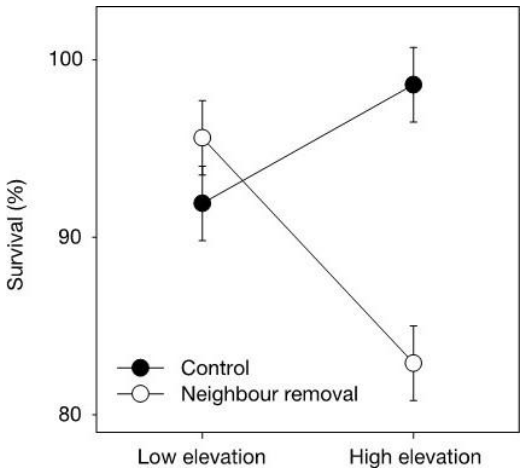
The experiment used **11** different locations. [L10 s56]

Plants at **high elevation** (more stressful) produced fewer **flowers** when neighbors were removed. [L10 s57, L10 s58]



Flowers or fruit at low and high elevation with and without neighbors [L10 s58]

On the figure: high elevation · low elevation · flowers



Survival at low and high elevation: removing neighbors cuts survival high up [L10 s59]

On the figure: survival · high elevation · low elevation

Plants at **high elevation** also had reduced **survival** when neighbors were removed. [L10 s59]

At **low elevation**, removing neighbors raised flowers, not lowered them. [L10 s58]

Take-home: facilitation in stressful environments might matter more than in ideal conditions. [L10 s60]

Lecture 11: Predation and Herbivory

L11.1 Predators and other natural enemies

⚠ Do not mix up: Predation is NOT +/+ or +/0: it is +/- because the prey is killed and eaten. [L11 s06]

Predation *(one species kills and eats another)* is a +/- interaction between species. [L11 s06]

The **predator** *(the killer and eater)* gains (+); the **prey** *(the one eaten)* loses (-). [L11 s06]

Predation is an **interspecific** *(between different species)* interaction. [L11 s06]

Continuum *(a smooth range)*: runs microparasite, macroparasite, parasitoid, predator; body size rises along it. [L11 s07]

Parasitoid *(a parasite that eventually kills its host)*: similar in size to host, such as wasp and moth. [L11 s07]

Macroparasite *(parasite smaller than its host)*: smaller than host, usually mild effect, low ability to regulate host population. [L11 s07]

Regulation: predation has a high potential to regulate prey populations. [L11 s08]

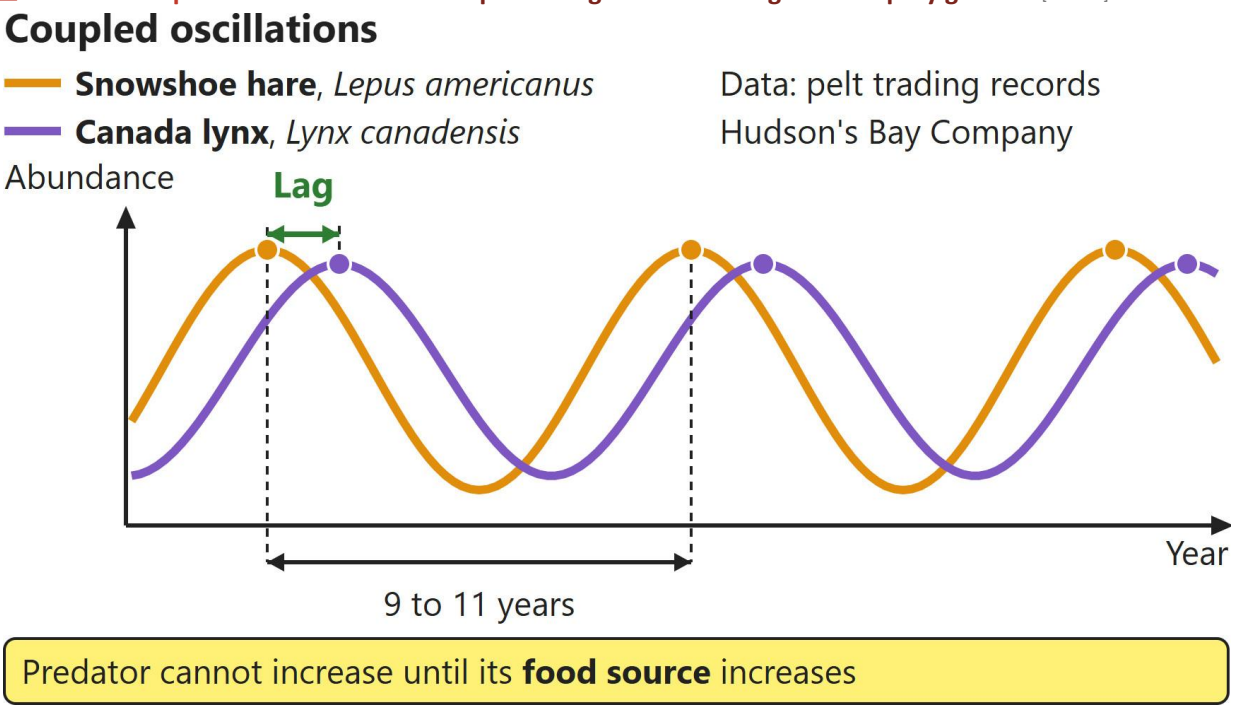
Microparasite to predator: life history traits

Trait	Microparasite	Macroparasite	Parasitoid	Predator
Body size	Microscopic	Smaller than host	Similar in size (wasp and moth)	Often larger than prey unless social hunter
Intrinsic rate of population growth	Rapid	Faster than hosts	Comparable to host	Comparable to but often slightly slower than prey
Number per host	One host usually supports populations of several different species	One host supports a few to many individuals of different species	One host usually supports one, but can support many individuals	Each predator eats many prey individuals
Fatality to host	Mild to severe	Usually mild	Eventually fatal	Immediately fatal
Stability of the interaction with the host	Intermediate	High	Intermediate	Usually low
Ability to regulate host population	Moderate to high	Low	Moderate to high	High

Table source: [L11 s07, L11 s08]

L11.2 Predation and population growth

⚠ **Do not mix up: Predators do NOT lead: predator growth often lags behind prey growth.** [L11 s10]



Hare and lynx waves: the lynx peak trails the hare peak by a lag [L11 s10]

On the figure: Coupled oscillations · Snowshoe hare · Canada lynx · Lag · 9 to 11 years

Coupled oscillations *(linked ups and downs)*: predator and prey abundances cycle in linked waves. [L11 s10]

Snowshoe hare and Canada lynx: coupled oscillations of **9 to 11 years**. [L11 s10]

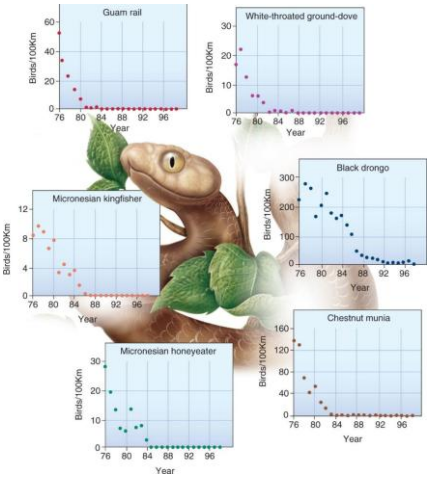
Lag *(delay)*: predator growth often trails prey growth. [L11 s10]

The predator cannot begin to **increase** until its food source begins to **increase**. [L11 s10]

Lynx peaks come just after hare peaks. [L11 s10]

Non-native predators can cause extinction because the prey are not adapted to the predator. [L11 s11]

Brown tree snake, introduced to **Guam**: native bird species fell to zero or near zero. [L11 s11]



Six Guam bird species fall to near zero after the snake arrives [L11 s11]

On the figure: Guam

L11.3 Lotka-Volterra predator-prey model

⚠ Do not mix up: NOT swapped: prey isocline is horizontal at r/s; predator isocline is vertical at m/es. [L11 s17]

Start with **geometric increase** *(growth by a fixed multiple each step)* of prey: N(t+1) = R0 x N(t). [L11 s13]

Searching efficiency *(how well predators find and attack prey)*, or attack rate, is called **s**. [L11 s14]

Prey attacked also depends on number of prey (N) and number of predators (P). [L11 s14]

Consumption of prey combines these three features: **sPN**. [L11 s14]

Prey equation: N(t+1) = R0 N(t) - s P(t) N(t). [L11 s14]

In the prey equation, the **sPN** term is prey removed by predators. [L11 s14]

The term for number of prey (N) is on both the positive and negative parts. [L11 s14]

If s is very high, like an introduced predator, extinction of prey could occur. [L11 s14]

Predator birth rate depends on sPN and **e**, how efficiently predators turn food into new predators. [L11 s15]

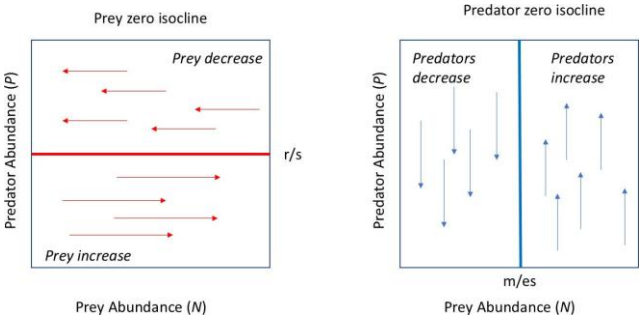
Predator growth: P(t+1) = e s P(t) N(t). [L11 s15]

Predator mortality depends on a mortality rate (m) and the number of predators (P). [L11 s16]

Predator equation: P(t+1) = e s P(t) N(t) - m P(t). [L11 s16]

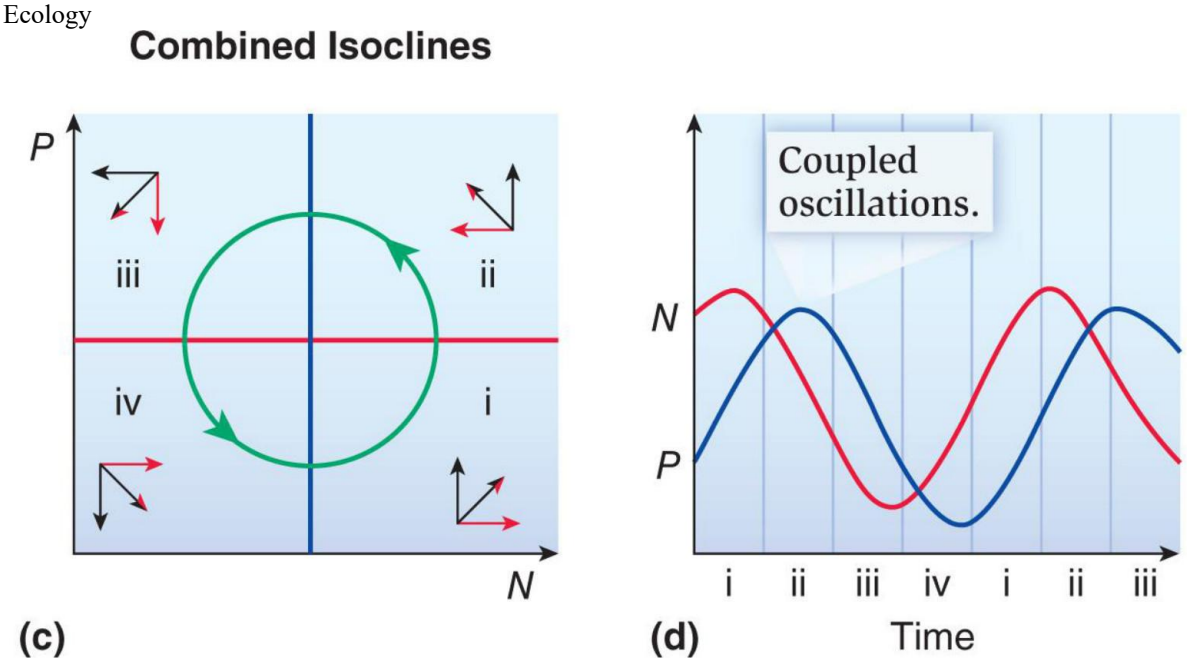
In the predator equation, esPN is predator growth and mP is predator death. [L11 s16]

Zero isocline *(line where a population stops changing)*: one for prey and one for predators. [L11 s17]



Prey isocline is horizontal at r/s; predator isocline is vertical at m/es [L11 s17]

On the figure: zero isocline · r/s · m/es



Combined isoclines make a cycle, giving coupled oscillations of prey and predators [L11 s18]

On the figure: coupled oscillations · isoclines

Combining both **isoclines** gives **coupled oscillations** *(linked ups and downs)* of prey and predators. [L11 s18]

Lotka-Volterra can also model parasitoid and host, or herbivore and plant, if attack **increases** death. [L11 s18]

Lotka-Volterra symbols

Symbol	Meaning
R0	Prey geometric **increase**: N(t+1) = R0 x N(t)
r	Prey growth term that sets the prey isocline position r/s (the equations write the prey multiplier as R0)
s	Searching efficiency, or attack rate, of predators
N	Number of prey
P	Number of predators
sPN	Consumption of prey (prey removal)
e	Efficiency of turning food into new predators
m	Predator mortality rate

Table source: [L11 s13, L11 s14, L11 s15, L11 s16, L11 s17]

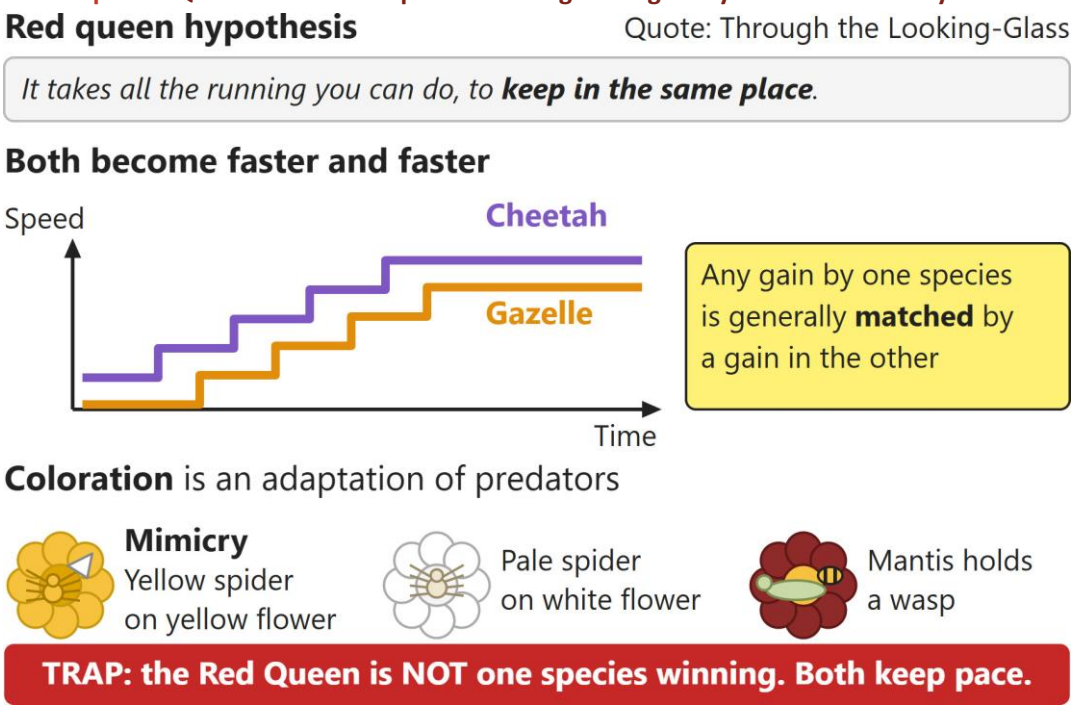
The two isoclines

Isocline	Shape	Position	What happens either side
Prey zero isocline	Horizontal line	r/s on the predator axis	Below: prey **increase**. Above: prey **decrease**
Predator zero isocline	Vertical line	m/es on the prey axis	Left: predators **decrease**. Right: predators **increase**

