BIOL 3340 Ecology Exam 2 acronyms

Each acronym spells its words in order; the italic line is the memory phrase, the gray line says what each cue word means. Built from the slides only. [L14 s19] = Lecture 14, slide 19.

Lecture 10

L10.1 Species interactions and types of competition

S · CA · P · MC · N Six interaction signs

Species interact / Competition hurts both, Amensalism hurts one / Predators take / Mutualism shares, Commensalism rides / Neutralism ignores

S	**Species interactions**	Interactions among populations, usually of different species, living in the same area
C	**Competition**	- and -: both species are harmed
A	**Amensalism**	- and 0: one species is harmed, the other is unaffected
P	**Predation, herbivory, parasitism**	+ and -: one species gains, the other is harmed (one row of the sign table)
M	**Mutualism**	+ and +: both species benefit
C	**Commensalism**	+ and 0: one species benefits, the other is unaffected
N	**Neutralism**	0 and 0: neither species is affected

Species: interactions; Competition: - -; Amensalism: - 0; Predators: + - (herbivory, parasitism); Mutualism: + +; Commensalism: + 0; Neutralism: 0 0. Amensalism harms

L10 s05, L10 s06

II · EI · AA Kinds of competition

Intraspecific, Interspecific / Exploitative pot, Interference fight / Apparent enemy, Amensalism extras

I	**Intraspecific**	Between individuals of the SAME species (same needs); they compete strongly
I	**Interspecific**	Between individuals of DIFFERENT species; the kind that is the main focus
E	**Exploitative**	Both species draw on one shared resource, no direct contact (overlapping root systems)
I	**Interference**	Species act directly on each other (two wolves snarling over a carcass)
A	**Apparent**	Runs through a shared natural enemy, NOT a shared resource or direct contact
A	**Amensalism and allelopathy**	Also included: amensalism (one harmed, one unaffected); allelopathy (plant chemicals harm)

Intraspecific: same species; Interspecific: different; Exploitative: shared resource; Interference: direct; Apparent: shared enemy; Amensalism, allelopathy: extras

L10 s07, L10 s08, L10 s09, L10 s60

N · SGR · F Apparent competition: squirrels

Natural enemy / Squirrelpox hits Gray and Red / Food is shared too

N	**Natural enemy**	Apparent competition involves a SHARED natural enemy; unlike exploitative or interference
S	**Squirrelpox virus**	The shared natural enemy of the red and gray squirrels
G	**Gray squirrel**	S. carolinensis: one of the two squirrels sharing squirrelpox
R	**Red squirrel**	S. vulgaris: the other squirrel sharing squirrelpox
F	**Food resource**	They also share a food resource: that part is exploitative competition, not apparent

Natural enemy: shared, what makes it apparent; Squirrelpox: the virus; Gray, Red: the squirrels; Food: shared, exploitative. Trap: apparent is NOT a shared resource

L10 s10, L10 s11

L10.2 Competitive exclusion, niches and resource partitioning

CA · E · BA · LU Competitive exclusion and Paramecium

Competitive exclusion for Any species / Each alone levels off / Bursaria shares, Aurelia wins / Lower and Upper tube

C	**Competitive exclusion**	Species with exactly the same requirements cannot live together (same place, resources: same niche)
A	**Any species**	Thought true of any species forced to compete: microbes, mammals, plants
E	**Each alone**	Paramecium grown alone: all three level off (population volume in mL over days)
B	**Bursaria with caudatum**	P. bursaria and P. caudatum COEXIST: both level off
A	**Aurelia with caudatum**	P. aurelia and P. caudatum do NOT coexist: P. caudatum dies out
L	**Lower tube**	P. bursaria uses yeast in the lower part of the tube, where oxygen is lower
U	**Upper tube**	P. caudatum uses yeast in the upper part; these different niches prevent exclusion

Competitive exclusion: same niche, one goes; Any: microbes to plants; Each: alone; Bursaria: coexists; Aurelia: excludes caudatum; Lower, Upper: where each feeds

L10 s13, L10 s14, L10 s15

E · N · FR · D Niche definitions

Eltonian role / Niche range / Fundamental could, Realized does / Dimensions shrink overlap

E	**Eltonian niche**	The role of an organism in an ecosystem; NOT the main definition used in the course
N	**Niche**	Range of conditions in the environment where an organism can exist; the main definition used in the course
F	**Fundamental niche**	The ENTIRE range of conditions a species could exist in; most species do not fill it
R	**Realized niche**	Only PART of that range, cut down by competition, predation, parasitism or another interaction
D	**Dimensions**	Resources used and interactions define a niche; big overlap on one dimension, small on two

Eltonian: role; Niche: range of conditions, main; Fundamental: could live; Realized: actually lives; Dimensions: two cut overlap. Trap: realized is NOT the full range

L10 s16, L10 s17, L10 s18, L10 s23

R · FF · IC · R Resource partitioning: warblers

Resource partitioning / Five warblers, Four zones / Insects differ, Cape bird outside / Reduced overlap

R	**Resource partitioning**	Differentiation of niches in space and time that lets similar species coexist
F	**Five warblers**	Five warbler species fed in New England spruce trees
F	**Four species**	Four used different heights and portions of the tree (a caption says each of five)
I	**Insects**	Each probably fed on a different range of insects
C	**Cape May warbler**	Attacked flying insects more than the Blackburnian; stayed on the outside of the trees
R	**Reduced overlap**	Reduced niche overlap, which promotes coexistence

Resource partitioning: space and time; Five: warblers; Four: different tree zones; Insects: different ranges; Cape: May, flying insects, outside; Reduced: niche overlap

L10 s19, L10 s20

G · AS · BC Character displacement: finches

Galapagos finches / Allopatric apart, Sympatric together / Beaks shift: Character displacement

G	**Galapagos finches**	Small Ground-Finch (Geospiza fuliginosa) and Medium Ground-Finch (Geospiza fortis)
A	**Allopatric**	Living apart: fuliginosa on Los Hermanos, fortis on Daphne Major; beak ranges overlap
S	**Sympatric**	Living together on San Cristobal and Santa Maria; beak depth ranges shift apart
B	**Beak depth**	The trait measured: percent of individuals at each beak depth
C	**Character displacement**	Traits shift apart where the two species live together

Galapagos: small and medium ground finches; Allopatric: apart, beaks overlap; Sympatric: together, beaks differ more; Beak: depth; Character displacement: the shift

L10 s21, L10 s22

L10.3 Testing for competition: barnacles and caddisflies

E · R · CS · NA Testing competition: barnacle setup

Evolutionary force / Remove one / Chthamalus up, Semibalanus down / Null no effect, Alternative excluded

E	**Evolutionary force**	Competition can be strong enough to cause non-overlapping distributions between species
R	**Removal method**	Temporarily remove one species, examine the effect on the other: one of the best tools
C	**Chthamalus**	Chthamalus stellatus occurs in the UPPER areas of the rocky intertidal zone
S	**Semibalanus**	Semibalanus balanoides is more abundant in the LOWER zone
N	**Null hypothesis**	H0: Chthamalus are not affected by the presence of Semibalanus
A	**Alternative hypothesis**	HA: Chthamalus are competitively excluded from the LOWER intertidal by Semibalanus

Evolutionary: force; Remove: one species, watch the other; Chthamalus: upper; Semibalanus: lower; Null: no effect; Alternative: excluded from LOWER zone, not upper

L10 s24, L10 s26, L10 s27, L10 s28

R · AN · C · F Barnacle removal steps

Rocks down / Allow settlers, Needle scrapes half / Chthamalus grows / Fundamental both zones

R	**Rocks moved down**	Step 1: rocks with young Chthamalus taken from the upper zone, screwed down in the lower zone
A	**Allow colonizing**	Step 2: allow Semibalanus to colonize the rocks
N	**Needle removal**	Step 3: needle clears Semibalanus off half of each rock; monitor Chthamalus on both sides
C	**Chthamalus grows**	Step 4: Chthamalus grows where Semibalanus was removed: Semibalanus may exclude it
F	**Fundamental vs realized**	Chthamalus: fundamental both zones, realized upper only; Semibalanus: both are the lower zone

Rocks: moved to lower zone; Allow: Semibalanus settles; Needle: scrape half; Chthamalus: grows on cleared half; Fundamental: both zones. Rocky Scottish coast

L10 s29

F · L · I · R Glossosoma natural experiment

Fungal pathogens kill caddis / Long natural test / Increase in others / Released from exclusion

F	**Fungal pathogens**	Cougourdella sp. wiped out Glossosoma caddisflies in Michigan streams
L	**Long-term natural experiment**	Rare example with minimal cage effects: nature, not a cage, removed the species
I	**Increased density**	Other herbivorous insect species increased in density after Glossosoma was gone
R	**Released**	They were released from exclusion via competition

Fungal: pathogens, Cougourdella; Long: natural experiment, minimal cage effects; Increase: other herbivores rose; Released: from competition. Trap: others did NOT decline

L10 s30

L10.4 Lotka-Volterra and R* models

L · RNK · SAB Lotka-Volterra symbols

Logistic base / Rate times Number under K / Subscripts, Alpha, Beta

L	**Logistic equation**	The Lotka-Volterra competition model is based on the logistic equation of population growth
R	**r (growth rate)**	Per-capita rate of population growth; r1 for species 1, r2 for species 2
N	**N (population size)**	Population size
K	**K (carrying capacity)**	Carrying capacity
S	**Subscripts 1, 2**	Refer to species 1 or species 2
A	**Alpha (α)**	Per capita competitive effect of species 2 ON species 1
B	**Beta (β)**	Per capita competitive effect of species 1 ON species 2

Logistic: the base; Rate: r; Number: N; K: carrying capacity; Subscripts: which species; Alpha: 2 on 1; Beta: 1 on 2. Trap: alpha is NOT species 1 on species 2

L10 s31, L10 s32, L10 s34

L · A · SS · R · ZE Building the competition equations

Logistic first / Add competition / Species one, Species two / Room shrinks / Zero line, Ends

L	**Logistic first**	Start with dN1/dt = r1N1 (K1 - N1) / K1; dN1/dt is the growth rate of the population
A	**Add competition term**	Then add a term for each species' effect on the other
S	**Species 1 equation**	dN1/dt = r1N1 (K1 - N1 - αN2) / K1
S	**Species 2 equation**	dN2/dt = r2N2 (K2 - N2 - βN1) / K2
R	**Room shrinks**	More N2 (α above 0) subtracts room, so species 1 grows slower
Z	**Zero growth isocline**	Diagonal where dN/dt = 0: shaded side grows, unshaded side shrinks, both settle on it
E	**Ends K1, K1/α**	x axis K1: species 1 uses all resources; y axis K1/α: species 2 takes all, none for species 1

Logistic: start; Add: competition term; Species one: minus αN2; Species two: minus βN1; Room: more N2, slower N1; Zero: dN/dt = 0 line; Ends: K1, K1/α