Table source: [L11 s17]

L11.4 Red Queen and predator adaptations

⚠ **Do not mix up: Red Queen is NOT one species winning: each gain by one is matched by the other.** [L11 s21]



Cheetah and gazelle speeds rise in matched steps; predators use coloration and mimicry [L11 s21]

On the figure: Red queen hypothesis · Cheetah · gazelle · Coloration · Mantis · wasp · keep in the same place

Red queen hypothesis *(both sides keep evolving just to stay level)*: predator and prey keep pace. [L11 s20]

Quote: it takes all the running you can do, to **keep in the same place**. [L11 s20]

Cheetah and gazelle are the classic example supporting the red queen hypothesis. [L11 s21]

Both became faster and faster. [L11 s21]

Any gain in speed by one was generally matched by gains in speed of the other. [L11 s21]

Coloration is an adaptation of predators. [L11 s22]

Predators use coloration to hide while hunting; prey use **cryptic coloration** *(blending in)* to avoid being detected. [L11 s22, L11 s27]

Predator examples: a lizard (beside a grasshopper), crab spiders on flowers, a **mantis** with a **wasp**. [L11 s22, L11 s23, L11 s24, L11 s25, L11 s26]

The spiders match their flowers: yellow spider on yellow petals, pale spider on white flowers. [L11 s23, L11 s25]

L11.5 Antipredator adaptations

⚠ **Do not mix up: Batesian mimic is NOT toxic: it is palatable. Müllerian species are all noxious.** [L11 s27]

Antipredator adaptations *(prey defenses against being eaten)*: cryptic coloration, mimicry, physical defenses, predation satiation. [L11 s27]

Intimidation *(looking threatening)* is shown together with armor under physical defenses. [L11 s27]

Cryptic coloration *(blending in)* is the blending of an organism with its habitat background. [L11 s27]

Cryptic coloration is an aspect of **camouflage**. [L11 s27]

It is a common method of avoiding detection by predators. [L11 s27]

Cryptic coloration is prevalent in the vertebrate *(backboned animal)* world. [L11 s27]

Indian leaf butterfly mimics the leaves on which it rests. [L11 s28]

Pygmy seahorse blends in with its background. [L11 s28]

Mimicry *(looking like another species)*: the mimic resembles the model, which secures protection from predators. [L11 s27]

Batesian mimicry: a palatable *(tasty)* mimic copies an unpalatable *(bad tasting)* model. [L11 s27]

Batesian example: the innocuous *(harmless)* scarlet king snake mimics the poisonous coral snake. [L11 s29]

Müllerian mimicry: many noxious *(harmful or foul tasting)* species converge to look the same, reinforcing the distasteful design. [L11 s27]

Müllerian example: viceroy, queen, and monarch butterflies share warning coloration and are all toxic to birds. [L11 s29]

Physical defenses: armor, claws, stingers, horns. [L11 s27]

Armor: the strong shell of a juvenile ornate box turtle can deter much larger predators. [L11 s30]

Intimidation *(looking threatening)*: the porcupine fish puffs itself up to look threatening to predators. [L11 s30]

Predator satiation *(filling predators up)*, also called predation satiation: synchronous *(at the same time)* production of many progeny. [L11 s31]

All individuals in the population do it, so predators fill up and some survive. [L11 s31]

Periodical cicadas: **13**- and **17**-year cicadas are the example. [L11 s31]

Predators cannot **increase** their population quickly enough to eat a large percentage of cicadas. [L11 s31]

This holds until cicadas finish their life cycle and the grubs burrow back into the ground. [L11 s31]

Antipredator adaptations

Adaptation	Description	Example
Cryptic coloration	Blending of an organism with the background of its habitat	Indian leaf butterfly, pygmy seahorse
Mimicry	A mimic resembles a model; two major types	Two types: Batesian and Müllerian
Batesian mimicry	Palatable mimic copies an unpalatable model	Scarlet king snake copies coral snake
Müllerian mimicry	Many noxious species converge to look the same	Viceroy, queen, monarch butterflies
Physical defenses	Armor, claws, stingers, horns	Ornate box turtle shell
Intimidation	Looking threatening to predators	Porcupine fish puffs up
Predation satiation	Synchronous production of many progeny to satiate predators	**13**- and **17**-year cicadas

Table source: [L11 s27, L11 s28, L11 s29, L11 s30, L11 s31]

Batesian vs Müllerian mimicry

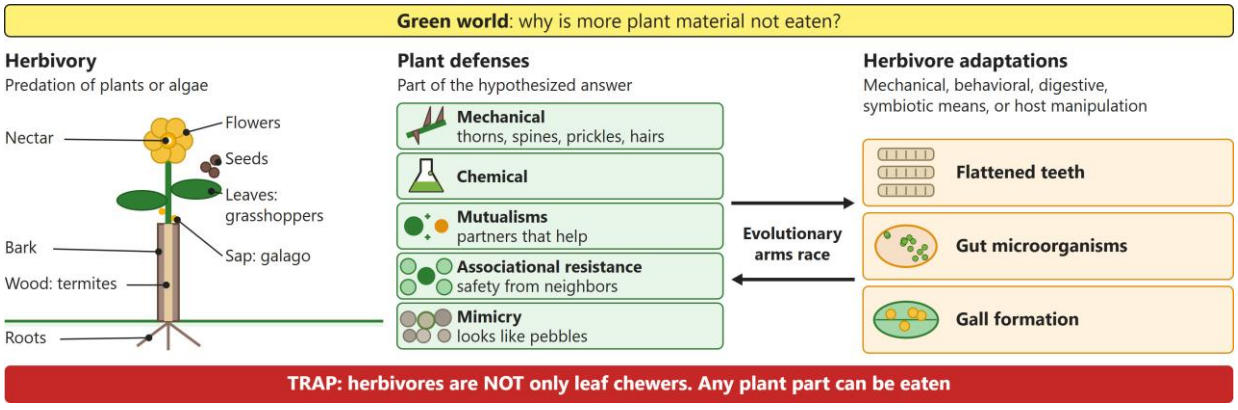
	Batesian mimicry	Müllerian mimicry
Who is involved	Unpalatable model, palatable mimic	Many noxious species that converge
Effect	Mimic gains protection	Reinforces the distasteful design
Example	Scarlet king snake and coral snake	Viceroy, queen, monarch butterflies

Table source: [L11 s27, L11 s29]

L11.6 Herbivory and plant defenses

⚠ **Do not mix up: Herbivores are NOT only leaf chewers: they also eat seeds, nectar, roots, wood, bark, and sap.** [L11 s33]

Herbivory *(eating plants)* is predation of plants or algae. [L11 s33]



Parts of a plant that are eaten, plant defenses and herbivore counters in an arms race [L11 s33]

On the figure: Nectar · Seeds · Bark · Sap · plant defenses · Evolutionary arms race · Flattened teeth · Gall formation

Herbivores feed on flowers, **seeds**, leaves, **nectar**, roots, wood, **bark**, and **sap**. [L11 s33]

Green world question: why is more plant material not eaten? [L11 s34]

Part of the hypothesized answer is **plant defenses**. [L11 s34]

Defenses: mechanical, chemical, **mutualisms** *(partners that help)*, **associational resistance** *(safety from neighbors)*, mimicry (pebble-like plants that blend with gravel). [L11 s34]

Mechanical defenses: thorn, cactus spines, stem prickles, a tiny hair, spiny holly leaves. [L11 s35]

Evolutionary arms race: plants and herbivores are often in one, like the Red-queen hypothesis. [L11 s36]

Herbivores adapt via mechanical, behavioral, digestive, or symbiotic means, or host manipulation. [L11 s36]

Examples: **flattened teeth** (mechanical), **gut microorganisms** (symbiotic), **gall formation** *(lump grown on a plant)* (host manipulation). [L11 s36]

The **goldenrod gall fly** makes a gall: host manipulation. [L11 s36]

Herbivore examples

Herbivore	What it eats
Leaf chewers like grasshoppers	Leaves
Termites	Wood
Galago	Sap

Table source: [L11 s33]

Lecture 12: Parasitism

L12.1 Parasitism vs predation and other interactions

⚠ **Do not mix up: Parasitism is NOT predation: parasites exploit hosts, while predators kill and eat prey.** [L12 s10]

Community ecology *(study of many species living together)* covers multiple species interactions. [L12 s05]

Community: what factors influence the number of species in an area? [L12 s05]

Community: the assemblage *(group)* of many populations living in the same place at the same time. [L12 s06]



Levels of ecological organization from individuals up to the biosphere [L12 s05]

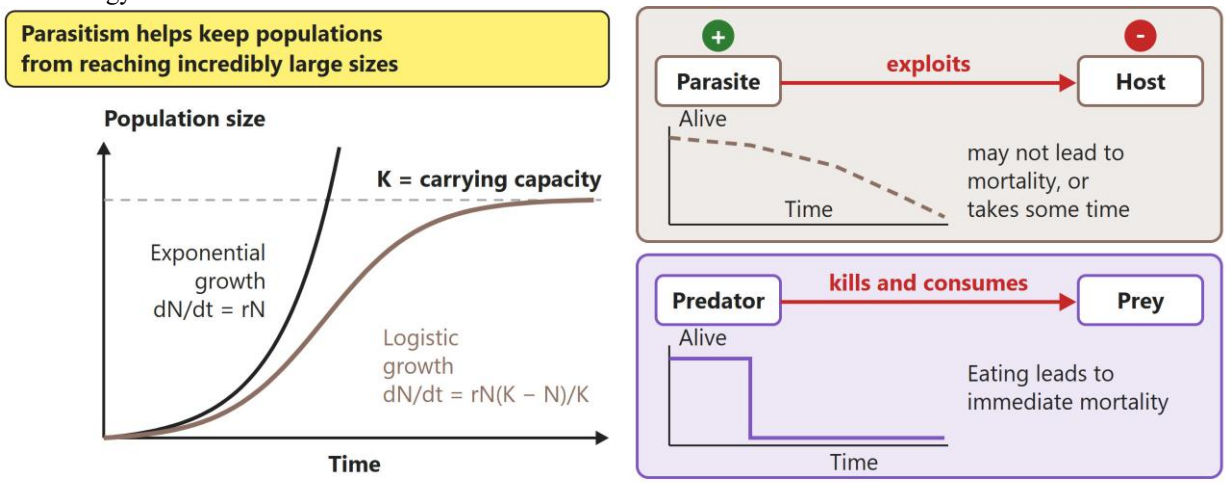
On the figure: Individuals · Population · Interaction · Community · Ecosystem · Landscape · Region · Biosphere

Level order: **individuals**, **population**, **interaction**, **community**, **ecosystem**, **landscape**, **region**, **biosphere**. [L12 s05, L12 s06]

Parasitism (+/-): the **parasite** gets nourishment from its **host**, which is harmed in the process. [L12 s08]

All pathogens *(disease-causing organisms)* fall into the parasitism category. [L12 s08]

Parasitism is one of the things that can prevent populations from reaching incredibly large sizes. [L12 s09]



Exponential and logistic growth, parasite exploiting a host, predator killing prey [L12 s09]

On the figure: Exponential growth · Logistic growth · parasite · host · predator · exploits

Exponential growth: dN/dt = rN. [L12 s09]
Logistic growth: dN/dt = rN(K - N)/K; it levels off at K. [L12 s09]
Parasitism: the **parasite exploits** the **host**, which is affected adversely. [L12 s10]
Predation: the **predator** kills and consumes the host. [L12 s10]
Predation leads to immediate mortality. [L12 s10]
Parasitism may not lead to mortality, or at least takes some time for mortality to occur. [L12 s10]
Microparasite examples are bacteria and viruses. [L12 s11]
Macroparasite examples are multicellular eukaryotes *(many-celled organisms with a nucleus)*. [L12 s11]
Parasitoid examples are often larva developing inside hosts. [L12 s11]
The table title says body size, growth rate, and host fatality **increase** from microparasite through predator. [L12 s11]
Careful: cells do not rise evenly; macroparasite fatality (usually mild) is below microparasite. [L12 s11]

Parasite to predator continuum

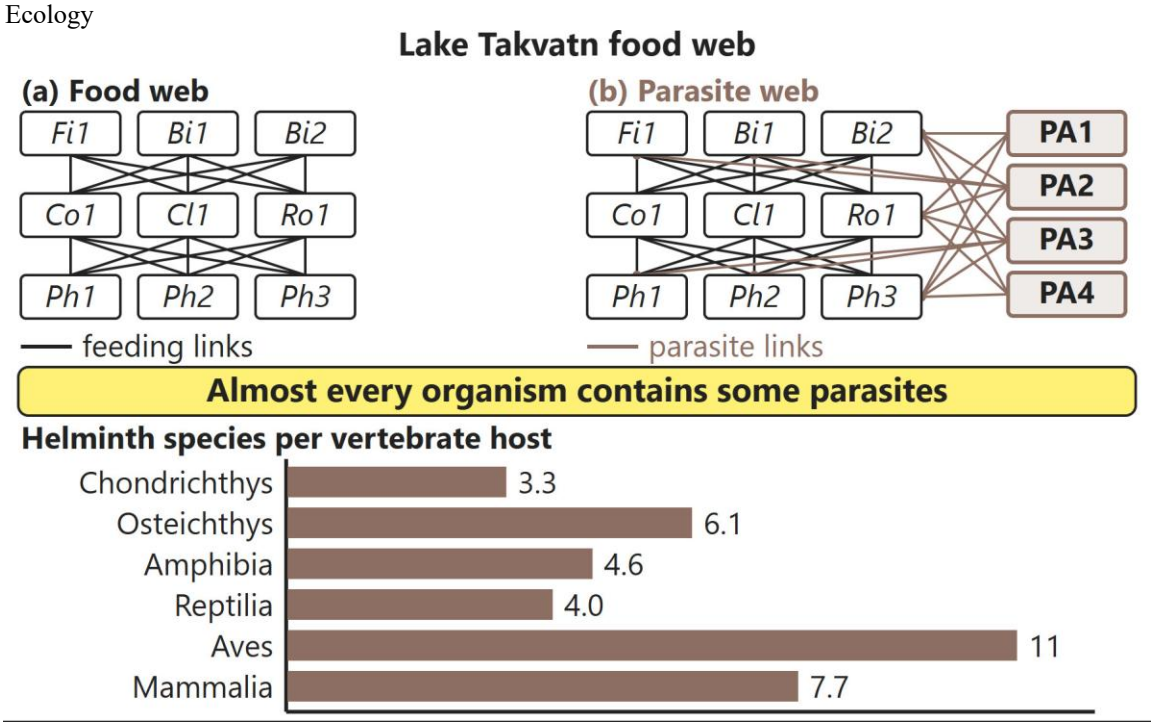
Trait	Microparasite	Macroparasite	Parasitoid	Predator
Body size	Microscopic	Smaller than host	Similar in size (wasp and moth)	Often larger than prey unless social hunter
Intrinsic rate of population growth	Rapid	Faster than hosts	Comparable to host	Comparable to but often slightly slower than that of prey
Number per host	One host usually supports populations of several different species	One host supports a few to many individuals of different species	One host usually supports one, but can support many	Each predator eats many prey individuals
Fatality to host	Mild to severe	Usually mild	Eventually fatal	Immediately fatal
Stability of the interaction with the host	Intermediate	High	Intermediate	Usually low
Ability to regulate host population	Moderate to high	Low	Moderate to high	High

Table source: [L12 s11]