L10 s33, L10 s34, L10 s35

LAB · CD · I Four Lotka-Volterra outcomes

Local loss: A drops two, B drops one / C either wins, D both stay / Intra beats inter

L	**Local extinction**	Competition is predicted to lead to the local extinction of one species
A	**A: species 2 eliminated**	Outcome A of the competition equations
B	**B: species 1 eliminated**	Outcome B of the competition equations
C	**C: either eliminated**	Either species can win; it depends on the starting numbers
D	**D: both coexist**	Both species coexist at a stable equilibrium; the lines cross at a stable point
I	**Intraspecific greater**	Extinction fails if intra > interspecific: each species limits itself more than the other

Local: extinction predicted; A: species 2 out; B: species 1 out; C: either, by start numbers; D: coexist; Intra: self-limiting. Trap: 'fewer' in outcome C is a slip

L10 s36, L10 s37, L10 s40

M · R · SL · TD Tilman's R star model

Mechanism matters / R star balance / Slow but Lower wins / Two resources, Differing levels

M	**Mechanism**	Tilman criticized Lotka-Volterra: we need the mechanism of competition for better predictions
R	**R star (R*)**	Resource level where gains by growth equal losses to predators or disease; size holds steady
S	**Slower growth**	Species B grows slower than A; A grows faster first, peaks, then declines
L	**Lower R star wins**	B has the lower R*, displaces A, and drives the resource down to R* of B
T	**Two resources**	A has the lower R* for one, B for the other: they coexist if habitats differ in which is richer
D	**Differing levels**	R* studies: coexistence can occur when species require differing levels of the same resource

Mechanism: Tilman's point; R star: gains equal losses; Slow: B grows slower; Lower: lower R* wins; Two: resources allow coexistence; Differing: levels of one resource

L10 s38, L10 s39, L10 s40

L10.5 Invasive species and biological control

R · ESP · L · R Four invasiveness hypotheses

Rusty invader / Enemy release, Superior competitor, Propagule pressure / Lack of constraints / Rarely tested together

R	**Rusty crayfish**	Invader in Wisconsin: its competition reduced native crayfish abundance (native O. virilis fell)
E	**Enemy release**	Freed from natural enemies, invasives put more into growth and competition (and evolve that)
S	**Superior competitor**	Invasives use natural resources more efficiently than natives or non-invasives
P	**Propagule pressure**	Invasives produce more progeny; sheer numbers let them enter natural communities
L	**Lack of environmental constraints**	Some invaders are pre-adapted to existing environmental conditions
R	**Rarely tested together**	The four hypotheses have rarely been tested concurrently

Rusty: crayfish beat natives; Enemy: no natural enemies; Superior: efficient users; Propagule: sheer numbers; Lack: pre-adapted; Rarely: tested together

L10 s41, L10 s42, L10 s60

CB · N · E Two methods of pest control

Chemical spray or Biological enemy / from the Native country / Enemy release assumed

C	**Chemical control**	A variety of pesticides is used
B	**Biological control**	Natural enemies such as predators and parasites are released against pests
N	**Native country**	The enemies are often those believed to control the pest in its native country
E	**Enemy release assumed**	Biological control assumes the enemy release hypothesis is correct

Chemical: pesticides; Biological: release predators, parasites; Native: enemy from the pest's home country; Enemy release: what biocontrol assumes is true

L10 s43

PC · L · SJ Biocontrol cases: cactus and ladybeetles

Prickly pear meets Cactus moth / Ladybeetles take over / Sometimes works, be Judicious

P	**Prickly pear**	Opuntia stricta to Australia mid-1800s; 20 million ha by 1930; spread blamed on no natural enemies
C	**Cactus moth**	Cactoblastis cactorum introduced: Opuntia fell to only a few thousand ha in only 2 years
L	**Ladybeetles**	Maine potato fields: 3 exotic ladybeetle species replaced 2 natives over 30 years
S	**Sometimes works**	Biological control species sometimes, but not always, control the pest
J	**Judicious use**	Introduced agents may outcompete native species, so be judicious in their use

Prickly: pear, 20 million ha by 1930; Cactus: moth, down to a few thousand ha in 2 years; Ladybeetles: 3 exotic beat 2 native; Sometimes: works; Judicious: use

L10 s44, L10 s45, L10 s46

L10.6 Facilitation: mutualism and commensalism

F · MOF · C Mutualism vs commensalism

Facilitation helps / Mutualism, Obligatory or Facultative / Commensalism one sided

F	**Facilitation**	One species helping another: the general term covering mutualism and commensalism
M	**Mutualism**	Association between two species that benefits BOTH species (+ +)
O	**Obligatory**	A mutualism the partners require
F	**Facultative**	A mutualism that is optional: each partner could survive without the other
C	**Commensalism**	Benefits one species while the other species is unaffected (+ 0)

Facilitation: helping; Mutualism: both gain; Obligatory: required; Facultative: optional; Commensalism: one gains, other unaffected. Trap: commensalism is NOT mutualism

L10 s06, L10 s48

DD · RE Four types of mutualism

Dispersive bee, Defensive ants / Resource roots, Endosymbiosis inside

D	**Dispersive**	A bee on a flower and a bird on a flower head
D	**Defensive**	Acacia trees and Pseudomyrmex ants: the ants defend the tree
R	**Resource-based**	Mycorrhizae and plants trade nutrients and carbohydrates
E	**Endosymbiosis**	Partner lives inside the other: coral and algae; lichens (photosynthetic organism and fungi)

Dispersive: bee and bird on flowers; Defensive: acacia ants; Resource: mycorrhizae; Endosymbiosis: coral algae, lichens. Trap: predatory is NOT a mutualism type

L10 s49, L10 s50, L10 s51, L10 s52, L10 s53

EB · D · MH Acacia ants and mycorrhizae

Extrafloral nectar, Beltian bodies / ants Defend / Mycorrhizae spread Hyphae

E	**Extrafloral nectaries**	Acacia trees provide nectar glands outside the flower to Pseudomyrmex ants
B	**Beltian bodies**	Protein-rich food nodules acacia also provides to the ants
D	**Defend**	In exchange, the ants defend the acacia tree from herbivores
M	**Mycorrhizae**	Root fungi in critical mutualisms with plants; more efficient at obtaining nutrients
H	**Hyphae**	Invade plant roots and receive carbohydrates; in exchange they give the plant nutrients

Extrafloral: nectaries; Beltian: protein bodies; Defend: ants guard acacia; Mycorrhizae: root fungi; Hyphae: get carbohydrates, give nutrients. Trap: fungi get CARBS

L10 s50, L10 s51

Z · HSB Coral bleaching steps

Zooxanthellae feed / Healthy, Stressed, Bleached

Z	**Zooxanthellae**	Algae in coral tissue: the coral's primary food source, and they give it color
H	**Healthy coral**	Coral and algae depend on each other to survive
S	**Stressed coral**	Increased ocean temperature or pollution: the algae leave the coral tissue
B	**Bleached coral**	Left white without its main food: vulnerable and more prone to disease

Zooxanthellae: algae, food and color; Healthy: partners; Stressed: heat or pollution, algae leave; Bleached: white, vulnerable, disease prone

L10 s52

R · EC · B Commensalism examples

Remora rides / Epiphytes perch, Clown fish hide / Bioturbation stirs

R	**Remora**	Hitches rides on sharks
E	**Epiphytes**	Plants growing on other plants: use them for habitat without damaging them
C	**Clown fish and anemone**	Clown fish use the anemone for habitat without damaging it
B	**Bioturbation**	Organisms stirring soil or sediment: cattle and cattle egrets

Remora: rides sharks; Epiphytes: perch on plants; Clown fish: hide in anemone; Bioturbation: cattle and egrets. Trap: acacia ants are mutualism, NOT commensalism

L10 s54

L10.7 Facilitation in stressful environments

S · H · SWH Why neighbors help under stress

Stress lifts / Higher plants get / Shade, Wind, Herbivore shields

S	**Stressful conditions**	Evidence: plant mutualisms are more common in stressful environmental conditions
H	**Higher elevations**	Hypothesis: plants at higher elevations benefit more from neighbors, through facilitation
S	**Shade**	Neighbors provide shade
W	**Wind protection**	Neighbors give protection from disturbance like wind
H	**Herbivore protection**	Neighbors also give protection from herbivores

Stress: mutualisms more common; Higher: elevation gains more; Shade, Wind, Herbivore: what neighbors give. Trap: more sunlight with no shade is NOT a benefit

L10 s55

RE · FR · L · T Neighbor removal experiment

Remove neighbors in Eleven places / Fewer flowers, Reduced survival up high / Low sites differ / Take-home

R	**Removed neighbors**	Global experiment: neighboring plants removed at high and low elevation plots
E	**Eleven locations**	The experiment ran in 11 different locations
F	**Fewer flowers**	High elevation (more stressful): fewer flowers when neighbors were removed
R	**Reduced survival**	High elevation: reduced survival when neighbors were removed
L	**Low elevation**	Less stressful comparison: removing neighbors raised flowers there, not lowered them
T	**Take-home**	Facilitation in stressful environments might matter more than in ideal conditions

Remove: neighbors; Eleven: locations; Fewer: flowers up high; Reduced: survival up high; Low: flowers rose; Take-home: stress makes facilitation matter more

L10 s56, L10 s57, L10 s58, L10 s59, L10 s60

Lecture 11

L11.1 Predators and other natural enemies

PPP · I Predation: who gains, who loses

Predation: the Predator eats the Prey / Interspecific

P	**Predation**	One species, the predator, kills and eats the other, the prey; a +/- interaction
P	**Predator (+)**	The killer and eater gains (+)
P	**Prey (-)**	The one eaten loses (-); it is killed, so NOT +/0
I	**Interspecific**	Predation is an interaction between different species

Predation: kills and eats, +/-; Predator: gains (+); Prey: loses (-); Interspecific: between different species. Trap: NOT +/+ or +/0

L11 s06

MM · PP · H Natural enemy continuum

Microparasite, Macroparasite / Parasitoid, Predator / High potential

M	**Microparasite**	Microscopic; rapid growth; mild to severe; one host holds several species; regulation moderate to high
M	**Macroparasite**	Smaller than host; grows faster than hosts; usually MILD; stability high; LOW ability to regulate host
P	**Parasitoid**	Similar in size to host (wasp and moth); EVENTUALLY fatal; one host usually supports one
P	**Predator**	Often larger unless social hunter; eats many prey; immediately fatal; stability usually LOW
H	**High potential**	Predation has a high potential to regulate prey: each predator eats many prey, each kill is fatal

Microparasite: microscopic; Macroparasite: smaller, usually mild, LOW regulation; Parasitoid: same size, fatal later; Predator: larger, kills at once; High: regulation

L11 s07, L11 s08

BG · NF · SR Six traits across the continuum

Body size, Growth rate / Number per host, Fatality / Stability, Regulation

B	**Body size**	Microscopic; smaller than host; similar in size (wasp and moth); often larger than prey
G	**Growth rate**	Intrinsic rate: rapid; faster than hosts; comparable to host; often slightly slower than prey
N	**Number per host**	Several species per host; a few to many per host; usually one per host; each predator eats many prey
F	**Fatality to host**	Mild to severe; usually mild; eventually fatal; immediately fatal
S	**Stability**	Of the interaction with host: intermediate; high; intermediate; usually low
R	**Regulation**	Ability to regulate host: moderate to high; LOW (macroparasite); moderate to high; high

Body size: rises; Growth: rapid to slower; Number: many per host to many prey; Fatality; Stability; Regulation. Trap: NOT every trait rises; macroparasite is usually mild

L11 s07

L11.2 Predation and population growth

C · SL · FP Hare and lynx cycles

Coupled / Snowshoe hare, Lag / Food first, Peaks after

C	**Coupled oscillations**	Predator and prey abundances cycle in linked ups and downs
S	**Snowshoe hare, Canada lynx**	9 to 11 year coupled oscillations, from Hudson's Bay Company pelt trading records
L	**Lag**	Predator growth often trails (lags behind) prey growth; predators do NOT lead
F	**Food source first**	The predator cannot begin to increase until its food source begins to increase
P	**Peaks**	Lynx peaks come just after hare peaks: at a hare peak, lynx keep rising, then peak

Coupled: linked waves; Snowshoe: hare and lynx, nine to eleven years; Lag: predator trails; Food: comes first; Peaks: lynx after hare. Trap: predators do NOT lead

L11 s10

NN · B · GH Introduced predators and extinction

Non-native, Not adapted / Brown tree snake / Guam birds, High s

N	**Non-native predators**	Introduction of non-native predators can cause extinction of prey
N	**Not adapted**	Why: the prey are not adapted to a predator they have never met
B	**Brown tree snake**	Boiga irregularis, introduced to the island of Guam: the introduced predator example
G	**Guam birds**	Native bird species on Guam fell to zero or near zero
H	**High s**	If searching efficiency s is very high, like an introduced predator, prey removal can cause extinction

Non-native: introduced predator; Not adapted: prey never met it; Brown tree snake: on Guam; Guam birds: to zero; High s: prey removal beats prey growth

L11 s11, L11 s14

L11.3 Lotka-Volterra predator-prey model

GS · N · CS · N Prey equation step by step

Geometric start, Searching s / Number of prey and predators / Consumption, Subtract / N both sides

G	**Geometric increase**	Start with geometric increase of prey: N(t+1) = R0 x N(t)
S	**Searching efficiency (s)**	s = searching efficiency, or attack rate, of the predators (NOT a prey survival rate)
N	**Number of prey, predators**	Prey attacked also depends on the number of prey (N) and the number of predators (P)
C	**Consumption (sPN)**	Consumption of prey combines all three: sPN, the prey removed by predators
S	**Subtract sPN**	Prey equation: N(t+1) = R0 N(t) - s P(t) N(t)
N	**N on both parts**	N is in the positive and negative parts: more prey means more births and more prey to eat

Geometric: N(t+1) = R0 N(t); Searching: s, attack rate; Number: N and P; Consumption: sPN; Subtract: R0N - sPN; N: on both sides. Trap: sPN is removal, NOT growth

L11 s13, L11 s14

BEG · MS Predator equation step by step

Births from E, Growth / Mortality, Subtract

B	**Birth rate**	Predator birth rate depends on sPN (prey eaten) and on e
E	**e (efficiency)**	How efficiently predators turn food into new predators
G	**Growth term esPN**	P(t+1) = e s P(t) N(t): in the predator equation, esPN is predator growth
M	**Mortality (m)**	Predator death depends on a mortality rate m and the number of predators P, regardless of prey
S	**Subtract mP**	Predator equation: P(t+1) = e s P(t) N(t) - m P(t); mP is predator death

Births: depend on sPN; E: efficiency, food into new predators; Growth: esPN; Mortality: m times P; Subtract: esPN - mP. Trap: e is NOT search, s is

L11 s15, L11 s16

Z · PB · PL · CO Two zero isoclines

Zero line / Prey flat, Below and above / Predator upright, Left and right / Combined, Other pairs

Z	**Zero isocline**	Line where a population stops changing; one for prey, one for predators
P	**Prey zero isocline**	Horizontal line at r/s on the predator axis (r = prey growth, R0 in the equations)
B	**Below and above**	Below r/s prey increase; above r/s prey decrease
P	**Predator zero isocline**	Vertical line at m/es on the prey (N) axis
L	**Left and right**	Left of m/es (too few prey) predators decrease; right of m/es predators increase
C	**Combined**	Both isoclines together give coupled oscillations; the predator wave peaks after the prey wave
O	**Other pairs**	Lotka-Volterra also fits parasitoid and host, or herbivore and plant, if attack increases death

Zero: no change; Prey: flat at r/s; Below: prey up; Predator: upright at m/es; Left: predators down; Combined: cycles; Other: parasitoid, herbivore. Trap: NOT swapped

L11 s17, L11 s18

L11.4 Red Queen and predator adaptations

RR · CF Red Queen: running to stay put

Red queen keeps Running / Cheetah and gazelle, Faster

R	**Red queen hypothesis**	Predator and prey keep evolving just to stay level; each must keep adapting to hold its place
R	**Running**	Quote: it takes all the running you can do, to keep in the same place (Through the Looking-Glass)
C	**Cheetah and gazelle**	The classic example supporting the red queen hypothesis
F	**Faster and faster**	Both became faster; any gain in speed by one was generally matched by the other

Red queen: keep evolving to stay level; Running: all you can do, same place; Cheetah: classic example; Faster: both, gains matched. Trap: NOT one species winning

L11 s20, L11 s21

CL · CM · P Predator coloration

Coloration hides the Lizard / Crab spider, Mantis / Prey contrast

C	**Coloration**	An adaptation of predators: they use coloration to hide while hunting
L	**Lizard and grasshopper**	The first predator coloration example
C	**Crab spiders**	Match their flowers: yellow spider on yellow petals, pale spider on white flowers; ambush insects
M	**Mantis**	A flower colored mantis on an orchid seizes a wasp: a predator resembling a flower
P	**Prey contrast**	Prey use cryptic coloration to avoid detection; mass reproduction (satiation) is a PREY defense

Coloration: predators hide while hunting; Lizard: and grasshopper; Crab spider: matches its flower; Mantis: flower look, wasp; Prey: satiation is a PREY defense

L11 s22, L11 s23, L11 s25, L11 s26, L11 s27

L11.5 Antipredator adaptations

CM · PI · P Antipredator adaptations

Cryptic, Mimicry / Physical, Intimidation / Predation satiation

C	**Cryptic coloration**	Blending of an organism with the background of its habitat (Indian leaf butterfly, pygmy seahorse)
M	**Mimicry**	A mimic resembles a model, which secures protection; two major types, Batesian and Müllerian
P	**Physical defenses**	Armor, claws, stingers, horns; the ornate box turtle shell deters much larger predators
I	**Intimidation**	Looking threatening: the porcupine fish puffs itself up (NOT cryptic coloration)
P	**Predation satiation**	Synchronous production of many progeny to satiate predators: 13 and 17 year cicadas

Cryptic: blend in; Mimicry: look like a model; Physical: armor, claws, stingers, horns; Intimidation: puff up; Predation satiation: many young at once

L11 s27, L11 s28, L11 s29, L11 s30, L11 s31

CB · DV · IP Cryptic coloration

Camouflage, Background / Detection, Vertebrates / Indian leaf butterfly, Pygmy seahorse

C	**Camouflage**	Cryptic coloration is an aspect of camouflage
B	**Background**	The blending of an organism with the background of its habitat
D	**Detection**	A common method of avoiding detection by predators
V	**Vertebrates**	Cryptic coloration is prevalent in the vertebrate world
I	**Indian leaf butterfly**	Mimics the leaves on which it rests
P	**Pygmy seahorse**	Blends in with its background

Camouflage: an aspect of it; Background: blend with habitat; Detection: avoided; Vertebrates: prevalent; Indian: leaf butterfly; Pygmy: seahorse. Trap: puffing up NOT it

L11 s27, L11 s28

BS · MV Batesian vs Müllerian mimicry

Batesian: Scarlet king snake / Müllerian: Viceroy

B	**Batesian mimicry**	A palatable (harmless) mimic copies an unpalatable model; the mimic gains protection, NOT toxic
S	**Scarlet king snake**	Batesian: the innocuous scarlet king snake mimics the poisonous coral snake
M	**Müllerian mimicry**	Many noxious species converge to look the same, reinforcing the distasteful design
V	**Viceroy, queen, monarch**	Müllerian: share the same warning coloration; all three are toxic to birds

Batesian: tasty mimic, bad model; Scarlet: king snake copies coral snake; Müllerian: all noxious converge; Viceroy: queen, monarch. Trap: Batesian mimic is NOT toxic

L11 s27, L11 s29

SM · FC · GS Predation satiation in cicadas

Synchronous, Many progeny / Full predators, Can't keep up / Grubs burrow, Some survive

S	**Synchronous**	All individuals in the population produce progeny at the same time
M	**Many progeny**	Huge numbers at once: 13 and 17 year periodical cicadas are the example
F	**Full predators**	Predators are satiated (fill up)
C	**Can't increase**	Predators can't increase their population quickly enough to eat a large percentage of cicadas
G	**Grubs burrow**	That holds until cicadas finish their life cycle and the grubs burrow back into the ground
S	**Some survive**	So some individuals survive

Synchronous: all at once; Many: progeny; Full: predators fill up; Can't: raise numbers in time; Grubs: burrow back; Some: survive. Trap: NOT toxic, NOT camouflage

L11 s27, L11 s31

L11.6 Herbivory and plant defenses

H · F · LTG Herbivory and what herbivores eat

Herbivory / Flowers to sap / Leaf chewers, Termites, Galago

H	**Herbivory**	Predation of plants or algae
F	**Flowers to sap**	Herbivores feed on flowers, seeds, leaves, nectar, roots, wood, bark, and sap
L	**Leaf chewers**	Like grasshoppers: eat leaves
T	**Termites**	Consume wood
G	**Galago**	Eats sap

Herbivory: predation of plants or algae; Flowers to sap: all plant parts; Leaf chewers: grasshoppers; Termites: wood; Galago: sap. Trap: NOT only leaf chewers

L11 s33

G · PMC · MA · M Green world and plant defenses

Green world / Plant defenses: Mechanical, Chemical / Mutualisms, Associational resistance / Mimicry