L12.2 How common parasitism is

⚠ **Do not mix up: Parasitism is NOT a rare oddity: it is VERY common and includes pathogens.** [L12 s12]

Parasitism is VERY common, and this includes **pathogens** *(disease-causing organisms)*. [L12 s12]
Almost every organism contains some parasites. [L12 s12]
Most species are parasitized by many different species. [L12 s12]
Parasitism is often overlooked because of modern medicine and animal husbandry *(livestock care)* practices. [L12 s12]
Parasitism still takes a toll on humans and agriculture. [L12 s12]
Disease ecology *(study of disease in nature)* is a large and growing subfield within ecology. [L12 s12]



Lake food web without and with parasite links, and helminth species per vertebrate host [L12 s13]

On the figure: Lake Takvatn · Parasite web · Helminth · Chondrichthys · Aves

> **Parasite web**: a food web that includes the parasite links. [L12 s02]
>
> **Lake Takvatn pelagic food web** *(open-water food web of a lake)*: studied without, then with, parasite-related links. [L12 s03, L12 s13]
>
> Adding the parasite links makes the food web much denser. [L12 s03, L12 s13]
>
> **Helminth** *(parasitic worm)* species per vertebrate host differ by host group. [L12 s15]
>
> Birds (**Aves**) have the most helminth species per host; mammals are second. [L12 s15]
>
> **Chondrichthys** has the fewest helminth species per host. [L12 s15]

L12.3 Microparasites

⚠ Do not mix up: Rinderpest spread from cattle to many grazers, but zebra were NOT affected. [L12 s18]

Rinderpest virus: about **80%** mortality in cattle across Africa, late **1800**s. [L12 s18]

The virus spread from cattle to **buffalo**, **wildebeest**, giraffe, warthog, and other grazers. [L12 s18]

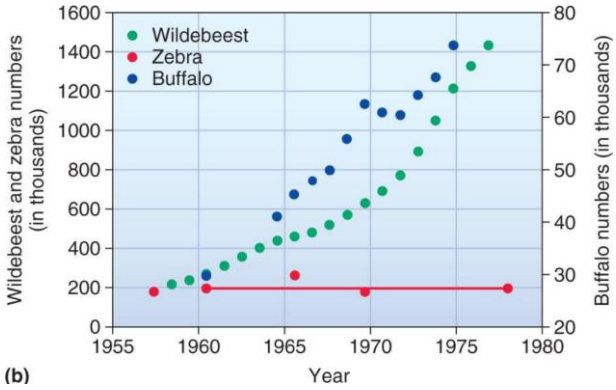
Cattle were vaccinated, and buffalo and wildebeest populations rebounded. [L12 s18]

Zebra was not affected by rinderpest. [L12 s18]

Plants are also attacked by viruses and bacteria, but fungal infections can be especially common. [L12 s19]

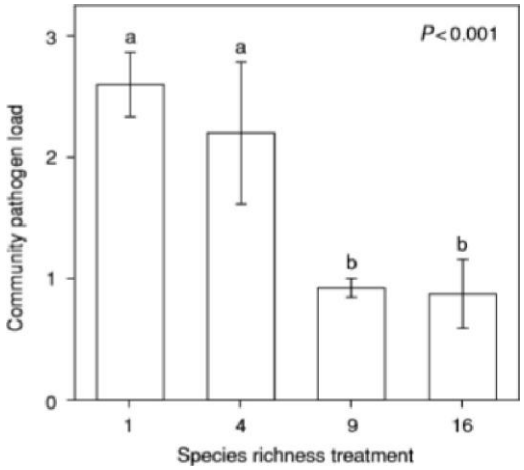
Infections are less common as the density of an individual species declines. [L12 s19]

Higher plant diversity means lower density per species, and less infection. [L12 s19]



Wildebeest and buffalo rise after vaccination while zebra stay flat [L12 s18]

On the figure: wildebeest · buffalo · Zebra



Pathogen load falls as plant species richness rises from 1 to 16 [L12 s19]

On the figure: pathogen load · species richness

Plant diversity and pathogen load: load is percent of leaf area infected. [L12 s19]

Pathogen load falls as plant **species richness** rises. [L12 s19]

Pathogen load is lower at **9** and **16** plant species than at **1** or **4.** [L12 s19]

Microparasite traits

Trait	Microparasite
Body size	Microscopic
Intrinsic rate of population growth	Rapid
Number per host	One host usually supports populations of several different species
Fatality to host	Mild to severe
Stability of the interaction with the host	Intermediate
Ability to regulate host population	Moderate to high

Table source: [L12 s17]

L12.4 Macroparasites and parasitoids

⚠ **Do not mix up: Endoparasites live INSIDE the host; ticks, leeches, and fleas are ectoparasites.** [L12 s21, L12 s24]

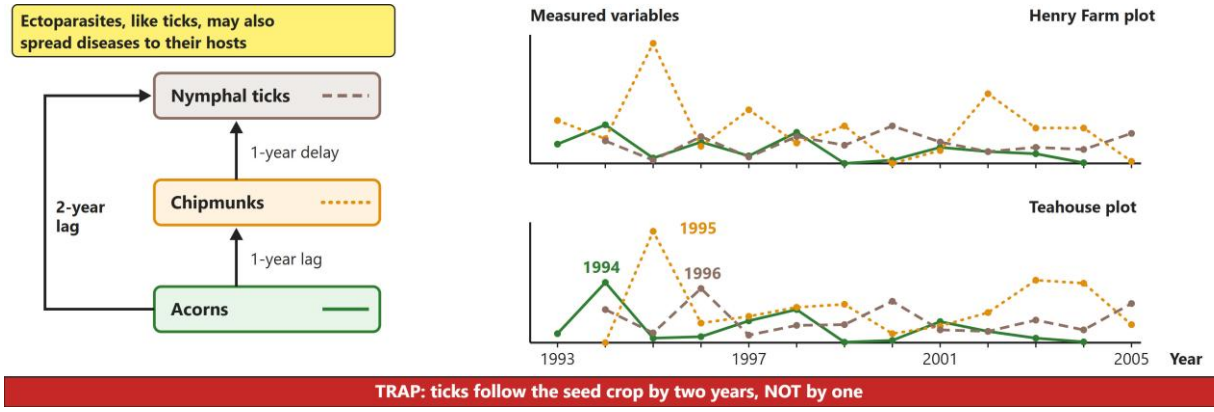
Macroparasite: one host supports a few to many individuals of different species. [L12 s20]

Ectoparasites *(parasites on the outside)* include ticks, leeches, and fleas. [L12 s21]

Ectoparasites often have more potential hosts (less specialized) than macroparasites that live inside the host. [L12 s21]

Ectoparasites and endoparasites are both kinds of macroparasite. [L12 s21, L12 s24]

Ectoparasites, like ticks, may also spread diseases to their hosts. [L12 s22]



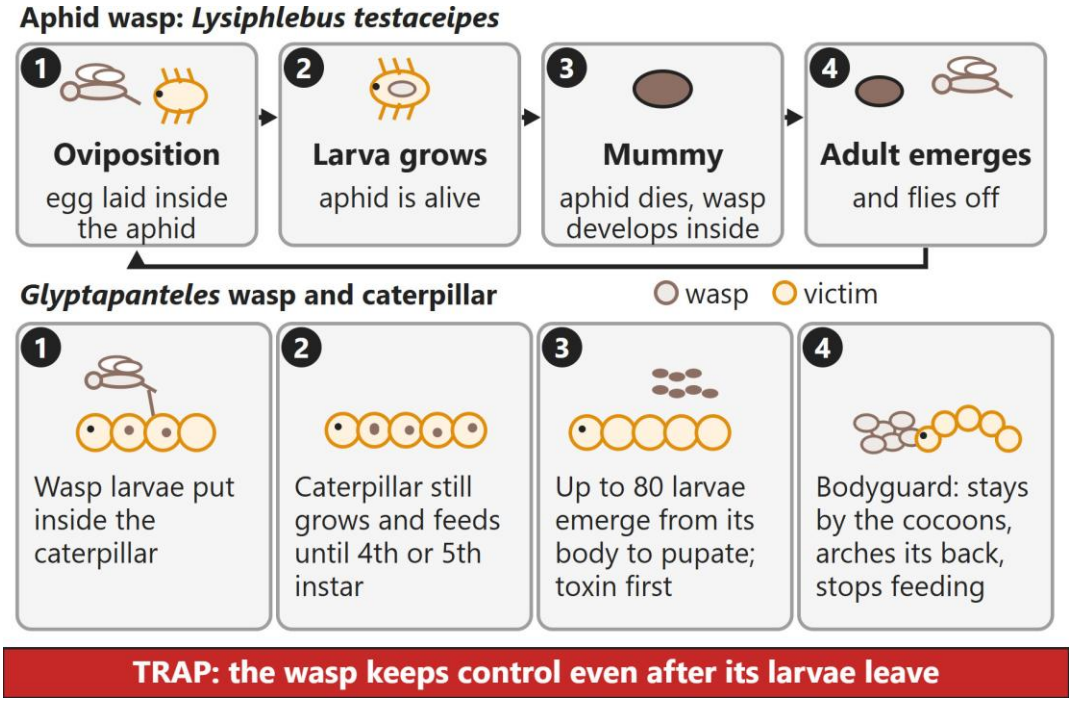
Acorns lead to chipmunks then nymphal ticks, with one and two year lags [L12 s23]

On the figure: Acorns · chipmunks · nymphal ticks · Ectoparasites

Acorns, chipmunks, and nymphal ticks (DON) were tracked at two plots. [L12 s23]

Macroparasites that live inside the host are **endoparasites** *(inside parasites)*. [L12 s24]

Endoparasites generally specialize on one or a few host species. [L12 s24]
Endoparasites often have **intermediate hosts** *(extra hosts in the life cycle)*. [L12 s24]
Endoparasite examples: roundworm, hookworm, fluke, tapeworm, nematode. [L12 s24, L12 s15]
Mystery of limb malformations in frogs *(deformed legs)*: frogs with abnormal limbs. [L12 s25]
Many endoparasites have complex life cycles with multiple hosts. [L12 s26]
Example hosts in one life cycle: a snail, a frog, and a heron. [L12 s26]
Parasitoid: similar in size to the host (example: wasp and moth). [L12 s27]
Parasitoid population growth is comparable to the host. [L12 s27]
One host usually supports one parasitoid, but can support many. [L12 s27]
Parasitoid effect on the host: eventually fatal. [L12 s27]
Stability of the interaction is intermediate; ability to regulate the host population is moderate to high. [L12 s27]



Aphid wasp life cycle and the Glyptapanteles wasp that makes its caterpillar a bodyguard [L12 s28]
On the figure: Aphid wasp · Lysiphlebus testaceipes · Glyptapanteles · instar · bodyguard

Aphid wasp life cycle (**Lysiphlebus testaceipes**) forms a loop. [L12 s28]
Glyptapanteles wasps control their caterpillar prey. [L12 s29]
Wasp larvae are deposited in the caterpillar, which keeps growing and feeding normally. [L12 s29]
At the **4**th or **5**th **instar** *(growth stage)*, up to **80** fully grown larvae emerge to pupate. [L12 s29]
Just before emerging, the larvae produce a toxin. [L12 s29]
The toxin makes the caterpillar act as a **bodyguard** until the larvae **pupate** *(turn into pupae)*. [L12 s29]
The caterpillar sits near the cocoons, arches its back, and stops moving and feeding. [L12 s29]
It sometimes spins silk over the pupae and thrashes violently when disturbed. [L12 s29]
A parasite no longer in the host induces the behavior. [L12 s29]

Macroparasite traits

Trait	Macroparasite
Body size	Smaller than host
Intrinsic rate of population growth	Faster than hosts
Number per host	One host supports a few to many individuals of different species
Fatality to host	Usually mild
Stability of the interaction with the host	High
Ability to regulate host population	Low

Table source: [L12 s20]

Acorn to chipmunk to tick chain

Link	Organism	Lag
1	Acorns	start
2	Chipmunks	**1**-year lag after acorns
3	Nymphal ticks	**1**-year lag after chipmunks
Acorns to nymphal ticks	Nymphal ticks, two steps after acorns	**2**-year lag

Table source: [L12 s23]

Endoparasite life cycle with multiple hosts

Step	Stage
1	Eggs
2	Snail
3	Swimming larvae
4	Tadpole
5	Young frog
6	Adult frog
7	Heron holding a frog, then eggs again

Table source: [L12 s26]

Aphid parasitoid life cycle

Step	Label
1	Oviposition *(egg laying)*: adult wasp lays an egg in the aphid (*(greenbug)* on later steps)
2	Growth of parasite larva; greenbug alive
3	Greenbug dies; parasite pupates; result is mummy
4	Adult parasite emerges
5	Adult parasite (winged adult, loop closes at oviposition)

Table source: [L12 s28]

L12.5 Parasitism and global change

⚠ Do not mix up: More warming is NOT always better for pathogens: it can exceed their upper thermal tolerance. [L12 s31]

Predicted pathogen responses to climate change: three patterns. [L12 s31]

Effect of warming depends on the metric of disease risk and the temperature curve shape. [L12 s31]

It also depends on projected temperature **increase**, optimal temperature value, and baseline temperature. [L12 s31]

Vectorial capacity or R0 *(ability of disease carriers to spread disease)* rises to an optimum temperature, then falls. [L12 s31]

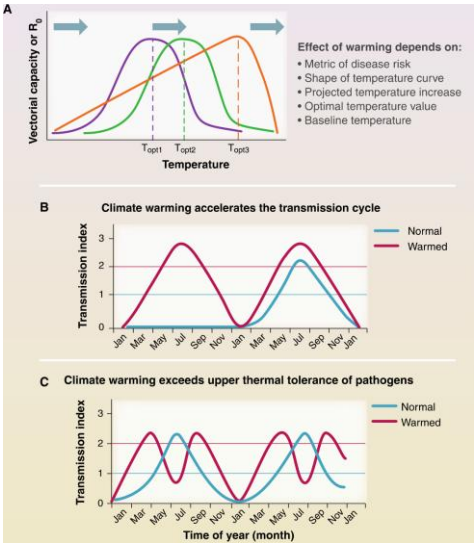
Pathogens differ in optimal temperature (**Topt1**, Topt2, Topt3), so warming affects them differently. [L12 s31]

Climate warming accelerates the transmission cycle: the warmed transmission rises earlier and higher. [L12 s31]

Climate warming can **exceed the upper thermal tolerance** of pathogens. [L12 s31]

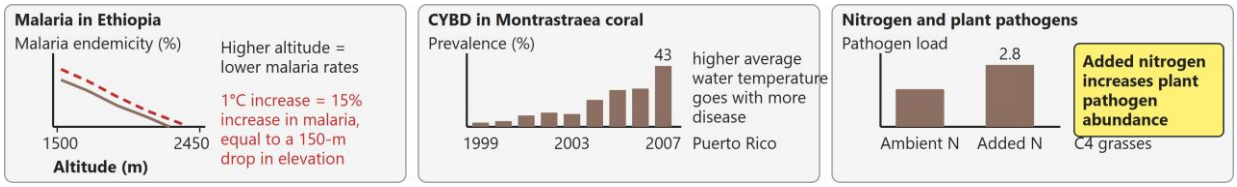
Past that tolerance, warmed transmission peaks early, dips in mid-summer, then rises again. [L12 s31]

Many parasites do better under warmer temperatures. [L12 s32, L12 s33]



Vectorial capacity peaks at an optimum temperature; warming speeds or overshoots transmission [L12 s31]

On the figure: vectorial capacity · Topt1 · climate warming accelerates the transmission cycle · upper thermal tolerance



Malaria by altitude, coral disease by year, and added nitrogen raising pathogen load [L12 s32]

On the figure: Malaria in Ethiopia · CYBD · Montrastraea · Nitrogen and plant pathogens · Ambient N

Malaria in Ethiopia: higher altitude means lower malaria rates. [L12 s32]

Malaria endemicity *(how common malaria is)* is shown as percent spleen enlargement. [L12 s32]

1 degree C warmer = **15%** more malaria, equal to a **150**-m drop in elevation. [L12 s32]

Coral disease CYBD *(Caribbean yellow banding disease)*: prevalence rose from **1999** to **2007** in **Montrastraea** coral off Puerto Rico. [L12 s33]

Higher average water temperature goes with higher mean prevalence of the disease. [L12 s33]

Increased nutrient availability can also **increase** pathogen abundance. [L12 s34]

Nitrogen and plant pathogens: added nitrogen **increases** plant pathogen abundance. [L12 s34]

C4 grass pathogen load was higher with added N than with **ambient N**. [L12 s34]

Increased nutrients can also **increase** pathogen abundance in the ocean and freshwater. [L12 s34]

Eutrophication *(nutrient enrichment of water)* affected amphibian infections by Ribeiroia trematodes *(parasitic flatworms)*. [L12 s35]

More parasite input means more infection: no input stays at **0,** high input rises most. [L12 s35]

Review question 1: two ways predators differ from parasites. [L12 s36]

Answer **1**: predation leads to immediate mortality; parasitism may not kill the host, or takes time. [L12 s36, L12 s10]

Answer **1,** second way: predators are often larger than prey; macroparasites are smaller than the host. [L12 s36, L12 s11]

Answer **1,** third way: each predator eats many prey. [L12 s36, L12 s11]

Answer **1,** fourth way: one host supports a few to many macroparasites. [L12 s36, L12 s11]

Answer **1,** fifth way: predation is immediately fatal; macroparasites are usually mild. [L12 s11]

Answer **1,** sixth way: predator stability is usually low; macroparasite stability is high. [L12 s11]

Review question 2: amensalism involves a (+/-/0) and a (+/-/0) interaction. [L12 s36]

Answer **2**: amensalism is - for one species and **0** for the other. [L10 s06]

Review question 3: how parasite population growth is affected by host population growth. [L12 s36]

Answer **3**: infections are less common as host density declines. [L12 s36, L12 s19]

Answer **3,** lag example: nymphal ticks follow chipmunks by a **1**-year lag. [L12 s36, L12 s23]

Review question 4: apply the red-queen hypothesis to host-parasite interactions. [L12 s36]

Red queen hypothesis: it takes all the running you can do to stay in place. [L11 s20]

Cheetah and gazelle: both became faster, and gains in one were generally matched by the other. [L11 s21]

Plants and herbivores are also in an evolutionary arms race, much like the red queen hypothesis. [L11 s36]

Answer **4**: like cheetah and gazelle, host gains would be matched by parasite gains. [L12 s36, L11 s21]

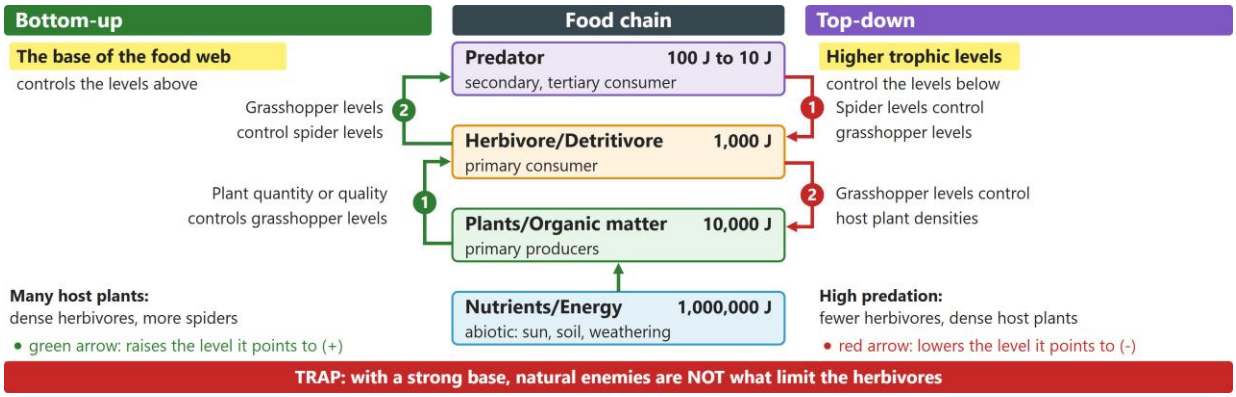
Lecture 13: Population Regulation (Bottom-up and Top-down)

L13.1 Trophic levels and the bottom-up vs top-down models

⚠ **Do not mix up: Bottom-up is NOT predator control: the food web base limits higher levels.** [L13 s05]

Bottom-up model: predicts that food or prey resources regulate herbivore and predator abundances. [L13 s03]

Top-down model: predicts that natural enemies are the key constraint on prey abundances. [L13 s03]



Bottom-up and top-down control along one food chain from nutrients to predators [L13 s05]

On the figure: Bottom-up · Top-down · Predator · Herbivore/Detritivore · Plants/Organic matter · Nutrients/Energy · grasshopper

Trophic levels *(steps in a food chain)*: **predator**, **herbivore/detritivore**, **plants/organic matter**, **nutrients/energy**. [L13 s04]

Predator: a secondary or tertiary consumer. [L13 s04]

Herbivore/Detritivore *(plant eater or dead matter eater)*: the primary consumer. [L13 s04]

Plants/Organic matter: primary producers, also called basal resources *(base food supply)*. [L13 s04]

Nutrients/Energy: usually from abiotic *(nonliving)* sources like the sun, soil, chemical weathering. [L13 s04]

Energy drops at each trophic level going up the pyramid. [L13 s04]

Bottom-up: the base of the food web controls the populations of higher trophic levels. [L13 s05]

Top-down: higher trophic levels control the trophic levels below. [L13 s06]

Bottom-up: host plant quantity or quality limits herbivore density, which limits predator abundance. [L13 s05]

Top-down: predators limit herbivores, and herbivores limit plant densities. [L13 s06]

Both ideas use host plant, **grasshopper** (herbivore) and spider (predator). [L13 s05, L13 s06]

Increased plant quantity or quality benefits herbivores and, in turn, predators. [L13 s05]

Predation of herbivores **increases** plant densities. [L13 s06]

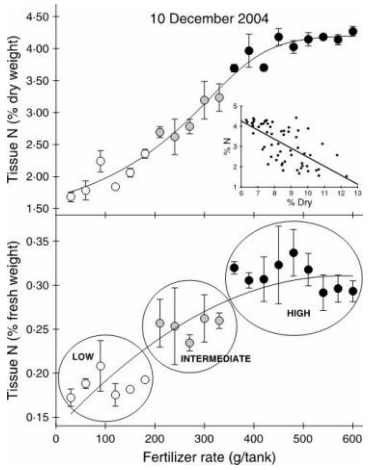
Bottom-up vs top-down (grasshopper, spider, plant)

Idea	Bottom-up	Top-down
Control comes from	Base of the food web	Higher trophic levels
Step 1 of control	Plants control grasshoppers	Spiders control grasshoppers
Step 2 of control	Grasshoppers control spiders	Grasshoppers control host plants
A high level gives	Many host plants: dense herbivores, more predators	High predation: fewer herbivores, dense host plants

Table source: [L13 s05, L13 s06]

L13.2 Evidence for bottom-up control: water hyacinth and weevils

⚠ **Do not mix up: Fertilized water hyacinth shows bottom-up control: food quality limits weevils, not predators.** [L13 s09, L13 s10]



Plant tissue nitrogen rises as the fertilizer rate rises [L13 s09]

On the figure: fertilizer · high

Water hyacinth and weevils (Neochetina bruchi and Neochetina eichhoriniae): evidence for bottom-up control of herbivore populations. [L13 s08]

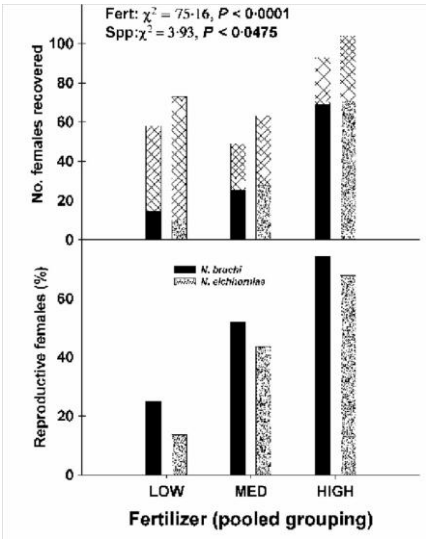
Water hyacinth grown with **fertilizer** has higher nitrogen in its tissues. [L13 s09]

Higher abundances of female weevils were found in **high** fertilizer treatments. [L13 s10]

And a greater percent of those **females** were **reproductive**. [L13 s10]

The fertilizer was N, P, K *(nitrogen, phosphorus, potassium)*. [L13 s10]

1. Fertilizer is added to the water hyacinth. [L13 s09, L13 s10]
2. Nitrogen in the plant tissue rises. [L13 s09]
3. More female weevils are found, and more of them are reproductive. [L13 s10]

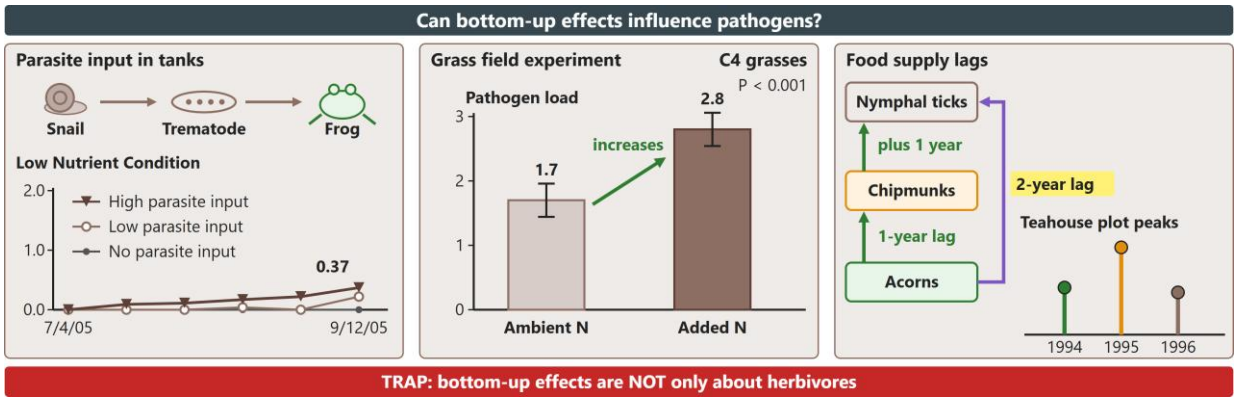


More female weevils, and a greater percent reproductive, at high fertilizer [L13 s10]

On the figure: females · reproductive · fertilizer · high

L13.3 Bottom-up effects on pathogens

⚠ **Do not mix up: Bottom-up is NOT only about herbivores: more nutrients also raised pathogen load.** [L13 s14]



Nutrients raise parasite infection in tanks, pathogen load on grasses, and tick lags [L13 s15]

On the figure: parasite input · C4 grasses · pathogen load · Acorns · Chipmunks · ticks

Question: can bottom-up effects influence pathogens *(disease-causing organisms)*? [L13 s11]

More **parasite input** in the tanks meant more infection. [L13 s12, L13 s13]

Eutrophication *(nutrient enrichment)* affected amphibian infections by Ribeiroia trematodes in the same tank experiment. [L12 s35]

C4 grasses *(one type of grass)*: added nitrogen raised **pathogen load**. [L13 s15]

Acorns, chipmunks and ticks: the arrows between them carry lags. [L13 s14]

Acorn, chipmunk, tick lags

Link	Lag
Acorns to chipmunks	1 year
Chipmunks to nymphal ticks	1 year
Acorns to ticks overall	2 years

Table source: [L13 s15]

L13.4 Bottom-up control in stream food webs and trophic dead ends

⚠ **Do not mix up: Bottom-up boosts do NOT always reach predators: dead end taxa stop the gain.** [L13 s19]

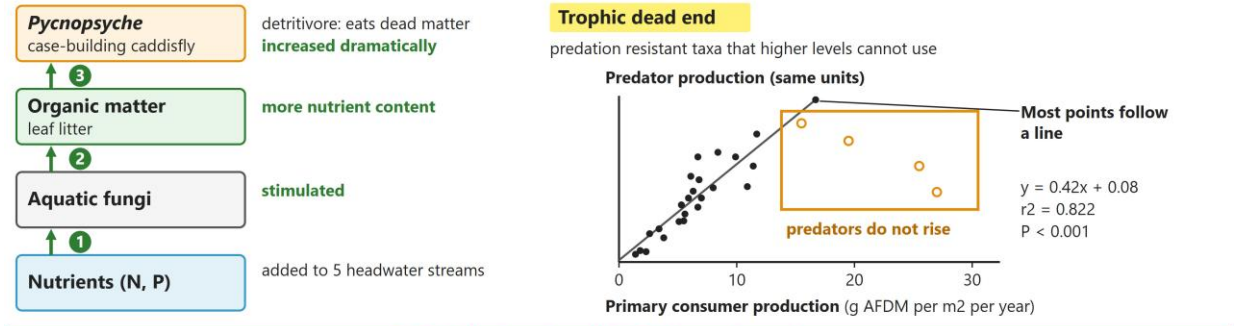
Stream experiment: nutrients (N, P) were added to **5** headwater *(streams near their source)*. [L13 s16]

Effects were measured on organic matter (leaf litter) and aquatic insects. [L13 s16]

Nutrients stimulated aquatic fungi from the bottom up. [L13 s17]

Organic matter had **increased** nutrient content. [L13 s17]

Populations of aquatic detritivores **increased**. [L13 s17]



Nutrients lift fungi, leaf litter and caddisflies, but predators do not rise [L13 s17]

On the figure: Pycnopsyche · Aquatic fungi · Organic matter · leaf litter · Trophic dead end · Nutrients (N, P)

1. Nutrients (N, P). **2.** Aquatic fungi. **3.** Leaf organic matter. **4.** Detritivore caddisfly. [L13 s17, L13 s18]

An important detritivore here is **Pycnopsyche** spp.. [L13 s18, L13 s19]

It is a **case-building caddisfly** *(aquatic insect with a protective case)* that eats dead organic matter. [L13 s18]

These populations **increased** dramatically with nutrient addition. [L13 s18]

Trophic dead end: predation resistant taxa *(kinds of organisms)* in a level that higher levels cannot use. [L13 s19]

Dead end taxa raise primary consumers but not predators. [L13 s19]

L13.5 Top-down control: lake, sea otter and the average effects

⚠ **Do not mix up: Fertilizer does NOT significantly raise herbivores on average: predator effects are stronger.** [L13 s24]

Experimental lake: largemouth bass were removed from one side of the lake. [L13 s21]

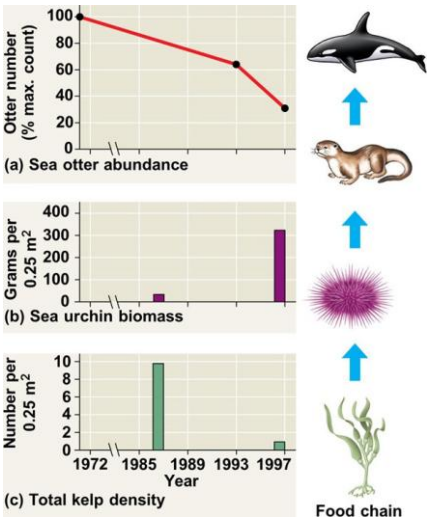
Question: which side of the lake had the bass removed? [L13 s21]

Answer: the left chain has no bass; the right chain has bass on top. [L13 s22]