G	**Green world**	Observation: we live in a green world; why is more plant material not eaten?
P	**Plant defenses**	Part of the hypothesized answer; five types (gall formation is an herbivore trick, NOT one)
M	**Mechanical**	Thorn, cactus spines, stem prickles, a tiny hair, spiny holly leaves
C	**Chemical**	Second defense on the list
M	**Mutualisms**	Partners that help defend the plant
A	**Associational resistance**	Safety from neighbors: a plant is eaten less because of plants growing near it
M	**Mimicry**	Pebble-like plants blend with the gravel around them

Green: why is more plant not eaten?; Plant defenses: answer; Mechanical: thorns; Chemical; Mutualisms: partners; Associational: neighbors; Mimicry: pebbles. NOT gall

L11 s34, L11 s35

E · MBD · SH Herbivores fight back

Evolutionary arms race / Mechanical, Behavioral, Digestive / Symbiotic, Host manipulation

E	**Evolutionary arms race**	Plants and herbivores, much like the Red-queen hypothesis; pebble mimicry is the PLANT side
M	**Mechanical**	Herbivore means 1: flattened teeth for grinding
B	**Behavioral**	Herbivore means 2
D	**Digestive**	Herbivore means 3
S	**Symbiotic**	Herbivore means 4: gut microorganisms, partners living in the gut that help digest plants
H	**Host manipulation**	Herbivore means 5: gall formation, like the goldenrod gall fly

Evolutionary: arms race, like Red Queen; Mechanical: flat teeth; Behavioral; Digestive; Symbiotic: gut microbes; Host: galls. Trap: pebble look is a PLANT defense

L11 s33, L11 s36

Lecture 12

L12.1 Parasitism vs predation and other interactions

CP · PP Community and parasitism basics

a Community of Plus minus / Pathogens Prevent huge growth

C	**Community**	Assemblage of many populations living in the SAME place at the same time; the level after interaction
P	**Plus minus (+/-)**	Parasitism is +/-: the parasite gets nourishment from its host, which is harmed in the process
P	**Pathogens**	ALL pathogens (disease-causing organisms) fall into the parasitism category
P	**Prevents large populations**	One of the things that can prevent populations from reaching incredibly large sizes

Community: many populations, same place, same time; Plus minus: +/-, host harmed; Pathogens: all count as parasites; Prevent: keeps populations from huge sizes

L12 s05, L12 s06, L12 s08, L12 s09

E · KI · T Parasitism vs predation

parasite Exploits / predator Kills, Immediate death / parasite Takes time

E	**Exploits the host**	Parasitism: the parasite exploits the host, which is affected adversely
K	**Kills and consumes**	Predation: the predator kills and consumes the host
I	**Immediate mortality**	Predation leads to immediate mortality
T	**Takes time**	Parasitism may not lead to mortality, or at least takes some time for mortality to occur

Exploits: host affected adversely; Kills: predator kills and consumes; Immediate: predation deaths; Takes time: parasitism may not kill. Trap: parasitism is NOT predation

L12 s10, L12 s36

MM · PP Micro, macro, parasitoid, predator

Micro, Macro / Parasitoid, Predator

M	**Microparasite**	Bacteria and viruses; microscopic; rapid growth; mild to severe; moderate to high regulation
M	**Macroparasite**	Multicellular eukaryotes smaller than host; usually mild; stability HIGH; LOW ability to regulate
P	**Parasitoid**	Often a larva inside the host; similar size (wasp and moth); usually one per host; eventually fatal
P	**Predator**	Often larger than prey; eats many prey; immediately fatal; stability usually LOW; regulation high

Micro: bacteria, viruses; Macro: many-celled, usually mild; Parasitoid: host-sized larva, eventually fatal; Predator: immediately fatal. Trap: macro is mildest

L12 s11, L12 s17, L12 s20, L12 s27

BG · NF · SR Enemy table read trait by trait

Body size, Growth / Number per host, Fatality / Stability, Regulate

B	**Body size**	Microscopic; smaller than host; similar to host; often larger than prey: rises toward predator
G	**Growth rate**	Rapid; faster than hosts; comparable to host; comparable or slightly slower than prey: it FALLS
N	**Number per host**	Several species per host; few to many per host; usually one per host; each predator eats many prey
F	**Fatality to host**	Mild to severe; usually mild; eventually fatal; immediately fatal: NOT a steady rise (macro mildest)
S	**Stability**	Intermediate; HIGH; intermediate; usually LOW: macroparasites most stable, predators least
R	**Regulate host population**	Moderate to high; LOW; moderate to high; high: macroparasites regulate the least

Body: size rises; Growth: falls; Number: per host; Fatality: macro mildest; Stability: macro high, predator low; Regulate: macro low. Trap: title says all rise; not so

L12 s11, L12 s20, L12 s27

L12.2 How common parasitism is

VA · M · OT Parasitism is very common

Very common, Almost all / host Many / Overlooked, yet a Toll

V	**Very common**	Parasitism is VERY common, and this includes pathogens; NOT a rare oddity
A	**Almost every organism**	Almost every organism contains some parasites
M	**Many parasite species**	Most species are parasitized by MANY different species, not just one
O	**Overlooked**	Often overlooked because of modern medicine and animal husbandry (livestock care) practices
T	**Toll**	Parasitism still takes a toll on humans and agriculture

Very: common, pathogens included; Almost: every organism has some; Many: parasite species per host; Overlooked: medicine, husbandry; Toll: on humans and agriculture

L12 s12

P · LD · HA Parasite web and helminth counts

Parasite web / a Lake gets Denser / Helminths love Aves

P	**Parasite web**	A food web that includes the parasite links
L	**Lake Takvatn**	Pelagic (open-water) food web studied without, then with, parasite-related links
D	**Denser web**	Adding parasite links adds many new links: the web gets much denser, NOT simpler
H	**Helminths**	Parasitic worms; helminth species per vertebrate host differ by host group
A	**Aves (birds)**	Birds have the most helminth species per host; Chondrichthys has the fewest

Parasite web: parasite links drawn in; Lake: Takvatn, without vs with; Denser: many more links; Helminths: parasitic worms; Aves: birds most, Chondrichthys fewest

L12 s02, L12 s03, L12 s13, L12 s15

L12.3 Microparasites

VS · V · Z Rinderpest and the zebra

a Virus Spreads / then Vaccine / Zebra spared

V	**Virus**	Rinderpest is a virus (microparasite): about 80% mortality in cattle across Africa, late 1800s
S	**Spread to grazers**	Spread from cattle to buffalo, wildebeest, giraffe, warthog, and other grazers
V	**Vaccinated cattle**	Cattle were vaccinated, and buffalo and wildebeest populations rebounded
Z	**Zebra**	Zebra was NOT affected by rinderpest; its numbers stayed flat

Virus: rinderpest, a microparasite, 80% cattle deaths; Spreads: to buffalo, wildebeest, giraffe, warthog; Vaccine: cattle, then rebound; Zebra: NOT affected

L12 s17, L12 s18

FD · HP Plant density and pathogen load

Fungi fade as Density drops / Higher diversity, low Pathogen load

F	**Fungal infections**	Plants get viruses and bacteria too, but fungal infections can be especially common
D	**Density declines**	Infections are less common as the density of an individual species declines
H	**Higher plant diversity**	Higher plant diversity means lower density per species, and less infection
P	**Pathogen load**	Percent of leaf area infected; it falls as plant species richness rises

Fungi: common in plants; Density: lower density, fewer infections; Higher: diversity lowers density; Pathogen load: % leaf infected. Trap: NOT less as density rises

L12 s19

L12.4 Macroparasites and parasitoids

EM · S Ectoparasites on the outside

Ectoparasites have More hosts / and Spread disease

E	**Ectoparasites**	Macroparasites on the OUTSIDE of the host: ticks, leeches, and fleas
M	**More potential hosts**	Often more potential hosts (less specialized) than macroparasites living inside the host
S	**Spread diseases**	Ectoparasites, like ticks, may also spread diseases to their hosts

Ectoparasites: outside the host, ticks, leeches, fleas; More: potential hosts, less specialized; Spread: ticks carry disease. Trap: leeches are ecto, NOT endo

L12 s21, L12 s22, L12 s24

AC · N · T Acorns, chipmunks, ticks in time

Acorns feed Chipmunks / Nymphal ticks / Two years behind

A	**Acorns**	Start of the chain; tracked with chipmunks and nymphal ticks at two plots
C	**Chipmunks**	Chipmunk numbers follow acorns with a 1-year lag
N	**Nymphal ticks**	Nymphal ticks follow chipmunks with another 1-year lag
T	**Two-year lag**	So ticks lag acorns by 2 years (the long arrow back to the ticks)

Acorns: start; Chipmunks: 1 year after acorns; Nymphal: ticks 1 year after chipmunks; Two: years from acorns to ticks. Trap: acorns come first, NOT ticks

L12 s23

IS · IC · T Endoparasites inside the host

Inside, Specialized / Intermediate hosts, Complex cycles / Tapeworms

I	**Inside the host**	Endoparasites are macroparasites that live INSIDE the host
S	**Specialize**	Endoparasites generally specialize on one or a few host species
I	**Intermediate hosts**	Endoparasites often HAVE intermediate hosts (extra hosts in the life cycle)
C	**Complex life cycles**	Many have complex life cycles with multiple hosts
T	**Tapeworm and fluke**	Worm examples: roundworm, hookworm, fluke, tapeworm, nematode; a tick is NOT one of them

Inside: lives in host; Specialized: one or a few hosts; Intermediate: extra hosts; Complex: multi-host cycles; Tapeworms: plus flukes, hookworms. Trap: ticks are ecto

L12 s15, L12 s24, L12 s26

ES · ST · FH Snail, frog, heron life cycle

Eggs, Snail / Swimming larvae, Tadpole / Frog, Heron

E	**Eggs**	Step 1: eggs
S	**Snail**	Step 2: a snail, the first host
S	**Swimming larvae**	Step 3: swimming larvae
T	**Tadpole**	Step 4: tadpole
F	**Frog**	Steps 5 and 6: young frog, then adult frog; infected frogs show limb malformations
H	**Heron**	Step 7: a heron holds a frog, then eggs again; hosts are snail, frog, and heron

Eggs: start; Snail: first host; Swimming: larvae; Tadpole: next host; Frog: young to adult, malformed limbs; Heron: eats frog, eggs again. Trap: no mouse in it

L12 s25, L12 s26

OG · MA Aphid wasp and the mummy

Oviposit, Grow / Mummy, Adult

O	**Oviposition**	Adult wasp (Lysiphlebus testaceipes) lays an egg in the aphid, a greenbug
G	**Growth of larva**	The parasite larva grows inside; the greenbug is still alive
M	**Mummy**	The greenbug dies; the parasite pupates; the result is a mummy
A	**Adult emerges**	The adult parasite emerges; the winged adult loops back to oviposition

Oviposit: egg laid in aphid; Grow: larva grows, host alive; Mummy: host dies, parasite pupates; Adult: emerges, loops back. It is a parasitoid: eventually fatal