Marine example: increasing predation from killer whales **decreased** otters, **increased** sea urchins, **decreased** **kelp**. [L13 s23]

Memory aid: enemy of my enemy is my friend. [L13 s23]

Average strength of effects: average results across **23** different studies. [L13 s24]



Otters fall, urchins rise and kelp falls over time [L13 s23]

On the figure: otter · urchin · kelp

Fertilizer comparison: effects of fertilizers in systems with and without predators. [L13 s24]

Predator removal comparison: effects of predator removal with and without fertilizer. [L13 s24]

Red dots are effects on **plants**; blue dots are effects on **herbivores**. [L13 s24]

Effects of predator removal (**top-down**) are stronger on herbivores than fertilizer effects (**bottom-up**). [L13 s24]

Adding predators **decreases** herbivores and **increases** plants. [L13 s24]

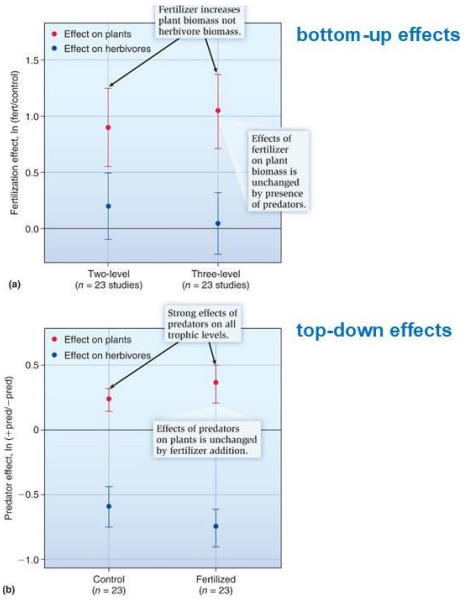
Adding fertilizer does not significantly **increase** herbivores, ON AVERAGE. [L13 s24]

Fertilizer **increases** plant biomass, not herbivore biomass. [L13 s24]

Fertilizer effect on plant biomass is unchanged by the presence of predators. [L13 s24]

Predators have strong effects on all trophic levels. [L13 s24]

Effects of predators on plants are unchanged by fertilizer addition. [L13 s24]



Average effects on plants and herbivores: fertilizer above, predators below [L13 s24]

On the figure: bottom-up · top-down · herbivores · plants

Killer whale, otter, urchin, kelp

Level	Change
Sea otter	Decrease
Sea urchin	Increase
Kelp	Decrease

Table source: [L13 s23]

L13.6 Trophic cascades

⚠ **Do not mix up: A trophic cascade is NOT a direct effect: predators help plants indirectly.** [L13 s26]

Trophic cascade: top-down effects cascade *(ripple)* to lower trophic levels. [L13 s25]

Predators typically reduce prey abundance, which benefits the next trophic level down. [L13 s25, L13 s26]

More simply: consumer effects on resources at the food web base (basal resources). [L13 s25]

A cascade is **indirect control** of lower trophic levels by top-down effects. [L13 s26]

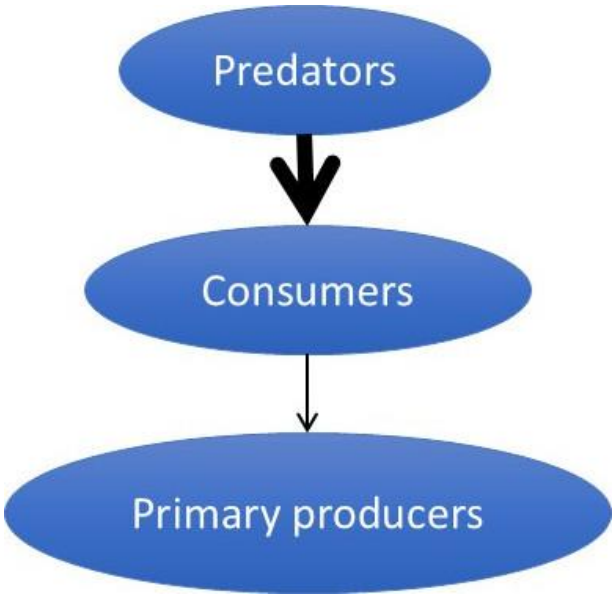
> **1.** Predators reduce **consumers**. [L13 s26]
>
> **2.** With fewer consumers, plants **increase** in biomass or abundance. [L13 s26]

Question: explain top-down effects with and without a secondary consumer (top predator). [L13 s27]

Rule: a predator lowers its prey and benefits the level below. [L13 s25, L13 s26]

Applying the rule: with bass, small fish fall, zooplankton rise, phytoplankton fall; without bass, the reverse. [L13 s26, L13 s28, L13 s29]

Only the presence of bass differs; every change comes from the rule. [L13 s28]



Predators reduce consumers, which lets primary producers increase [L13 s26]

On the figure: **Predators** · **Consumers**

The rule applied to the two lake chains

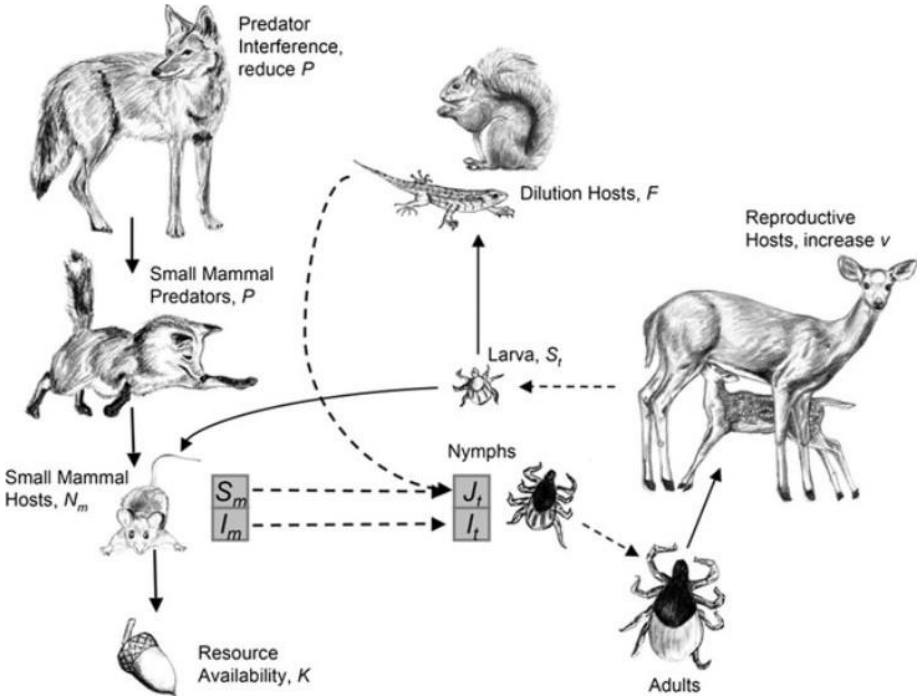
Level	No bass (left chain)	Bass (right chain)
Bass	Absent	Present
Small fish (minnows)	Top predator	Reduced by bass
Zooplankton (water fleas)	Reduced by small fish	Benefits: **increases**
Phytoplankton (algae)	Benefits: **increases**	Reduced by more zooplankton

Table source: [L13 s25, L13 s26, L13 s28, L13 s29]

L13.7 Trophic downgrading and zoonotic disease (Lyme)

⚠ **Do not mix up: Trophic downgrading means top-down interactions are becoming LESS common, not more.** [L13 s29]

> **Trophic downgrading** of earth: top-down interactions are becoming less common. [L13 s29]
>
> Loss of key top-down interactions completely changes ecosystem structure. [L13 s29]
>
> **In water**, examples: sea otter and kelp, Pisaster and mussels, bass-zooplankton-phytoplankton, sharks. [L13 s29]
>
> **On land**, examples: arctic fox and seabirds, jaguar and rainforest herbivores, wolves and elk. [L13 s30]
>
> Also on land: woody vegetation, wildebeest and rinderpest. [L13 s30]
>
> **On land too**: the same loss of top-down control also occurs on land. [L13 s30]



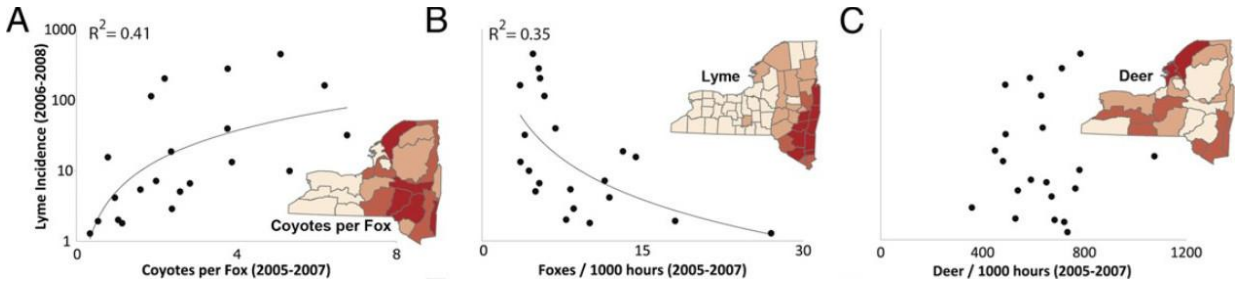
Lyme disease chain from coyote to fox, mouse and acorn, with tick stages [L13 s31]

On the figure: larva · nymphs · adults

Top-down control and zoonotic disease *(animal disease that infects people)*: the Lyme disease example. [L13 s31]

Restructuring of predator communities across the globe may have unintended consequences for human disease risk. [L13 s31]

The tick stages on the diagram are **larva**, **nymphs** and **adults**. [L13 s31]



Lyme incidence rises with coyotes per fox, falls with foxes, no trend with deer [L13 s32]

On the figure: coyotes per fox · foxes · deer · Lyme

Lyme incidence rises with more **coyotes per fox**. [L13 s32]

Lyme incidence falls with more **foxes**. [L13 s32]

Deer show no clear fitted trend with Lyme incidence. [L13 s32]

The Lyme disease chain has four levels: coyote, fox, mouse, acorn. [L13 s31, L13 s33]

Remove a top predator and its prey rise while the level below falls. [L13 s34, L13 s24, L13 s26]

Example: more killer whale predation, fewer otters, more urchins, less kelp. [L13 s34, L13 s23]

Top-down has the stronger effect on herbivores than bottom-up fertilizer, on average. [L13 s34, L13 s24]

Predator versus parasite: predation means immediate mortality; parasitism may not kill, or takes time. [L13 s34, L12 s10]

Predator versus parasite: the parasite exploits the host; the predator kills and consumes it. [L13 s34, L12 s10]

Predator versus parasite: predators are often larger than prey; macroparasites are smaller than the host. [L13 s34, L12 s11]

Predator versus parasite: each predator eats many prey; one host supports a few to many macroparasites. [L13 s34, L12 s11]

Frog limb malformations: the claim that **increased** pond contaminants cause them is false. [L13 s34, L12 s25, L12 s35]

The malformed frog is shown with **Ribeiroia** trematode infection. [L13 s34, L12 s25, L12 s35]

Eutrophication *(nutrient enrichment)* affected these Ribeiroia infections; contaminants are not named as the cause. [L12 s35]

Lyme disease chain: each level and its label

Label on the diagram	Organism or food
Predator interference, reduce P	Coyote
Small Mammal Predators, P	Fox
Small Mammal Hosts, Nm	Mouse
Resource Availability, K	Acorn
Dilution Hosts, F	Squirrel and lizard
Reproductive Hosts, increase v	Deer and fawn

Table source: [L13 s31]

Lecture 14: Community Ecology: Species Diversity

L14.1 Defining communities: organismic vs individualistic models

⚠ **Do not mix up: Individualistic is NOT sharp boundaries: species co-occur only because they share physiological needs.** [L14 s08, L14 s09]

Defining a community: walk up or down a mountain and the environment and communities change. [L14 s06]

Question: environment or competition, which matters more for predicting shifts in species composition? [L14 s06]

Organismic model: a community is equivalent to a **superorganism** *(one big living unit)*. [L14 s07]

Like an animal body, it is more than just a collection of organs. [L14 s07]

Organismic model (Clements): a community was predictable, with distinct associations of species. [L14 s08]

Organismic model: separate communities were separated by **sharp boundaries**. [L14 s08]

Individualistic model: species occur together because of similar physiological *(body function)* requirements and tolerances. [L14 s09]

Hypothesis **1** is the organismic model; hypothesis **4** is the individualistic model. [L14 s07, L14 s09]

Organismic vs individualistic model

Idea	Organismic model	Individualistic model
Community is	A superorganism	Species with similar physiological requirements and tolerances
Boundaries	Sharp boundaries between communities	No sharp boundaries
Species groups	Distinct, predictable associations	Species do not group together
Matches hypothesis	Hypothesis **1**	Hypothesis **4**
Whittaker's mountain results	Not supported	Supported

Table source: [L14 s07, L14 s08, L14 s09, L14 s11, L14 s12]

L14.2 Whittaker gradient test: what sets species composition

⚠ Do not mix up: Whittaker supported hypothesis 4, NOT the organismic model: no sharp boundaries, no defined groups. [L14 s12]

Environmental gradient *(steady change in conditions across space)*: such as moisture on an uninterrupted mountain slope. [L14 s10]

Whittaker proposed four hypotheses to explain plant distribution patterns on the gradient. [L14 s10]

In the four hypotheses, each curve is one species. [L14 s11]

Each curve shows that species population size along the environmental gradient. [L14 s11]

Whittaker tested the four hypotheses on vegetation of mountain ranges in the western U.S. [L14 s12]

Result: **competition** does not produce **sharp boundaries** between species. [L14 s12]

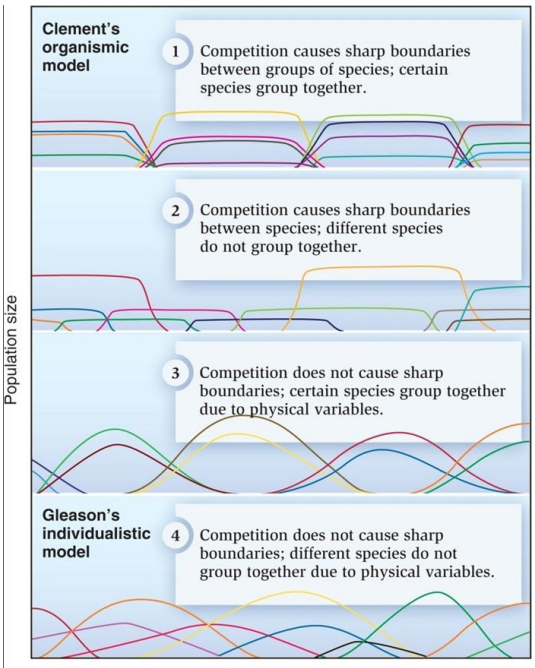
Adaptation to physical variables does not result in defined groups of species. [L14 s12]

Species interactions strongly affect where some species are able to exist. [L14 s12]

But adaptations of individual species to the environment matter more for most species' distributions. [L14 s12]

Answer to the mountain question: environment matters more than competition for most species. [L14 s06, L14 s12]

Composition at any gradient point is largely set by temperature, water availability, light, pH. [L14 s13]



Four hypotheses: one curve per species along an environmental gradient [L14 s11]

On the figure: environmental gradient · competition · sharp boundaries

Four hypotheses along a gradient

Hypothesis	Competition causes sharp boundaries?	Species group together?	Model
1	Yes, between groups of species	Yes, certain species group together	Organismic model
2	Yes, between species	No, different species do not group	Not named
3	No	Yes, certain species group, due to physical variables	Not named
4	No	No, different species do not group, due to physical variables	Individualistic model (supported)

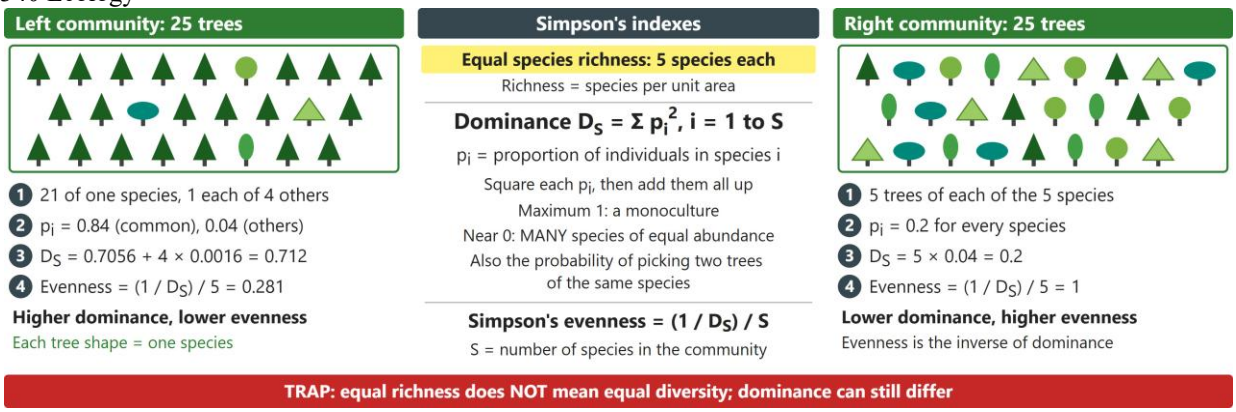
Table source: [L14 s11, L14 s12]

L14.3 Species richness and Simpson dominance

⚠ Do not mix up: Equal richness does NOT mean equal diversity: both have 5 species but dominance differs. [L14 s17, L14 s18]

Question: which of two tree communities contains greater species diversity? [L14 s15]

Two ways to measure one location: **1**) species richness; **2**) species dominance (or evenness). [L14 s16]



Two 25 tree communities with equal richness but different dominance and evenness [L14 s20]

On the figure: left community · species richness · dominance · monoculture · evenness

Species richness: the number of species per unit area (such as species per hectare). [L14 s17]

Both tree communities contain five species, so they are equal in species richness. [L14 s17]

Species dominance: higher when one species is present in greater proportion than others. [L14 s18]

Evenness is the inverse of dominance. [L14 s18]

The **left community** has higher species dominance than the right. [L14 s18]

Simpson's dominance is one of the most common of many dominance methods. [L14 s18]

Simpson's dominance index: Ds = sum of pi squared, from species **1** through species S. [L14 s19]

pi *(share of all individuals)*: the proportion of individuals in the ith species. [L14 s19]

Square each species' proportion, then sum the values for all species. [L14 s19]

Range: maximum **1** in a **monoculture** *(only one species)*; minimum near **0,** MANY species of equal abundance. [L14 s19]

Probability meaning: the chance of picking two trees of the same species. [L14 s21]

Community **1**: p(species **1** AND species **1**) = **0.84** x **0.84** = **0.7056.** [L14 s21]

Community **2**: p(species **1** AND species **1**) = **0.2** x **0.2** = **0.04.** [L14 s21]

The community with **21** trees of one species has lower species evenness. [L14 s21]

The community with **5** trees of each species has higher evenness. [L14 s21]

Simpson's dominance worked example

Step	Left community	Right community
1. Count trees	**21** trees of the most common species, **1** tree each of **4** others (25 trees)	**5** of each of the **5 species** (25 trees)
2. Proportion pi	**0.84** (most common), **0.04** (each other)	**0.2** for each species
3. Square each pi	**0.84** x **0.84** = **0.7056**; **0.04** x **0.04** = **0.0016**	**0.2** x **0.2** = **0.04**
4. Sum = Ds	**0.7056** + **0.0016** + **0.0016** + **0.0016** + **0.0016** = **0.712**	**0.04** + **0.04** + **0.04** + **0.04** + **0.04** = **0.2**

Table source: [L14 s20]

L14.4 Simpson evenness and rank abundance diagrams

⚠ **Do not mix up: Evenness is NOT Ds/S but (1/Ds)/S; higher dominance means LOWER evenness.** [L14 s22]

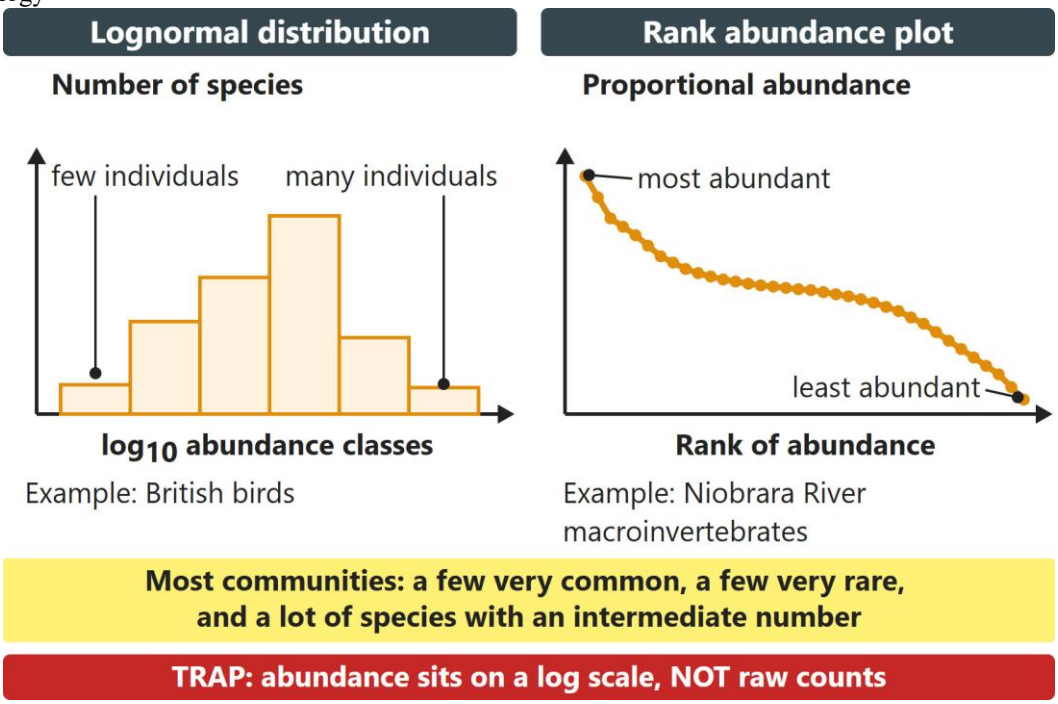
Simpson's evenness = (1 / Ds) / S. [L14 s22]

S: the number of species in the community. [L14 s22]

Evenness measures give a higher value when species are present at more equal proportions. [L14 s22]

Simpson's evenness is the best measure to use when examining evenness. [L14 s22]

1. Find Ds. **2.** Divide **1** by Ds. **3.** Divide that by S. [L14 s22]



Lognormal bell of abundance classes beside the rank abundance curve [L14 s25]

On the figure: Lognormal distribution · log10 abundance classes · number of species · rank of abundance · proportional abundance · British birds · Niobrara River macroinvertebrates

Rank abundance diagram: **proportional abundance** of species, on a log scale, against **rank of abundance**. [L14 s23]
It gives a more complete picture of a community, another way to describe richness and evenness. [L14 s23]
It visually describes the distribution of individuals among species in communities. [L14 s23]
Species are ranked in order from the most abundant to the least abundant. [L14 s25]
Lognormal distribution *(bell shape on a log scale)*: species grouped into **log10 abundance classes** form a normal distribution. [L14 s24, L14 s25]
British birds example: **number of species** plotted against log10 abundance classes. [L14 s24]
Niobrara River macroinvertebrates *(small animals without backbones)*: an example of a rank abundance plot. [L14 s26]
It shows a few very common species, a few very rare, many intermediate. [L14 s24, L14 s26, L14 s27]

Simpson's evenness worked example

Community	Ds	S	Evenness = (1 / Ds) / S
Left (21 + 1 + 1 + 1 + 1)	**0.712**	**5**	(1 / **0.712**) / **5** = **0.281**
Right (5 of each)	**0.2**	**5**	(1 / **0.2**) / **5** = **1**

Table source: [L14 s20, L14 s22]

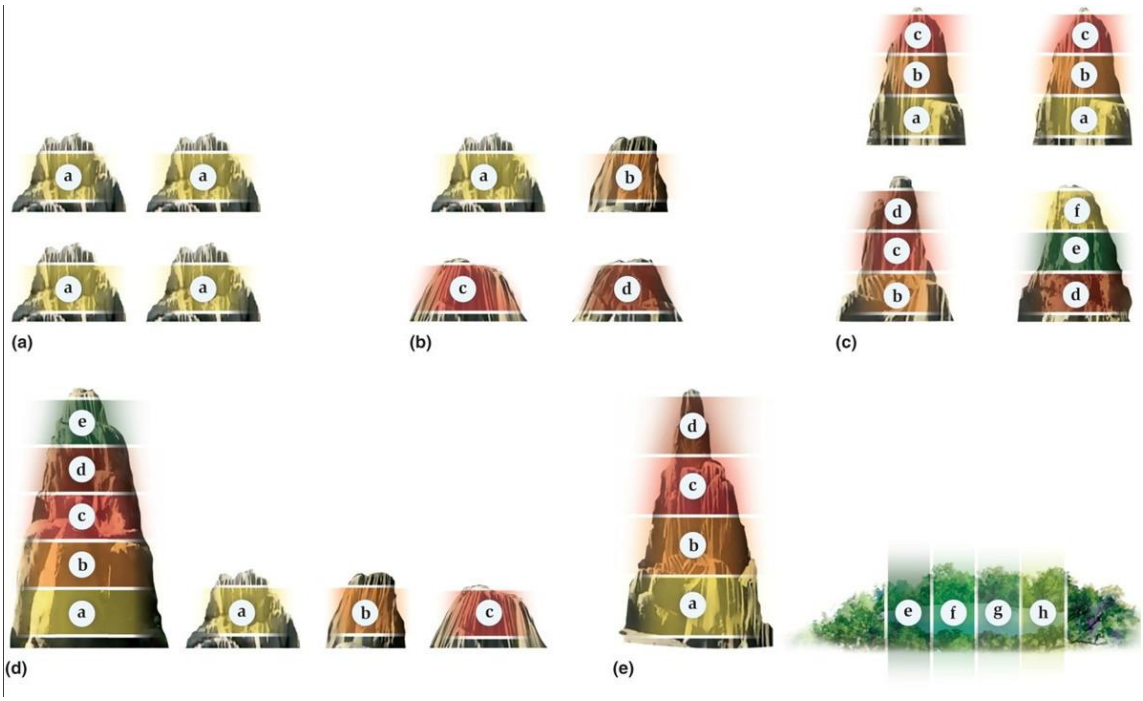
Rank abundance: main conclusion

Main conclusion
Most communities have a few species that are very common, a few species that are very rare, and a lot of species that have an intermediate number of individuals.

Table source: [L14 s27]

L14.5 Alpha, beta and gamma diversity

⚠ **Do not mix up: Alpha is NOT the regional total: alpha is local site richness, gamma is the overall area.** [L14 s30]



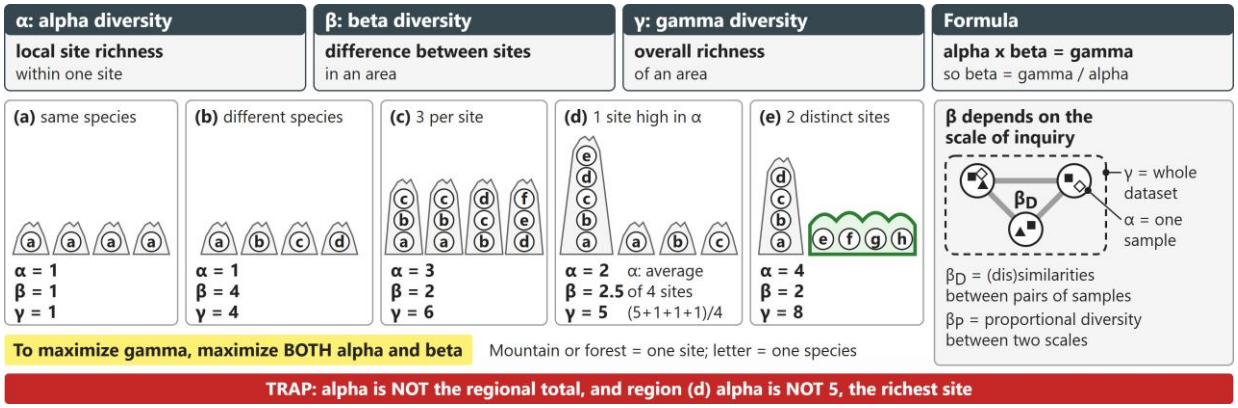
Five regions of mountains and a forest, each letter a different species [L14 s29]

On the figure: (a) · (b) · (c) · (d) · (e)

Question: which region, (a) to (e), contains a greater number of species? [L14 s29]

Letters are different species (a to h); each mountain or forest is a different location. [L14 s29]

Species diversity is lowest in region (a), highest in (e), intermediate in (b), (c), (d). [L14 s29]



Alpha, beta and gamma counted for each region, with the scale idea [L14 s29]

On the figure: Alpha · Beta · Gamma · local site richness · overall richness · difference between sites · scale of inquiry

Alpha (α) diversity: **local site richness**. [L14 s30]

Gamma (γ) diversity: the **overall richness** of an area. [L14 s30]

Beta (β) diversity: the **difference between sites** in an area. [L14 s30]

Formula: alpha x beta = gamma, therefore beta = gamma / alpha. [L14 s30]

Beta for regions (a), (b), (d) and (e) is found as gamma / alpha. [L14 s30, L14 s31, L14 s32, L14 s34, L14 s36]

Main point: to maximize gamma diversity, maximize **BOTH** alpha and beta diversity. [L14 s30]

Gamma diversity can therefore **increase** due to **increases** in alpha or beta diversity. [L14 s36]

Beta diversity can depend on the **scale of inquiry** *(size of the area studied)*. [L14 s35]

βD: (dis)similarities between pairs of samples. [L14 s35]

βP: proportional diversity, the relationship between two scales of investigation. [L14 s35]

βP = gamma / mean alpha *(average local richness)*. [L14 s35]

In the scale diagram, gamma is the whole dataset and alpha is each sample. [L14 s35]

Alpha, beta, gamma in regions (a) to (e)

Region	Alpha	Gamma	Beta = gamma / alpha	Why
(a)	**1**	**1**	**1** / **1** = **1**	**4** sites, each with the same single species a
(b)	**1**	**4**	**4** / **1** = **4**	**4** sites, each with a different species (a, b, c, d)
(c)	**3**	**6**	**6** / **3** = **2**	**3 species** per site; **6 species** (a to f) in the region
(d)	**2** (average of the **4** sites: (5 + **1** + **1** + **1**) / **4**)	**5**	**5** / **2** = **2.5**	**1** site has species a to e; the other **3** sites have one species each (a, b, c)
(e)	**4**	**8**	**8** / **4** = **2**	**2** distinct sites (mountain a to d, forest e to h), each with **4** unique species

Table source: [L14 s29, L14 s31, L14 s32, L14 s33, L14 s34, L14 s36]

L14.6 Habitat differences and protecting gamma diversity

⚠ **Do not mix up: TNC does NOT maximize alpha alone: it maximizes both alpha and beta to maximize gamma.** [L14 s38]

Question: yellow and blue circles cover equal land; which would contain more species, and why? [L14 s37]