L12 s27, L12 s28

LI · TB · SN Glyptapanteles bodyguard caterpillar

Larvae grow to an Instar / Toxin makes a Bodyguard / Silk, No longer inside

L	**Larvae deposited**	Wasp larvae are deposited in the caterpillar, which keeps growing and feeding normally
I	**Instar**	At the 4th or 5th instar, up to 80 fully grown larvae emerge to pupate
T	**Toxin**	Just BEFORE emerging, the larvae produce a toxin
B	**Bodyguard**	Caterpillar guards until they pupate: sits near cocoons, arches its back, stops moving and feeding
S	**Silk**	It sometimes spins silk over the pupae and thrashes violently when disturbed
N	**No longer in host**	The behavior is induced by a parasite that is no longer in the host

Larvae: put in caterpillar; Instar: 4th or 5th, up to 80 emerge; Toxin: just before; Bodyguard: guards cocoons; Silk: over pupae; No longer: parasite out of host

L12 s29

L12.5 Parasitism and global change

MC · P · OB What warming's effect depends on

Metric, Curve shape / Projected rise / Optimum, Baseline

M	**Metric of disease risk**	The metric of disease risk being measured
C	**Curve shape**	The shape of the temperature curve
P	**Projected increase**	The projected temperature increase
O	**Optimal temperature**	The optimal temperature value
B	**Baseline temperature**	The baseline temperature; the host's body size is NOT on the list

Metric: of disease risk; Curve: temperature curve shape; Projected: warming amount; Optimum: optimal temperature; Baseline: start temp. Trap: host body size NOT listed

L12 s31

V · A · E Three pathogen climate graphs

Vectors peak / warming Accelerates / or Exceeds tolerance

V	**Vectorial capacity**	Top: vectorial capacity (R0) rises to an optimum temperature, then falls; Topt1, Topt2, Topt3
A	**Accelerates transmission**	Middle: warming accelerates the transmission cycle; warmed line rises earlier and higher
E	**Exceed thermal tolerance**	Bottom: warming exceeds upper thermal tolerance; warmed line peaks, dips midsummer, peaks again

Vectors: vectorial capacity peaks at an optimum; Accelerates: earlier, higher transmission; Exceeds: upper tolerance, two peaks. Trap: more warming NOT always better

L12 s31

W · MO · CI Malaria and coral under warming

Warmer / Malaria, One degree / Coral, Increased

W	**Warmer temperatures**	Many parasites do better under warmer temperatures
M	**Malaria in Ethiopia**	Higher altitude means lower malaria; endemicity shown as percent spleen enlargement
O	**One degree C**	1 degree C warmer = 15% MORE malaria, equal to a 150 m DROP in elevation
C	**Coral disease CYBD**	Caribbean yellow banding disease rose over the years in Montrastraea coral off Puerto Rico
I	**Increased prevalence**	Higher average water temperature went with higher mean prevalence of the disease

Warmer: parasites do better; Malaria: falls with altitude; One degree: 15% more, a 150 m drop; Coral: CYBD rose over the years; Increased: warmer water, more disease

L12 s32, L12 s33

NN · OE · M Nutrients feed pathogens

Nutrients, Nitrogen / Ocean, Eutrophication / More input

N	**Nutrient availability**	Increased nutrient availability can also increase pathogen abundance
N	**Nitrogen**	Added nitrogen INCREASED plant pathogen load on C4 grasses vs ambient N
O	**Ocean and freshwater**	Increased nutrients can also increase pathogen abundance in the ocean and freshwater
E	**Eutrophication**	Eutrophication affected amphibian infections by Ribeiroia trematodes (parasitic flatworms)
M	**More parasite input**	More parasite input means more infection: no input stays at 0, high input rises most

Nutrients: raise pathogen abundance; Nitrogen: more C4 grass pathogens; Ocean: and freshwater too; Eutrophication: Ribeiroia in amphibians; More: input, more infection

L12 s34, L12 s35

AH · RC Review: amensalism and red queen

Amensalism, Host density / Red queen, Cheetah

A	**Amensalism**	Amensalism is - for one species and 0 for the other (review question 2)
H	**Host density**	Infections are less common as host density declines; nymphal ticks follow chipmunks by 1 year
R	**Red queen**	Red queen hypothesis: it takes all the running you can do to stay in place
C	**Cheetah and gazelle**	Both got faster, gains matched; so host gains would be matched by parasite gains

Amensalism: - for one, 0 for the other; Host density: fewer hosts, fewer infections; Red queen: run to stay in place; Cheetah: gains matched, like host and parasite

L12 s36, L12 s19, L12 s23, L11 s20, L11 s21

Lecture 13

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

BB · TH Bottom-up vs top-down models

Bottom-up from the Base / Top-down from Higher levels

B	**Bottom-up model**	Predicts that food or prey resources regulate herbivore and predator abundances
B	**Base of food web**	Bottom-up: the base of the food web controls the populations of higher trophic levels
T	**Top-down model**	Predicts that natural enemies are the key constraint on prey abundances
H	**Higher trophic levels**	Top-down: higher trophic levels control the trophic levels below

Bottom-up: food or prey resources regulate; Base: controls higher levels; Top-down: natural enemies constrain prey; Higher: levels control below. Trap: NOT predators

L13 s03, L13 s05, L13 s06

PH · PN · E Four trophic levels

a Predator eats the Herbivore / Plants take Nutrients / Energy drops

P	**Predator**	Secondary or tertiary consumer, the top level listed
H	**Herbivore/Detritivore**	Plant eater or dead matter eater: the primary consumer
P	**Plants/Organic matter**	Primary producers, also called basal resources (the base food supply)
N	**Nutrients/Energy**	Usually from abiotic sources like the sun, soil, chemical weathering (NOT detritivores)
E	**Energy drops**	Energy drops at each trophic level going up the pyramid

Predator: secondary, tertiary consumer; Herbivore: or detritivore, primary; Plants: basal resources; Nutrients: abiotic; Energy: drops. Trap: detritivores NOT abiotic

L13 s04

HG · SG Grasshopper, spider, host plant drawing

Host plants feed Grasshoppers / Spiders eat Grasshoppers

H	**Host plant quality**	Bottom-up step 1: host plant quantity or quality limits grasshopper (herbivore) density
G	**Grasshoppers limit spiders**	Bottom-up step 2: herbivores limit predators; many host plants: dense herbivores, more spiders
S	**Spiders limit grasshoppers**	Top-down step 1: spiders (predators) limit grasshoppers (herbivores)
G	**Grasshoppers limit plants**	Top-down step 2: herbivores limit plants; high predation: fewer herbivores, dense host plants

Host plants: quantity or quality sets herbivores; Grasshoppers: set spiders; Spiders: control grasshoppers; Grasshoppers: set plants. Top-down result: dense plants

L13 s05, L13 s06

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

FN · FR · B Water hyacinth and weevils

Fertilizer adds Nitrogen / Females Reproduce / from the Bottom up

F	**Fertilizer (N, P, K)**	Step 1: water hyacinth is grown with N, P, K fertilizer
N	**Nitrogen in tissues**	Step 2: fertilized water hyacinth has higher nitrogen in its tissues
F	**Female weevils**	Step 3: higher abundances of female weevils in the high fertilizer treatments
R	**Reproductive**	And a greater percent of those females were reproductive (more AND more reproductive)
B	**Bottom-up control**	Evidence for bottom-up control of herbivore populations: food quality limits weevils

Fertilizer: N, P, K; Nitrogen: rises in plant tissue; Females: more female weevils; Reproduce: greater percent reproductive; Bottom-up: food limits weevils, NOT predators

L13 s08, L13 s09, L13 s10

L13.3 Bottom-up effects on pathogens

PC · TE · F Bottom-up effects on pathogens

Pathogens in C4 grass / Tanks with Eutrophication / Frog malformations

P	**Pathogens**	The question: can bottom-up effects influence pathogens? Yes, more nutrients raised disease
C	**C4 grasses**	Added nitrogen RAISED C4 grass pathogen load, compared with ambient nitrogen
T	**Tanks**	More parasite input in the tanks meant more infection
E	**Eutrophication**	Nutrient enrichment affected amphibian infections by Ribeiroia trematodes
F	**Frog malformations**	Review: False that contaminants cause them; they are tied to trematode infection

Pathogens: yes, bottom-up reaches them; C4: added N raised load; Tanks: more parasites, more infection; Eutrophication: nutrients; Frog: trematodes, NOT contaminants

L13 s11, L13 s12, L13 s13, L13 s14, L12 s35, L13 s34

ACT · T Acorn, chipmunk, tick lags

Acorns, Chipmunks, Ticks / Two years

A	**Acorns**	The bottom of the chain: acorns come first, then chipmunks, then ticks
C	**Chipmunks**	Follow acorns by a 1-year lag
T	**Ticks (nymphal)**	Nymphal ticks follow chipmunks by a 1-year lag
T	**Two-year lag**	Acorns to ticks overall: a 2-year lag

Acorns: the start; Chipmunks: 1 year after acorns; Ticks: nymphs 1 year after chipmunks; Two years: acorns to ticks overall. Trap: acorns come first, NOT chipmunks

L13 s15

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

NF · O · DP Stream nutrient chain

Nutrients feed Fungi / on Organic matter / for Detritivores like Pycnopsyche

N	**Nutrients (N, P)**	Step 1: nutrients (N, P) added to 5 headwater streams; effects on leaf litter, aquatic insects
F	**Fungi**	Step 2: nutrients stimulated aquatic fungi from the bottom up
O	**Organic matter**	Step 3: leaf organic matter had increased nutrient content
D	**Detritivores**	Step 4: populations of aquatic detritivores increased (predators did NOT rise with them)
P	**Pycnopsyche**	Case-building caddisfly that eats dead organic matter; populations increased dramatically

Nutrients: N, P in 5 headwater streams; Fungi: aquatic, stimulated; Organic: leaf litter richer; Detritivores: increased; Pycnopsyche: case-building caddisfly

L13 s16, L13 s17, L13 s18

TR · PN Trophic dead end

a Trophic dead end of Resistant taxa / Primary consumers up, Not predators

T	**Trophic dead end**	A bottom-up gain that stops before the predators
R	**Resistant taxa**	Predation resistant taxa within a trophic level that higher trophic levels cannot use
P	**Primary consumers**	Nutrients added to a headwater stream stimulate primary consumers (like Pycnopsyche)
N	**Not predators**	But NOT predators: the gain stops at the primary consumers

Trophic dead end: gain stops early; Resistant: predation resistant taxa; Primary: consumers rise; Not: predators. Trap: a bottom-up boost does NOT always reach predators

L13 s19

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

L · W · LR Experimental lake: bass removed

Largemouth bass removed / Which side / Left none, Right on top

L	**Largemouth bass**	Top-down lake example: largemouth bass were removed from one side of the lake
W	**Which side**	The question: which side of the lake had the bass removed?
L	**Left chain**	No bass: small fish, water flea, algae
R	**Right chain**	Bass on top of the same chain