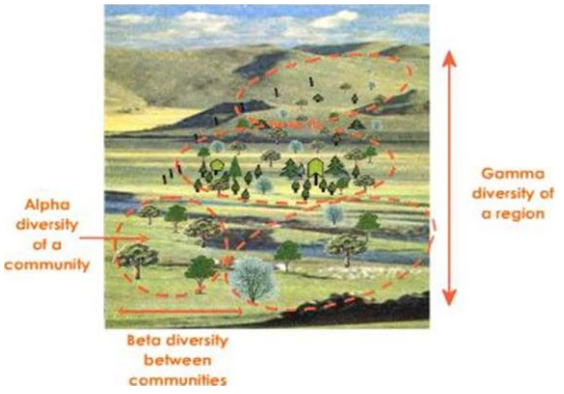
Principle: greater difference between habitats across the landscape should **increase** **beta** and **gamma** diversity. [L14 s38]

So the circles that cross more different habitats should contain more species. [L14 s37, L14 s38]

Across a landscape: **alpha** is one community, beta is **between communities**, gamma is the whole region. [L14 s38]

The Nature Conservancy (TNC): buys land to protect as many species as possible. [L14 s38]

TNC maximizes both alpha and beta diversity in land purchases, thereby maximizing gamma. [L14 s38]



Alpha is one community, beta is between communities, gamma is the whole region [L14 s38]

On the figure: alpha · beta · gamma · between communities

TNC California preserves are spread across many habitats. [L14 s38]

Restructuring predator communities may change human Lyme disease risk. [L14 s39, L13 s31]

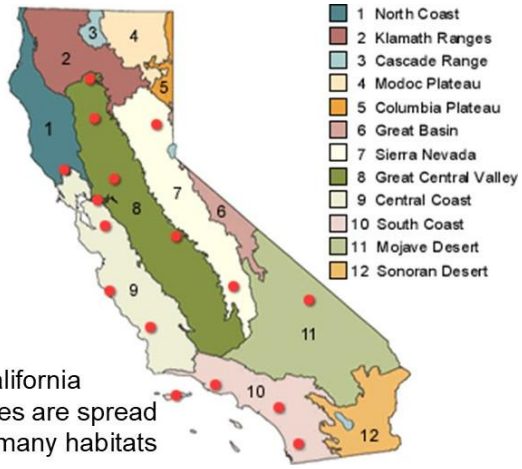
More coyotes per fox, more Lyme; more foxes, less Lyme. [L14 s39, L13 s32]

Lyme diagram chain: coyotes reduce foxes, and foxes reduce small mammal hosts. [L14 s39, L13 s31]

Trophic dead end = predation resistant taxa within a trophic level that higher levels cannot use. [L14 s39, L13 s19]

Trophic dead end example: nutrients added to a headwater stream raised primary consumers but not predators. [L14 s39, L13 s19]

Pycnopsyche *(case-building caddisfly)* is the example taxon of a trophic dead end. [L14 s39, L13 s19, L13 s18]



Nature Conservancy preserves in California are spread across many habitats [L14 s38]

On the figure: TNC · California

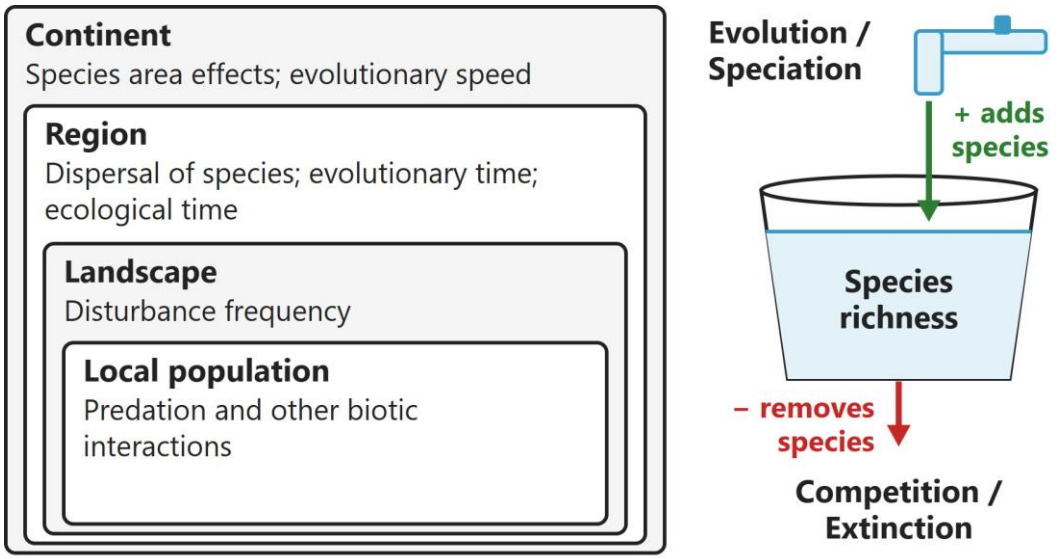
It is a detritivore *(dead matter eater)* that **increased** dramatically with nutrient addition. [L14 s39, L13 s18]

Lecture 15: Community Ecology: Species Richness Patterns

L15.1 What controls richness: scale, speciation vs extinction, the latitudinal gradient

⚠ **Do not mix up: Observed richness is NOT speciation alone: it is the net result of speciation and extinction.** [L15 s08]

Fundamental question: how and why species abundance and diversity vary in time and space. [L15 s06]
Know the energy, time and area relationships, with evidence for and against each. [L15 s05]
Different processes control richness at different **spatial scales** *(sizes of area studied)*. [L15 s07]



Each scale includes all lower ones and nests within all higher ones

TRAP: richness is NOT species added alone; it is the net result

Nested scales with their controls, and the bucket of species gained and lost [L15 s07]
On the figure: Speciation · Competition · extinctions · Evolution · species richness

Each scale includes all lower ones and nests within all higher ones. [L15 s07]
Think about **speciation** and extinction in the context of geographical richness gradients. [L15 s07]
Speciation *(new species forming)* is adding species. [L15 s08]
Competition and other negative species interactions can lead to **extinctions**. [L15 s08]
Observed species richness in one location (a continent) is the net result of speciation and extinction. [L15 s08]
Richness as a bucket: **evolution** and speciation pour species in; competition and extinction drain them out. [L15 s08]
Both evolution and competition control species richness at small scales. [L15 s08]
Latitudinal species richness gradient: species of most **taxa** *(groups of organisms)* **increase** from polar to temperate to tropical. [L15 s10]

Also called the **polar-equatorial gradient** *(poles to equator)*. [L15 s11]

North American birds: lines of equal bird species numbers rise from the **arctic** to the **tropics**. [L15 s11]

Birds: very low diversity in the arctic, very high diversity in the tropics. [L15 s11]

Birds: high diversity in **mountainous** areas; low diversity on the Florida peninsula (**peninsular effect**). [L15 s11]

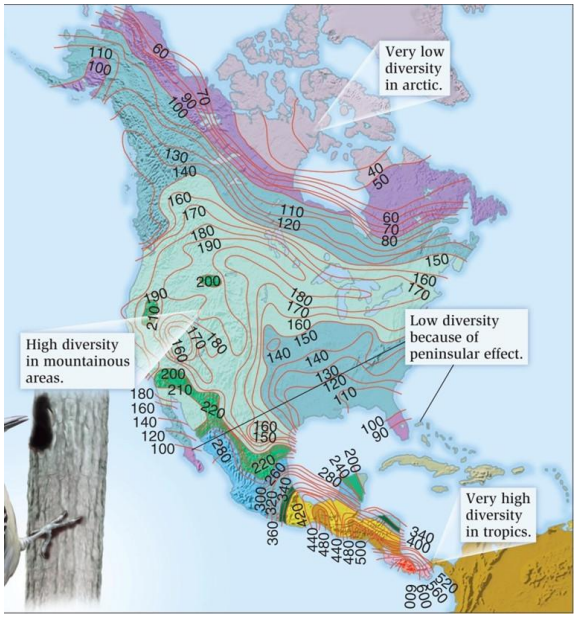
North American mammals: a pronounced gradient, with more mammal species heading south toward the Tropics. [L15 s12]

Mammals: high diversity in California and northern Mexico, regions of **topographic relief** *(mountains and valleys)* and habitat diversity. [L15 s12]

United States fish: species richness is highest in the Southeast and lowest across the West. [L15 s02, L15 s03]

Three main hypotheses for the gradient: richness **increases** with more **productivity/energy**, **time**, and **area**. [L15 s13]

Review question: compare and contrast the three large-scale richness hypotheses (energy, time, area). [L15 s49]



North American bird species richness: lowest in the arctic, highest in the tropics [L15 s11]

On the figure: **arctic** · **tropics** · **mountainous** · **peninsular effect**

> Shared point: all three try to explain why richness rises from poles to tropics. [L15 s13, L15 s49]

What controls richness at each scale

Scale	Process affecting species richness
Local population	Predation and other biotic interactions
Landscape	Disturbance frequency
Region	Dispersal of species; evolutionary time; ecological time
Continent	Species area effects; evolutionary speed

Table source: [L15 s07]

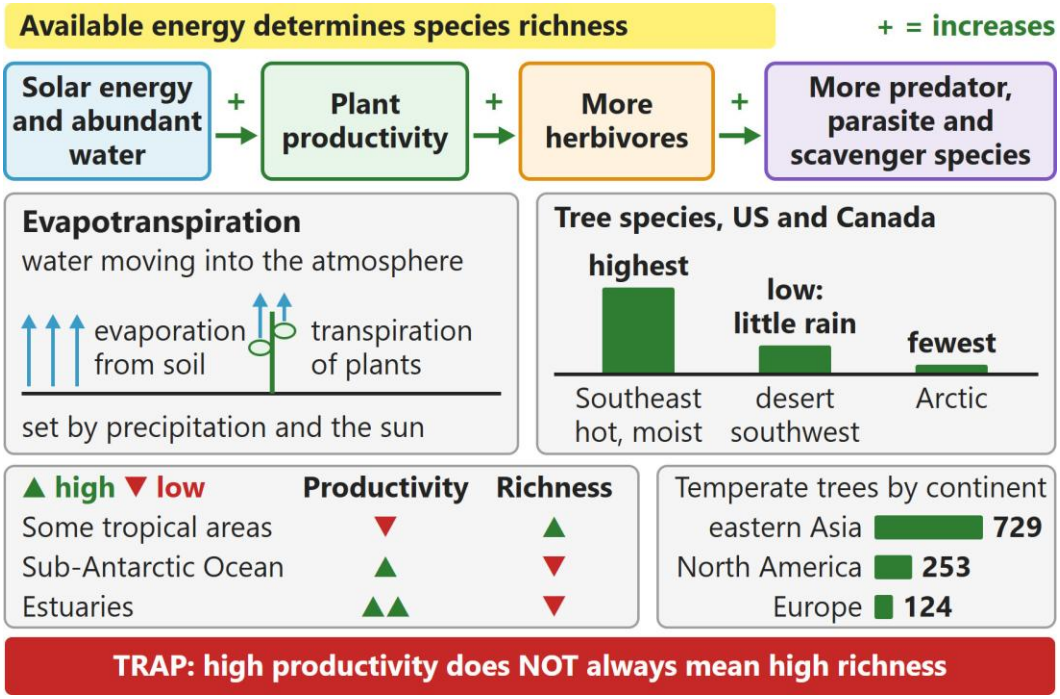
Comparing the three richness hypotheses

Hypothesis	Idea	One support	One problem
Species-energy	More sun and water, more plant productivity, more species	North American trees richest where evapotranspiration is highest (Southeast)	Sub-Antarctic Ocean and estuaries are productive but species poor; fails between continents
Species-time	Older regions gained more species; temperate areas are young after glaciations	Ice sheets displaced temperate species **18,000 years** ago	Gradient still exists in the sea; habitat mattered more than host age for parasites
Species-area	Larger areas: larger populations, more habitats, more species	Insects on British trees rise with tree range; Tropics have the largest land area	Asia, tundra and open ocean are large but not the richest

Table source: [L15 s49, L15 s13, L15 s15, L15 s17, L15 s18, L15 s19, L15 s21, L15 s22, L15 s25, L15 s26, L15 s30, L15 s34, L15 s35, L15 s36]

L15.2 Species-energy hypothesis and its exceptions

⚠ **Do not mix up: High productivity does NOT always mean high richness: sub-Antarctic Ocean and estuaries are species poor.** [L15 s18]



Energy to plant productivity to herbivores to predators, with exceptions and tree counts [L15 s15]

On the figure: productivity · herbivores · evapotranspiration · sub-Antarctic Ocean · Estuaries · Arctic

Species-energy hypothesis: available energy determines species richness. [L15 s15]

1. More solar energy plus abundant water gives high **productivity of plants**. [L15 s15]
2. Higher **plant productivity** *(total weight of plant material made per year)* **increases** the number of **herbivores**. [L15 s15]
3. More herbivores **increase** the number of predator, parasite and scavenger species. [L15 s15]

Trees in the United States and Canada: tree richness is influenced by climate and rainfall. [L15 s16]

Highest tree richness is in the **hot, moist Southeast**, where **evapotranspiration** rates are highest. [L15 s16, L15 s17]

Tree species counts drop toward the far north, with the fewest in the **Arctic**. [L15 s16]

Terrestrial evapotranspiration: rate water moves into the atmosphere by soil evaporation and plant **transpiration** *(water loss from leaves)*. [L15 s17]

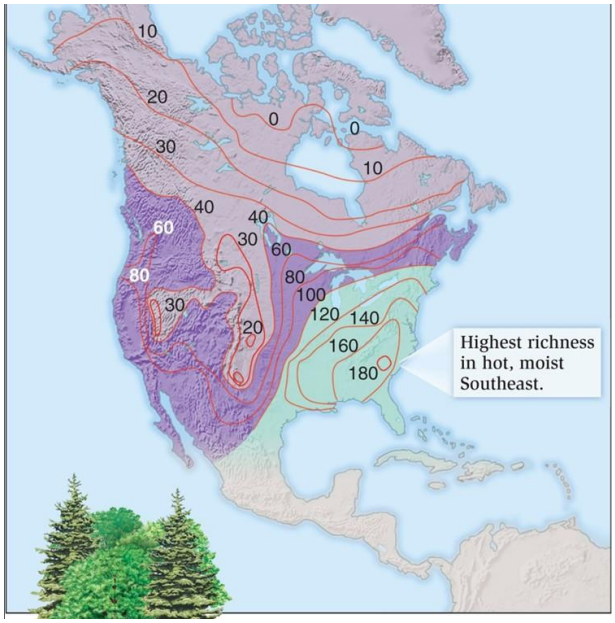
Evapotranspiration is affected by both precipitation and solar energy. [L15 s17]

Desert southwest: tree richness is low because rainfall and water are low, though temperatures are high. [L15 s17]

North American tree richness supports species-energy, but the pattern does not hold between continents. [L15 s19]

Temperate forest trees: **729 species** in eastern Asia, **253** in North America, **124** in Europe. [L15 s19]

Open problem: why would more productivity give more species, not high densities of a few species? [L15 s19]



Tree species richness in the United States and Canada: highest in the Southeast [L15 s16]

On the figure: hot, moist · Southeast

Exceptions to the species-energy hypothesis

Place	Productivity	Species richness
Some tropical areas (southeast Pacific near coastal Colombia and Ecuador)	Low	High
Sub-Antarctic Ocean	High	Low
Estuarine areas (where rivers empty into the sea)	Very high	Low

Table source: [L15 s18]

L15.3 Species-time hypothesis and the evidence against it

⚠ **Do not mix up: Birds and mammals do NOT speciate fastest in tropics: speciation AND extinction peak at high latitudes.** [L15 s24, L15 s28]

Species-time hypothesis: communities **diversify** *(gain species)* with time. [L15 s21]