Largemouth: bass removed from one side; Which: the question; Left: no bass; Right: bass on top. Trap: nothing was fertilized; this is a top-down example

L13 s21, L13 s22

KO · UK · E Killer whale, otter, urchin, kelp

Killer whales eat Otters / Urchins eat Kelp / Enemy of my enemy

K	**Killer whales**	Top predators: predation from killer whales increased
O	**Otters**	Sea otters DECREASED
U	**Urchins**	Sea urchins INCREASED
K	**Kelp**	Kelp DECREASED
E	**Enemy of my enemy**	Memory aid: enemy of my enemy is my friend

Killer whales: more predation; Otters: decrease; Urchins: increase; Kelp: decrease; Enemy: of my enemy is my friend. Pattern down, up, down

L13 s23

T · PA · FUS Average strength: top-down wins

Twenty-three studies / Predators stronger, Adding predators / Fertilizer for plants, Unchanged, Strong

T	**Twenty-three studies**	Average of 23 studies: (a) fertilizer with and without predators; (b) predator removal
P	**Predator removal**	Top-down predator removal has a STRONGER effect on herbivores than fertilizer (bottom-up)
A	**Adding predators**	Decreases herbivores and increases plants
F	**Fertilizer**	Raises plant biomass but does NOT significantly raise herbivores, ON AVERAGE
U	**Unchanged**	Fertilizer effect on plants unchanged by predators; predator effect on plants unchanged by fertilizer
S	**Strong effects**	Strong effects of predators on all trophic levels

Twenty-three: studies; Predators: stronger on herbivores; Adding: fewer herbivores; Fertilizer: plants only; Unchanged: by the other; Strong: all levels

L13 s24

L13.6 Trophic cascades

T · P · BI Trophic cascade defined

a Trophic cascade / Predators reduce prey / down to Basal resources, Indirect

T	**Trophic cascade**	Top-down effects cascade to lower trophic levels
P	**Predators reduce prey**	Predators typically reduce prey abundance, which benefits the next trophic level down
B	**Basal resources**	More simply: consumer effects on resources at the food web base (basal resources)
I	**Indirect control**	A cascade is indirect control of lower levels; predators do NOT control plants directly

Trophic cascade: top-down effects ripple down; Predators: reduce prey, next level benefits; Basal: food web base; Indirect: NOT direct, predators do not eat plants

L13 s25, L13 s26

PC · P Cascade in steps

Predators cut Consumers / so Plants grow

P	**Predators**	Step 1: predation reduces consumers
C	**Consumers fall**	Step 2: fewer consumers are left to eat the plants
P	**Plants increase**	Step 3: plants increase in biomass or abundance

Predators: reduce consumers; Consumers: fewer of them; Plants: increase in biomass or abundance. Trap: plants do NOT increase first, and predators add no nutrients

L13 s26

S · R · NB Two lake chains by the cascade rule

Secondary consumer / by the Rule / No bass or Bass on top

S	**Secondary consumer**	The question: explain top-down effects with and without a secondary consumer (top predator)
R	**Rule**	The rule: a predator lowers its prey and benefits the level below
N	**No bass**	Small fish lower zooplankton (water flea), which benefits phytoplankton (algae): they rise
B	**Bass on top**	Bass lower small fish, zooplankton benefit and rise, so phytoplankton fall

Secondary: top predator question; Rule: a predator lowers its prey, benefits the level below; No bass: algae rise; Bass: algae fall. The chains show no arrows

L13 s25, L13 s26, L13 s27, L13 s28

L13.7 Trophic downgrading and zoonotic disease (Lyme)

T · LWL Trophic downgrading of earth

Trophic downgrading / Loss in Water and on Land

T	**Trophic downgrading**	Top-down interactions are becoming LESS common
L	**Loss**	Loss of key top-down interactions completely changes ecosystem structure
W	**Water**	Sea otter and kelp; Pisaster and mussels; bass, zooplankton, phytoplankton; sharks
L	**Land**	Arctic fox and seabirds; jaguar and rainforest herbivores; wolves and elk; wildebeest, rinderpest

Trophic downgrading: top-down becoming LESS common, NOT more; Loss: changes structure; Water: otter, Pisaster, bass, sharks; Land: fox, jaguar, wolves

L13 s29, L13 s30

CF · MA · DR · T Lyme diagram chain

Coyote over Fox / over Mouse over Acorn / Dilution and Reproductive hosts / Ticks

C	**Coyote**	Predator interference, reduce P: coyotes reduce the small mammal predators (foxes)
F	**Fox**	Small mammal predators, P
M	**Mouse**	Small mammal hosts, Nm
A	**Acorn**	Resource availability, K: the bottom of the four-level chain
D	**Dilution hosts**	Dilution hosts, F: squirrel and lizard
R	**Reproductive hosts**	Reproductive hosts, increase v: deer and fawn
T	**Ticks**	Tick stages: larva, nymphs and adults

Coyote: reduce P; Fox: P; Mouse: Nm hosts; Acorn: K; Dilution: squirrel, lizard; Reproductive: deer; Ticks: larva, nymphs, adults. Trap: coyotes reduce foxes, NOT mice

L13 s31, L13 s33

Z · CF · U Lyme risk and predator restructuring

Zoonotic disease / Coyotes per fox up, Foxes down / Unintended consequences

Z	**Zoonotic disease**	Animal disease that infects people; the top-down example is Lyme disease
C	**Coyotes per fox**	Lyme incidence RISES with more coyotes per fox
F	**Foxes**	Lyme incidence FALLS with more foxes
U	**Unintended consequences**	Restructuring of predator communities may have unintended consequences for human disease risk

Zoonotic: animal disease that infects people; Coyotes per fox: more, Lyme rises; Foxes: more, Lyme falls; Unintended: human disease risk. Trap: coyotes do NOT lower Lyme

L13 s31, L13 s32

R · I · ELM Review: top predator and parasites

Remove the top / Immediate death / Exploit, Larger, Many

R	**Remove top predator**	Review 1: remove a top predator and its prey rise while the level below falls
I	**Immediate mortality**	Predation means immediate mortality; parasitism may not kill, or takes time
E	**Exploit**	The parasite exploits the host; the predator kills and consumes it
L	**Larger**	Predators are often larger than prey; macroparasites are smaller than the host
M	**Many prey**	Each predator eats many prey; one host supports a few to many macroparasites

Remove: prey rise, level below falls; Immediate: predation kills now; Exploit: parasite uses host; Larger: predators bigger; Many: predator eats many prey

L13 s34, L12 s10, L12 s11

Lecture 14

L14.1 Defining communities: organismic vs individualistic models

SP · S · H Organismic model

a Superorganism is Predictable / with Sharp edges / Hypothesis one

S	**Superorganism**	Community equals a superorganism, like an animal body that is more than just a collection of organs
P	**Predictable**	A community was predictable, with distinct associations of species
S	**Sharp boundaries**	Separate communities were separated by sharp boundaries
H	**Hypothesis 1**	The organismic model is hypothesis 1; the mountain vegetation results did NOT support it

Superorganism: like an animal body, more than its organs; Predictable: distinct associations; Sharp: boundaries; Hypothesis one: NOT supported by the results

L14 s07, L14 s08, L14 s11, L14 s12

P · NN · H Individualistic model

Physiological needs / No boundaries, No groups / Hypothesis four

P	**Physiological requirements**	Species occur in the same place because of similar physiological requirements and tolerances
N	**No sharp boundaries**	Species do NOT form sharp boundaries between communities
N	**No groups**	Species do not group together into distinct, predictable associations
H	**Hypothesis 4**	Gleason's individualistic model is hypothesis 4; the mountain vegetation results supported it

Physiological: similar requirements and tolerances; No boundaries: none sharp; No groups: no set associations; Hypothesis four: supported. Trap: NOT sharp boundaries

L14 s09, L14 s11, L14 s12

L14.2 Whittaker gradient test: what sets species composition

E · OT · TF Four hypotheses on a gradient

an Environmental gradient / One, Two / Three, Four

E	**Environmental gradient**	Steady change in conditions, like moisture on an uninterrupted mountain slope; each curve = 1 species
O	**One (organismic)**	Competition causes sharp boundaries between groups of species; certain species group together
T	**Two**	Competition causes sharp boundaries between species; different species do not group together
T	**Three**	No sharp boundaries; certain species group together, due to physical variables
F	**Four (individualistic)**	No sharp boundaries; different species do not group, due to physical variables. Supported

Environmental: gradient, one curve per species; One: edges and groups (organismic); Two: edges, no groups; Three: groups, no edges; Four: neither (individualistic)

L14 s10, L14 s11, L14 s12

M · NN · IA · H Mountain vegetation results

the Mountain question / No boundaries, No groups / Interactions for some, Adaptations for most / Hypothesis four

M	**Mountain question**	Walk up a mountain, communities change: environment or competition, which better predicts the shifts?
N	**No sharp boundaries**	Competition does NOT produce sharp boundaries between species (western U.S. mountain ranges)
N	**No defined groups**	Adaptation to physical variables does NOT result in defined groups of species
I	**Interactions**	Species interactions strongly affect where SOME species are able to exist
A	**Adaptations**	Adaptations of individual species to the environment matter more for MOST species: environment wins
H	**Hypothesis 4 supported**	Results supported hypothesis 4, the individualistic model, NOT the organismic model

Mountain: environment or competition?; No boundaries; No groups; Interactions: some species; Adaptations: most species, environment wins; Hypothesis four: NOT organismic

L14 s06, L14 s12, L14 s39

TW · LP What sets composition on a gradient

Temperature and Water / Light and PH

T	**Temperature**	Largely determines species composition at any one point on an environmental gradient
W	**Water availability**	Second factor on the list of what largely sets composition at a gradient point
L	**Light**	Third factor on the list
P	**pH**	Fourth factor on the list; competition alone is NOT one of them

Temperature, Water availability, Light, PH (pH): the factors that largely set composition at one gradient point. Trap: competition alone is NOT on the list

L14 s13

L14.3 Species richness and Simpson dominance

RDE · LR · S Richness vs dominance and evenness

Richness, Dominance, Evenness / Left dominated, Right even / Same richness

R	**Richness**	Way 1: species richness = number of species per unit area (such as species per hectare)
D	**Dominance**	Way 2: species dominance is higher when one species is present in greater proportion than others
E	**Evenness**	The inverse of dominance; higher when species are present at more equal proportions
L	**Left community**	21 trees of one species, 1 each of 4 others: HIGHER dominance, LOWER evenness
R	**Right community**	5 trees of each of the 5 species: lower dominance, higher evenness
S	**Same richness**	Both have 5 species, so richness is equal, yet dominance and evenness differ

Richness: species per area; Dominance: one species in greater share; Evenness: its inverse; Left: dominated; Right: even; Same: richness equal, diversity NOT equal

L14 s15, L14 s16, L14 s17, L14 s18, L14 s21, L14 s22

CP · SS Simpson's dominance step by step

Count, Proportion / Square, Sum

C	**Count**	Count individuals of each species: left 21, 1, 1, 1, 1; right 5 of each (25 trees each)
P	**Proportion pi**	pi = proportion of individuals in the ith species: 21/25 = 0.84, 1/25 = 0.04, 5/25 = 0.2
S	**Square**	Square each pi: 0.84 x 0.84 = 0.7056; 0.04 x 0.04 = 0.0016; 0.2 x 0.2 = 0.04
S	**Sum**	Ds = sum of pi squared, species 1 through S: left 0.712, right 0.2

Count: individuals per species; Proportion: pi = count / total; Square: each pi; Sum: all species = Ds. Trap: pi is a proportion, NOT a count of individuals

L14 s19, L14 s20

M · M · P · C Simpson's dominance range and meaning

Monoculture is one / Many equal near zero / Probability of a same pair / Common method

M	**Monoculture**	Maximum Ds of 1 in a monoculture (only one species)
M	**Many equal species**	Minimum Ds near 0 with MANY species of equal abundance
P	**Probability**	Chance of picking two trees of the SAME species: 0.84 x 0.84 = 0.7056; 0.2 x 0.2 = 0.04
C	**Common method**	One of the most common of many ways to calculate dominance; NOT the only way

Monoculture: Ds max 1; Many: equal species give Ds near 0; Probability: two picks of the SAME species; Common: one of many methods. Trap: higher Ds = LESS even

L14 s18, L14 s19, L14 s21

L14.4 Simpson evenness and rank abundance diagrams

DO · S · LR Simpson's evenness step by step

Ds first, One over it / then divide by S / Left low, Right one

D	**Ds first**	Find Simpson's dominance Ds first (left 0.712, right 0.2)
O	**One over Ds**	Divide 1 by Ds: 1 / 0.712 = 1.404; 1 / 0.2 = 5
S	**S (number of species)**	Divide by S: evenness = (1 / Ds) / S; the best measure to use for evenness
L	**Left result**	(1 / 0.712) / 5 = 0.281: higher dominance means lower evenness
R	**Right result**	(1 / 0.2) / 5 = 1: species at more equal proportions give a higher evenness value

Ds: find dominance first; One over: 1 / Ds; S: divide by number of species; Left: 0.281; Right: 1. Trap: evenness is (1 / Ds) / S, NOT Ds / S

L14 s20, L14 s22

PR · CD · L Rank abundance diagram

Proportion against Rank / Complete picture, Distribution / Lognormal bell

P	**Proportional abundance**	Plotted for each species on a log scale, against rank of abundance
R	**Rank of abundance**	Species ranked in order from the MOST abundant to the LEAST abundant
C	**Complete picture**	Gives a more complete picture of a community; another way to describe richness and evenness
D	**Distribution of individuals**	Visually describes the distribution of individuals among species in communities
L	**Lognormal distribution**	Species grouped into log10 abundance classes form a normal distribution (British birds)

Proportion: abundance on a log scale; Rank: most to least abundant; Complete: fuller picture; Distribution: of individuals; Lognormal: log10 classes form a bell

L14 s23, L14 s24, L14 s25

FF · I · N Main conclusion: abundance pattern

Few common, Few rare / lots Intermediate / in the Niobrara

F	**Few very common**	Most communities have a few species that are very common
F	**Few very rare**	and a few species that are very rare
I	**Intermediate**	and a lot of species that have an intermediate number of individuals
N	**Niobrara River**	Rank abundance example: Niobrara River macroinvertebrates show the same pattern

Few common, Few rare: the two ends; Intermediate: a lot of species; Niobrara: river macroinvertebrate example. Trap: NOT mostly rare, NOT all equal

L14 s24, L14 s26, L14 s27

L14.5 Alpha, beta and gamma diversity

ABG · M · E Alpha, beta, gamma diversity

Alpha times Beta makes Gamma / Maximize both / Either raises it

A	**Alpha**	Local site richness (use average site richness when sites differ)
B	**Beta**	The difference between sites in an area; beta = gamma / alpha, NOT alpha / gamma
G	**Gamma**	The overall richness of an area (the region total); alpha x beta = gamma
M	**Maximize both**	Main point: to maximize gamma diversity, maximize BOTH alpha and beta
E	**Either one**	Gamma can increase due to increases in alpha OR beta diversity

Alpha: local site; Beta: between sites; Gamma: whole area; Maximize: both alpha and beta; Either: alpha or beta raises gamma. Trap: alpha is NOT the region total

L14 s30, L14 s36

AG · D · R Beta from gamma and alpha

Alpha average, Gamma total / Divide gamma by alpha / Reverse to multiply

A	**Alpha**	Local site richness; if sites differ, average them: region (d) (5 + 1 + 1 + 1) / 4 = 2
G	**Gamma**	Count every species in the whole region: region (d) has species a to e = 5
D	**Divide**	Beta = gamma / alpha: region (d) 5 / 2 = 2.5
R	**Reverse**	Gamma = alpha x beta: region (e) 4 x 2 = 8

Alpha: average site richness; Gamma: region total; Divide: beta = gamma / alpha; Reverse: gamma = alpha x beta. Trap: beta is NOT alpha / gamma

L14 s30, L14 s34, L14 s36

SD · TO · T Regions (a) to (e)

Same everywhere, Different each site / Three per site, One rich site / Two distinct sites

S	**Same species everywhere**	(a): 4 sites, one species a: alpha 1, gamma 1, beta 1 / 1 = 1; lowest diversity
D	**Different species per site**	(b): 4 sites, a different species each: alpha 1, gamma 4, beta 4 / 1 = 4
T	**Three per site**	(c): 3 species per site, 6 in the region: alpha 3, gamma 6, beta 2
O	**One rich site**	(d): 1 site has a to e, 3 sites have 1 species each: alpha 2, gamma 5, beta 2.5
T	**Two distinct sites**	(e): mountain a to d, forest e to h: alpha 4, gamma 8, beta 2; highest diversity

Same: (a) beta 1; Different: (b) beta 4; Three: (c) beta 2; One rich: (d) beta 2.5; Two distinct: (e) gamma 8, highest. Equal alpha can hide unequal gamma

L14 s29, L14 s31, L14 s32, L14 s33, L14 s34, L14 s36

S · BB · G Beta and scale of inquiry

Scale matters / Beta pairs, Beta proportional / Gamma whole

S	**Scale of inquiry**	Beta diversity can depend on the scale of inquiry (the size of the area studied)
B	**Beta D (βD)**	(Dis)similarities between pairs of samples
B	**Beta P (βP)**	Proportional diversity: relationship between two scales; βP = gamma / mean alpha
G	**Gamma whole dataset**	Scales: gamma = the whole dataset; alpha = each sample

Scale: scale of inquiry; Beta pairs: βD, (dis)similarity of sample pairs; Beta proportional: βP = gamma / mean alpha; Gamma: whole dataset, alpha each sample

L14 s35

Lecture 15

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

SCE · NB Richness: speciation in, extinction out

Speciation pours in, Competition causes Extinction / the Net of Both

S	**Speciation**	Adds species; evolution and speciation pour species into the richness bucket
C	**Competition**	Competition and other negative species interactions can lead to extinctions
E	**Extinction**	Removes species; competition and extinction drain the richness bucket
N	**Net result**	Observed richness in one location (a continent) = the net result of speciation and extinction
B	**Both control**	Both evolution and competition control species richness at small scales

Speciation: adds species; Competition: negative interactions; Extinction: drains species; Net: in minus out; Both: evolution and competition. Trap: NOT speciation alone

L15 s08

L14.6 Habitat differences and protecting gamma diversity

DC · O · TB · M Habitat differences and TNC

Different habitats, Circles crossing them / One community vs region / TNC buys Both / Many habitats

D	**Different habitats**	The greater the difference between habitats across the landscape, the more beta and gamma increase
C	**Circles crossing habitats**	Equal land: circles crossing more different habitats should hold more species (higher beta)
O	**One community**	Alpha = one community, beta = between communities, gamma = the whole region
T	**TNC**	The Nature Conservancy buys land to protect as many species as possible
B	**Both alpha and beta**	TNC maximizes BOTH alpha and beta in land purchases, thereby maximizing gamma
M	**Many habitats**	TNC California preserves are spread across many habitats, NOT one richest habitat

Different: habitats raise beta and gamma; Circles: crossing habitats win; One: alpha is one community; TNC: Nature Conservancy; Both: alpha and beta; Many: habitats

L14 s37, L14 s38

LL · RC · N What controls richness at each scale

Local predators, Landscape disturbance / Region dispersal, Continent area / Nested

L	**Local population**	Predation and other biotic interactions
L	**Landscape**	Disturbance frequency
R	**Region**	Dispersal of species; evolutionary time; ecological time
C	**Continent**	Species area effects; evolutionary speed (the largest scale)
N	**Nested scales**	Each scale includes all lower ones and nests within all higher ones; scales are NOT separate

Local: predation, biotic interactions; Landscape: disturbance; Region: dispersal, evolutionary and ecological time; Continent: area, evolutionary speed; Nested: scales

L15 s07

LP · BMF Latitudinal richness gradient

Latitude, Poles to equator / Birds, Mammals, Fish

L	**Latitudinal gradient**	Species of MOST taxa generally increase from polar to temperate to tropical areas
P	**Polar-equatorial gradient**	The other name for the latitudinal species richness gradient (poles to equator)
B	**Birds**	North American birds: very low in the arctic, very high in the tropics; low on the Florida peninsula
M	**Mammals**	Pronounced rise south toward the Tropics; high in California and northern Mexico (topographic relief)
F	**Fish**	United States fish: richest in the Southeast, lowest across the West

Latitude: richness rises polar to temperate to tropical in MOST taxa; Poles: polar-equatorial; Birds, Mammals, Fish: examples. Trap: most taxa generally, not all always

L15 s02, L15 s10, L15 s11, L15 s12

F · ETA · S Three richness hypotheses compared

a Fundamental question / Energy, Time, Area / Shared goal

F	**Fundamental question**	How and why species abundance and diversity vary in time and space
E	**Energy (productivity)**	More sun and water, more plant productivity, more species; fails: productive sub-Antarctic Ocean
T	**Time**	Older regions gained more species; temperate areas are young after glaciations; fails: gradient in the sea
A	**Area**	Larger areas: larger populations, more habitats, more species; fails: Asia, tundra, open ocean
S	**Shared goal**	All three try to explain why richness rises from the poles to the tropics

Fundamental: how and why diversity varies; Energy: productivity; Time: age since glaciation; Area: bigger land; Shared: all explain poles to tropics. Trap: each fails