Temperate regions are less species rich than tropical regions because they are **younger**. [L15 s21]

Younger: recently recovered from glaciations and severe climate disruption. [L15 s21]

Last ice age: ice sheets reached their maximum extent **18,000 years** ago. [L15 s22]

Temperate species in North America and northern Europe were displaced during this time. [L15 s22]

In all three explanations, tropical richness stays above temperate richness over time. [L15 s23, L15 s24]

Evolutionary speed hypothesis: evolution is faster in the **Tropics**, and this produced more species. [L15 s23]

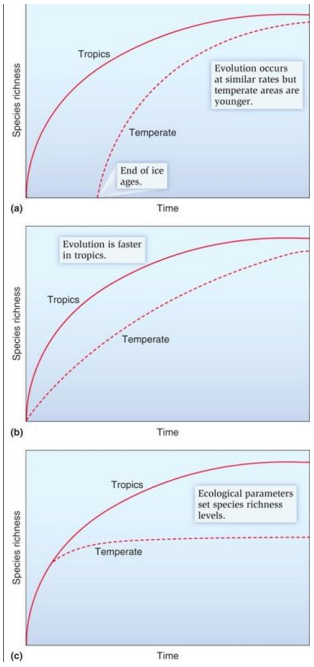
Its reasons: high ambient temperatures, short generation times and **increased** mutation rates. [L15 s23]

2,300 mammal and 6,700 bird species: evolution faster in temperate regions, but extinction also much faster. [L15 s24]

Drawback **1**: other datasets do not support the species-time hypothesis. [L15 s25]

Helminth *(parasitic worm)* **richness of vertebrates**: species-time predicts the oldest hosts (fish) carry the most species. [L15 s25]

Predicted order: fish most, lizards and snakes in between, birds and mammals (youngest) fewest. [L15 s25]



Three ways tropical richness stays above temperate richness over time [L15 s24]

On the figure: Tropics · Temperate · younger

Result: habitat mattered more; **aquatic** vertebrates of any taxon had more helminth species than terrestrial ones. [L15 s25]

Fish, the **oldest host lineage**, had the **fewest parasite species** among aquatic hosts. [L15 s25]

Drawback **2**: species-time has limited applicability to **marine organisms**. [L15 s26]

Land species might not redistribute quickly after a glaciation, especially past a barrier. [L15 s26]

Marine organisms seem to have no barriers to shifting their distributions during glaciations. [L15 s26]

Yet the polar-equatorial richness gradient still exists in marine habitats. [L15 s26]

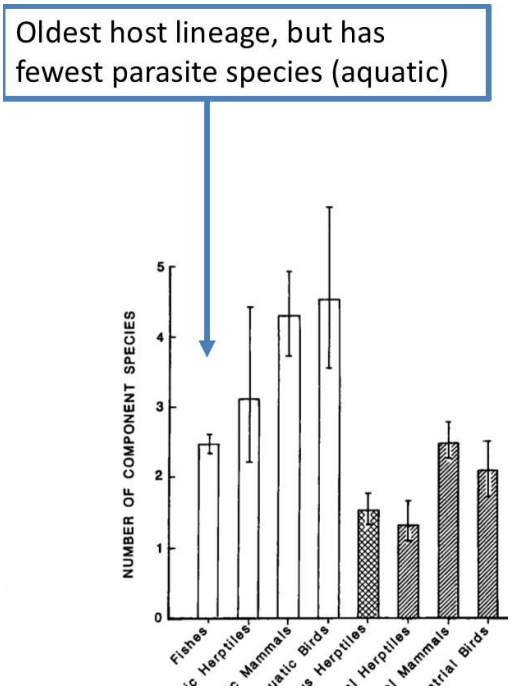
Drawback **3**: tropical versus temperate speciation rate comparisons have yielded conflicting results. [L15 s27]

45 rainforest plant species pairs: one tropical, one temperate, **congeneric** *(same genus)* or **conspecific** *(same species)*. [L15 s27]

Tropical plants had more than twice the rate of molecular evolution of temperate relatives. [L15 s27]

309 sister pairs *(closest related species pairs)* **of New World birds and mammals**: speciation and extinction rates compared. [L15 s28]

Highest speciation AND extinction rates were at high latitudes, declining toward the tropics. [L15 s28]



Helminth species per host group: oldest host lineage has fewest parasite species [L15 s25]

On the figure: oldest host lineage · fewest parasite species · aquatic

Three ways the tropics gained more species

Explanation	Idea
Longer time in the tropics	Evolution at similar rates, but temperate areas are younger and start at the end of the ice ages
Faster evolution in the tropics	Higher speciation and/or extinction rates; the tropics curve rises faster
Different ecological factors	Ecological factors in each realm set richness levels; the temperate curve levels off lower

Table source: [L15 s23]

L15.4 Species-area hypothesis (S = cA^z) and freshwater fish

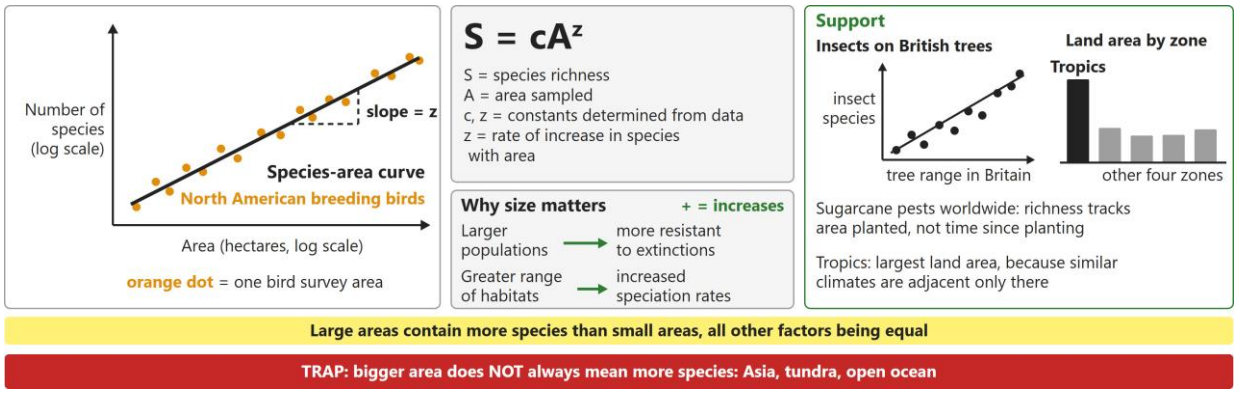
⚠ **Do not mix up: Bigger area does NOT always mean more species: Asia, tundra and open ocean are exceptions.** [L15 s36]

Species-area hypothesis: large areas contain more species than small areas. [L15 s30]

Why: large areas support larger populations and a greater range of habitats. [L15 s30]

Larger populations are more resistant to extinctions. [L15 s30]

Greater ranges of habitats promote **increased** speciation rates. [L15 s30]



Species-area curve, the S = cA^z terms, and the support from trees and land zones [L15 s34]

On the figure: Species-area curve · North American breeding birds · Larger populations · Insects on British trees · Sugarcane pests · Tropics

S = cA^z: species richness equals a constant c times area raised to the power z. [L15 s31]

Species-area curve: all other factors equal, a larger geographic area has more species. [L15 s32]

North American breeding birds: the number of species rises steadily as area **increases**. [L15 s32]

Slope of the species-area line = z, the rate species **increase** with area. [L15 s31, L15 s32]

Insects on British trees: insect richness on each tree species rises with its range in Britain. [L15 s33, L15 s34]

Range here = area in Britain known to contain trees of that species. [L15 s34]

Sugarcane pests worldwide: pest richness correlates better with area planted than with time since planting. [L15 s33]

Earth's land zones: the **Tropics** are half an order of magnitude bigger than other zones. [L15 s35]

Of tropics, subtropics, temperate, boreal and tundra, the Tropics have the largest land area. [L15 s35]

Climate symmetry: polar and temperate climates mirror each other in Northern and Southern Hemispheres. [L15 s35]

Symmetrically similar climates are adjacent **only** in the Tropics, creating one large area. [L15 s35]

Proposed reason the tropics are richer than temperate or polar areas: one large area. [L15 s35]

Problem: the vast contiguous landmass of Asia does not have more species. [L15 s36]

Problem: tundra is a large land biome but has very low species richness. [L15 s36]

Problem: open ocean has the greatest volume but fewer species than small-volume tropical surface waters. [L15 s36]

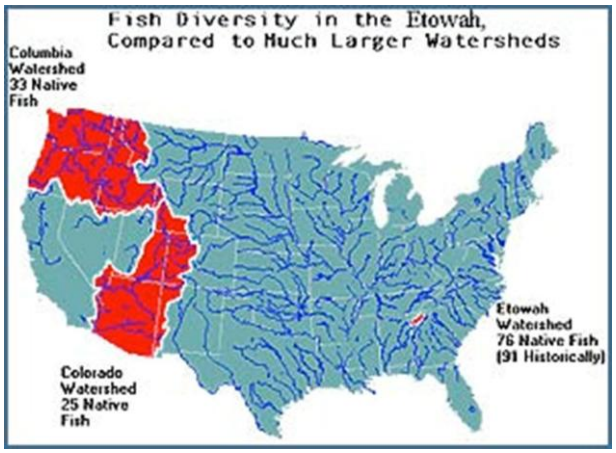
North American fish watersheds: the small **Etowah** watershed has **76 native fish** (91 historically). [L15 s37]

The much larger **Columbia** (33 native fish) and **Colorado** (25) watersheds have far fewer. [L15 s37]

Age: age is a really important factor that drives fish diversity. [L15 s37]

Global freshwater fish: richness per drainage basin still follows the latitudinal pattern. [L15 s38]

Richest basins lie in tropical South America, central Africa and southern Asia; high latitudes have few. [L15 s38]



Small Etowah watershed has far more native fish than the larger Columbia and Colorado [L15 s37]

On the figure: **Etowah** · **Columbia** · **Colorado** · **native fish**

Terms of S = cA^z

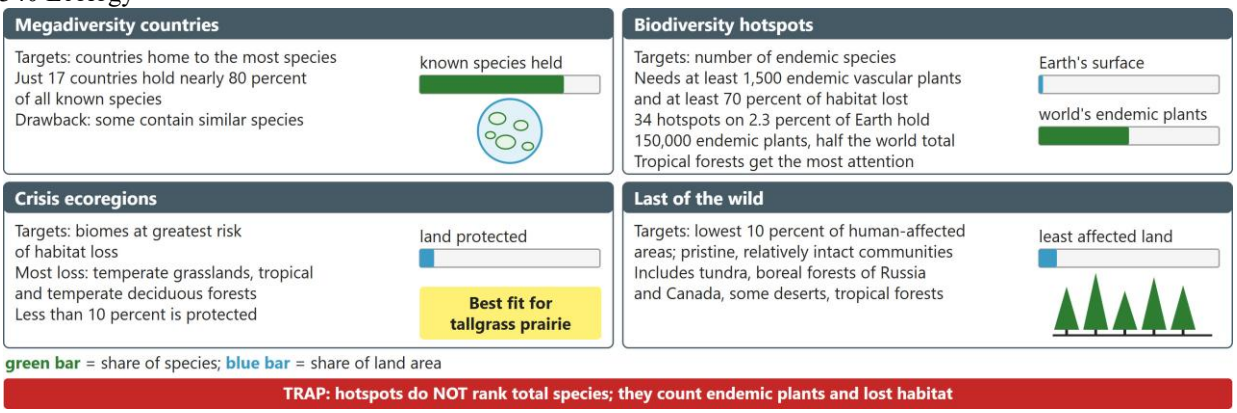
Letter	Meaning
S	Species richness
A	Area sampled
c	Constant determined from data
z	Constant determined from data: rate of **increase** in species with area

Table source: [L15 s31]

L15.5 Four large-scale conservation strategies

⚠ **Do not mix up: Hotspots do NOT rank total species: they count endemic species and need 70 percent habitat lost.** [L15 s43]

Conservation biologists save species with four large-scale strategies. [L15 s40]



Four large scale conservation strategies with what each targets [L15 s45]

On the figure: Megadiversity countries · Biodiversity hotspots · Crisis ecoregions · Last of the wild · endemic · tallgrass prairie

Megadiversity countries: just **17** countries are home to nearly **80** percent of all known species. [L15 s41]

So conservation efforts should be focused on these countries. [L15 s41]

Drawback: some megadiversity countries contain similar species. [L15 s41]

Biodiversity hotspots: focus on the number of **endemic** *(found only in one place or region)* species. [L15 s43]

A hotspot must contain at least **1,500 species** of endemic **vascular plants**. [L15 s43]

A hotspot must also have lost at least **70** percent of its original habitat. [L15 s43]

34 hotspots occupy **2.3** percent of Earth's surface but contain **150,000** endemic plant species. [L15 s43]

Those **150,000** endemic plant species are **50** percent of the world's total. [L15 s43]

Using the hotspot strategy, tropical forests would receive most of the attention. [L15 s43]

Crisis ecoregions: biomes at greatest risk of habitat loss. [L15 s45]

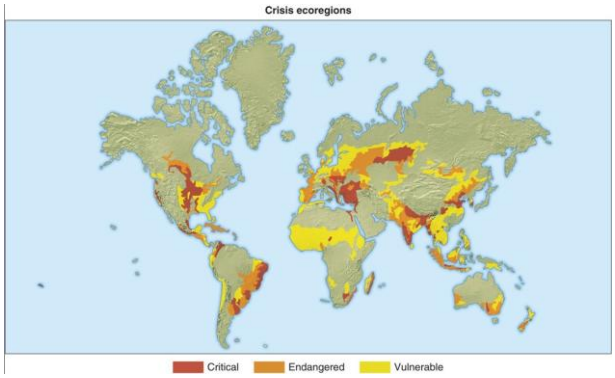
Habitat loss is most extensive in temperate grasslands and tropical and temperate deciduous forests. [L15 s45]

Less than **10** percent of these agriculturally rich areas are protected, so they are crisis ecoregions. [L15 s45]

Crisis ecoregions are ranked **critical**, **endangered** or **vulnerable**; central North America includes critical areas. [L15 s46]

Last of the wild: areas in the lowest **10** percent of human-affected areas. [L15 s47]

Such **pristine** *(untouched)* areas offer a great opportunity because of their relatively intact communities. [L15 s47]



World map of crisis ecoregions ranked critical, endangered or vulnerable [L15 s46]

On the figure: Crisis ecoregions · critical · endangered · vulnerable

Includes tundra and boreal forests of Russia and Canada, plus some deserts and tropical forests. [L15 s47]

Review question, tallgrass prairie: choose the **crisis ecoregions** strategy. [L15 s49, L15 s45]

Why: habitat loss is most extensive in temperate grasslands, and less than **10** percent is protected. [L15 s45, L15 s49]

Hotspots fit poorly: that strategy sends most attention to tropical forests. [L15 s43, L15 s49]

Last of the wild fits poorly: it targets pristine areas, but grasslands lost much habitat. [L15 s45, L15 s47, L15 s49]

Four large-scale conservation strategies

Strategy	What it targets	Key numbers	Note
Megadiversity countries	Countries home to the most species	**17** countries hold nearly **80** percent of known species	Drawback: some contain similar species
Biodiversity hotspots	Number of endemic species	At least **1,500** endemic vascular plants; at least **70** percent habitat lost; **34** hotspots	Tropical forests get most attention
Crisis ecoregions	Biomes at greatest risk of habitat loss	Less than **10** percent protected	Temperate grasslands, tropical and temperate deciduous forests
Last of the wild	Least human-affected areas	Lowest **10** percent of human-affected areas	Tundra, boreal forests of Russia and Canada, some deserts, tropical forests

Table source: [L15 s40, L15 s41, L15 s43, L15 s45, L15 s47]