L15 s06, L15 s13, L15 s49

L15.2 Species-energy hypothesis and its exceptions

SP · HP Species-energy chain, in order

Solar energy feeds Plants / Herbivores, then Predators

S	**Solar energy**	Species-energy: available energy sets richness; more sun plus abundant water gives high plant productivity
P	**Plant productivity**	Total weight of plant material produced per year; more of it increases the number of herbivores
H	**Herbivores**	More herbivores increase the number of predator, parasite and scavenger species
P	**Predators, parasites, scavengers**	Last link: their species numbers INCREASE with more herbivores, never decrease

Solar: sun plus abundant water; Plants: productivity, plant weight made per year; Herbivores: increase; Predators: plus parasites, scavengers increase. Trap: NOT reduced

L15 s15

TS · EP · DA Species-energy support: tree richness

Trees peak in the Southeast / where Evapotranspiration needs Precipitation / Desert, Arctic poor

T	**Trees**	Tree richness in the United States and Canada is influenced by climate and rainfall
S	**Southeast**	Highest tree richness in the hot, moist Southeast, where evapotranspiration rates are highest
E	**Evapotranspiration**	Rate water moves into the atmosphere by evaporation from soil and transpiration of plants
P	**Precipitation and solar energy**	Both of these affect the evapotranspiration rate
D	**Desert southwest**	Low tree richness: rainfall and water availability are low, even though temperatures are high
A	**Arctic**	Tree species counts drop toward the far north, with the fewest in the Arctic

Trees: climate and rainfall; Southeast: richest; Evapotranspiration: soil evaporation plus transpiration; Precipitation: plus solar energy; Desert: dry; Arctic: fewest

L15 s16, L15 s17

TSE · CD Species-energy exceptions and problems

Tropics, Sub-Antarctic, Estuaries / Continents, Densities

T	**Tropical areas**	Southeast Pacific near coastal Colombia and Ecuador: LOW productivity but HIGH richness
S	**Sub-Antarctic Ocean**	HIGH productivity but LOW species richness
E	**Estuaries**	Where rivers empty into the sea: very productive yet low in species
C	**Continents**	Temperate trees: 729 eastern Asia, 253 North America, 124 Europe; pattern fails between continents
D	**Densities**	Open question: why more productivity gives more species, not high densities of just a few species

Tropics: low productivity, high richness; Sub-Antarctic: productive, few species; Estuaries: very productive, few species; Continents: fails; Densities: why not a few

L15 s18, L15 s19

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

DY · GI · D Species-time hypothesis

Diversify with time; temperate is Younger / after Glaciations, the Ice age / Displaced species

D	**Diversify**	Species-time: communities diversify (gain species) with time
Y	**Younger**	Temperate regions are less species rich than tropical regions because they are younger
G	**Glaciations**	Temperate regions recently recovered from glaciations and severe climate disruption
I	**Ice age**	Ice sheets reached their maximum extent 18,000 years ago in the last ice age
D	**Displaced**	Temperate species in North America and northern Europe were displaced from their ranges

Diversify: gain species with time; Younger: temperate areas; Glaciations: recent recovery; Ice age: 18,000 years ago; Displaced: temperate species moved out

L15 s21, L15 s22

LF · D · E Three ways the tropics gained more species

Longer time, Faster evolution / Different ecology / Evolutionary speed

L	**Longer time**	Tropics had LONGER time; similar evolution rates, but temperate areas restart at the end of the ice ages
F	**Faster evolution**	Higher speciation and/or extinction rates in the tropics; the tropical curve rises faster
D	**Different ecological factors**	Ecological factors in each realm set richness; the temperate curve levels off lower
E	**Evolutionary speed**	Evolution faster in Tropics: high ambient temperatures, short generation times, more mutation

Longer: more time in tropics; Faster: higher speciation and/or extinction; Different: ecological factors; Evolutionary speed: heat, short generations. Trap: NOT less time

L15 s23, L15 s24

BHF · MRS Species-time evidence and problems

Birds, Helminths, Fish / Marine, Rainforest, Sister pairs

B	**Birds and mammals**	2,300 mammal, 6,700 bird species: evolution faster in TEMPERATE areas, but extinction also much faster
H	**Helminths of vertebrates**	Parasitic worms: aquatic hosts of any taxon had more species; habitat mattered more than host age
F	**Fish**	Oldest host lineage, predicted to carry the most helminths, had the fewest among aquatic hosts
M	**Marine organisms**	No barriers to shifting during glaciations, yet the polar-equatorial gradient still exists in the sea
R	**Rainforest plant pairs**	45 congeneric or conspecific pairs: tropical plants had over twice the rate of molecular evolution
S	**Sister pairs**	309 New World bird and mammal pairs: highest speciation AND extinction at high latitudes

Birds: temperate faster, extinction too; Helminths: habitat beats age; Fish: oldest, fewest; Marine: gradient stays; Rainforest: tropics twice; Sister: high latitude peak

L15 s24, L15 s25, L15 s26, L15 s27, L15 s28

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

LPH Species-area hypothesis

Larger areas hold big Populations and many Habitats

L	**Larger areas**	Species-area: large areas contain more species than small areas
P	**Populations**	Large areas support larger populations, which are more resistant to extinctions
H	**Habitats**	Large areas hold a greater range of habitats, which promotes increased speciation rates

Larger: areas hold more species than small ones; Populations: larger, more resistant to extinction; Habitats: greater range, more speciation

L15 s30

AZC · SS Computing S = cA^z, step by step

Area, raise to Z, times C / Species on a Slope

A	**Area sampled**	Start with A, the area sampled; the larger the area sampled, the more species
Z	**z exponent**	Raise A to the power z; z = rate of increase in species with area, found from data
C	**c constant**	Multiply by c, a constant determined from data
S	**Species richness**	The result is S; example: c = 2, z = 1, A = 10 gives S = 2 x 10 = 20
S	**Slope**	Slope of the species-area line = z; if area doubles with c and z fixed, S increases

Area: A sampled; Z: power, rate species rise with area; C: constant from data; Species: S, the answer; Slope: of the line equals z. Trap: slope is z, NOT c

L15 s31, L15 s32

BIS · TC Species-area support

Birds, Insects, Sugarcane / Tropics, Climate symmetry

B	**Breeding birds**	North American breeding birds: species number rises steadily as area increases
I	**Insects on British trees**	Insect richness on each tree species rises with its range (area in Britain holding that tree)
S	**Sugarcane pests**	Pest richness correlates better with area planted than with time since planting
T	**Tropics**	Largest land area of the five zones, half an order of magnitude bigger than the others
C	**Climate symmetry**	Similar climates of both hemispheres are adjacent only in the Tropics, making one large area

Birds: rise with area; Insects: track tree range; Sugarcane: area beats time; Tropics: largest land zone; Climate: similar climates adjoin only in the Tropics

L15 s32, L15 s33, L15 s34, L15 s35

ATO · EA · G Species-area problems and fish

Asia, Tundra, Open ocean / Etowah, Age / Global fish

A	**Asia**	The vast contiguous landmass of Asia does not have more species
T	**Tundra**	A large land biome but with very low species richness
O	**Open ocean**	Greatest volume of any habitat, yet fewer species than small-volume tropical surface waters
E	**Etowah watershed**	Small, yet 76 native fish (91 historically); larger Columbia has 33 and Colorado 25
A	**Age**	Age, not area, is a really important factor that drives fish diversity
G	**Global freshwater fish**	Richness per drainage basin still follows the latitudinal pattern; richest in the tropics

Asia: vast but not richest; Tundra: large, few species; Open ocean: most volume, fewer species; Etowah: small, many fish; Age: drives fish; Global: latitude pattern holds

L15 s36, L15 s37, L15 s38

L15.5 Four large-scale conservation strategies

MB · CL Four large-scale conservation strategies

Megadiversity, Biodiversity / Crisis, Last

M	**Megadiversity countries**	17 countries hold nearly 80 percent of known species; focus there. Drawback: some contain similar species
B	**Biodiversity hotspots**	Target the number of ENDEMIC species, not total species
C	**Crisis ecoregions**	Biomes at greatest risk of habitat loss; less than 10 percent protected
L	**Last of the wild**	Lowest 10 percent of human-affected areas: the least human-affected areas

Megadiversity: 17 countries, 80 percent of species; Biodiversity: hotspots of endemics; Crisis: ecoregions losing habitat; Last: of the wild, least human affected

L15 s40, L15 s41, L15 s43, L15 s45, L15 s47

EV · S · TT Biodiversity hotspots

Endemic Vascular plants / Seventy lost / Thirty-four on Tropical forests

E	**Endemic**	Found only in one particular place or region; hotspots count endemic species
V	**Vascular plants**	A hotspot must contain at least 1,500 species of endemic vascular plants
S	**Seventy percent lost**	A hotspot must have LOST at least 70 percent of its original habitat (not protected it)
T	**Thirty-four hotspots**	Cover 2.3 percent of Earth's surface but hold 150,000 endemic plants, 50 percent of the world total
T	**Tropical forests**	Using the hotspot strategy, tropical forests would receive most of the attention

Endemic: found in only one place; Vascular: 1,500 endemic plants; Seventy: percent habitat LOST; Thirty-four: hotspots; Tropical: forests favored. Trap: lost, not saved

L15 s43

CGT · R · LT Crisis ecoregions vs last of the wild

Crisis in Grasslands, Ten protected / Ranked / Last wild in Tundra

C	**Crisis ecoregions**	Biomes at greatest risk of habitat loss
G	**Grasslands, deciduous forests**	Habitat loss most extensive in temperate grasslands and tropical and temperate deciduous forests
T	**Ten percent protected**	Less than 10 percent of these agriculturally rich areas are protected
R	**Ranked**	Crisis ecoregions are ranked critical, endangered or vulnerable; central North America has critical areas
L	**Last of the wild**	Lowest 10 percent of human-affected areas; pristine, with relatively intact communities
T	**Tundra and boreal forests**	Last of the wild: tundra, boreal forests of Russia and Canada, some deserts and tropical forests

Crisis: biomes at risk; Grasslands: plus deciduous forests; Ten: under 10 percent protected; Ranked: critical to vulnerable; Last: least human use; Tundra: boreal too

L15 s45, L15 s46, L15 s47

CG · HL Tallgrass prairie strategy

Crisis for Grasslands / not Hotspots or Last of the wild

C	**Crisis ecoregions**	The best single strategy for tallgrass prairie ecosystems
G	**Grasslands**	Habitat loss most extensive in temperate grasslands, and less than 10 percent is protected
H	**Hotspots**	Poor fit: the hotspot strategy sends most attention to tropical forests
L	**Last of the wild**	Poor fit: it targets pristine areas, but grasslands have lost much habitat

Crisis: ecoregions; Grasslands: most habitat lost, under 10 percent protected; Hotspots: tropical forests; Last: pristine areas. Trap: prairie is NOT pristine

L15 s43, L15 s45, L15 s47, L15 s49