EEBIOL 161
Plant Ecology
Nathan Kraft

Final Exam– distributed Tuesday December 7th, 1:00PM (over CCLE); due by 1:00 PM Friday December 10th.

We expect this exam to take *three hours* to complete- the extra time is to give you flexibility due to COVID- related disruptions. While there are no strict word limits, we expect the short answer questions to take a few sentences to answer and the long answer questions to take at most a few paragraphs to address (across all parts together). The amount of white space left for each question is also a guide as to expected length. Please TYPE your answers on this document and upload it to CCLE as a pdf (answers will go through *Turn It In*).

Part 1- Last section of class (Lectures 10-19), three sections, 65 points total

Part 2- Cumulative, three sections, 65 points total

TOTAL: 130 points

Please define all abbreviations you might use. You may draw on lecture material, the textbook or section readings for your answers, but examples that we cannot readily verify with course content will not be given full credit. Be sure to answer all parts of a question. Please be precise in your answers- *points will be deducted for incorrect statements even if the correct answer is also given*.

This is an open book and open note take-home exam (due to COVID), and you may use a calculator or MS Excel/ Google Sheets for calculations. However, you may not consult with anyone about the exam, and you must craft your own answers. Plagiarism and other forms of cheating will result in a score of 0 for the exam and a referral of the case to the Dean of Students. Please acknowledge you have read and understood these instructions by typing your name and your UID below.

Name: Christina Kilkeary

UID: 605416454 **Date: 10 December 2021**

Equations you *may* find useful for the exam

$\Delta H = SR_{in} + SR_{out} + IR_{in} + IR_{out} + H_{conv} + H_{cond} + H_{et} + H_{met}$

$\psi_{total} = \psi_{\pi} + \psi_{p} + \psi_{g} + \psi_{m}$

$\lambda = l + F$

$N_{t+1} = \lambda N_t$ *and* $N_t = \lambda^t N_0$

$$\lambda = e^{\left(\frac{\ln\left(\frac{N_t}{N_0}\right)}{t}\right)}$$

$l_0 = 1$ *and* $l_x = \prod_{0}^{x-1} S_x$

$R_0 = \sum l_x F_x$

$G = \sum (x\, l_x F_x) / R_0$

$\lambda^G = R_0$

$$\frac{dN}{dt} = rN$$

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

$$\frac{dN_1}{dt} = r_1 N_1 \frac{\left(1 - \frac{N_1 + \alpha N_2}{K_1}\right) \wedge dN_2}{dt} = r_2 N_2 \left(1 - \frac{N_2 + \beta N_1}{K_2}\right)$$

Part 1- Last section of class (Lectures 10-19)
Section 1A (*3 questions*, 5 points each): Short answer questions focused on key concepts. (about 4 min each). *We expect each question to require a few sentences to address.*

1A.i What is a ***chronosequence***? How (*briefly*) did Chapin use the concept of a chronosequence to test competing theories of succession in Glacier Bay, Alaska? *(Note: you **do not** need to address Fastie's work to answer this question)*

A chronosequence is a set of sites that are similar but represent different periods. Chronosequences allow scientists to see succession and "time travel" by going to different locations. Chapin looked at the ice recession in Glacier Bay, Alaska to examine the different successional stages based on the elapsed time of that community's exposure after the glacial retreat. He used his studies to test the competing theories of succession by adding spruce seeds to different ecological sites that represented different stages of succession and was able to rule out that tolerance was why "late" species replaced "early species in succession.

1A.ii Your friend states "ecosystems with higher **Gross Primary Productivity (GPP)** always have higher **Net Primary Productivity (NPP)."** What is one reason your friend might be wrong?

Net Primary Productivity (NPP) is calculated by subtracting the cost of respiration from the Gross Primary Production (GPP). The amount of the cost of respiration is different from plant to plant as they use the energy for growth and maintenance. Because of the respiration cost, a plant that has higher GPP isn't guaranteed to have a high NPP because its respiration costs may offset it. If a plant were to have a high leaf area index (LAI) then it would increase its photosynthetic uptake and its GPP, but because of the respiration cost of growing each new leaf you are also increasing respiration and decreasing NPP.

1A.iii What is meant by “**the velocity of climate change**?” How does topography relate to climate change velocity?

“The velocity of climate change” is an estimation of how fast populations will have to move to offset the rising temperature of climate change. Topography relates to climate change velocity because the velocity is a combination of the changes of both latitude and elevation. With a change in temperature, species need to have a shift higher in elevation if they live on a mountain or such. Topography also relates to climate change velocity in the way that topography can be a physical barrier to species trying to migrate at the speed and distance that is predicted with the velocity of climate change.

CONTINUE TO SECTION 1.B

Section 1B (2 questions, 15 points each). In depth questions (12 min each).

1B.i Species distribution models are used to project possible shifts in species geographic range in response to climate change. Identify ***three*** significant sources of uncertainty in the projections that result from such models. For each source of uncertainty, briefly describe the kind of research that is needed help to improve these models. *Note that we are asking about current uncertainty in the models, not reasons why model predictions might have changed over time.* We expect about one paragraph per source.

First source:

One significant source of uncertainty is species distribution models is the lack of including positive interactions with other species. Currently, species distribution models consider climate (precipitation and temperature) but may not take into account that species can base a large part of their survival on mutualistic relationships. Species distribution models can be overly pessimistic in their predictions when they forego the resilience that comes with strong mutualism. The research that would be needed to improve this is a deep dive into the possible relationships between species that haven't been observed because they don't currently occur together.

Second source:

Another significant source of uncertainty comes from overlooking another factor: soil predictions. A climate can match the preferences of a species but can fail to see the soil conditions needed for a species to live there. The soil not being the type for a plant species to thrive in can affect the species distribution prediction of both that plant species, and all the other species that rely on that plant. Species distribution models can be overly optimistic compared to actuality in this case. More research can be done into the types of soil for species as well as the effect of climate change on soils.

Third source:

Lastly, a significant source of uncertainty can potentially be the speed and pattern of a species dispersing. Although a species can suit the climate in another area, it is unknown through the model if the species can actually disperse far enough or fast enough to get to this new suitable area. Especially with plants, dispersal can be complicated and needs to be fast enough to keep up with the velocity of climate change. Species distribution models can be either too optimistic or too pessimistic when it comes to predicting if a species will be able to migrate to a new suitable area. Research needs to be done on dispersal patterns and average speeds in order to have a more accurate species distribution model based on this shortcoming.

1B.ii Environments in nature are intrinsically heterogeneous (e.g., resource availability, temperature, etc.). Pick **two** different scales of organization from the class (individual interactions with the environment, populations, species interactions, communities, ecosystems) and discuss **one** important consequence of heterogeneity for each level of organization. Please use a specific example (empirical study or a theory) from class or section to illustrate each consequence. We expect this to take a few paragraphs.

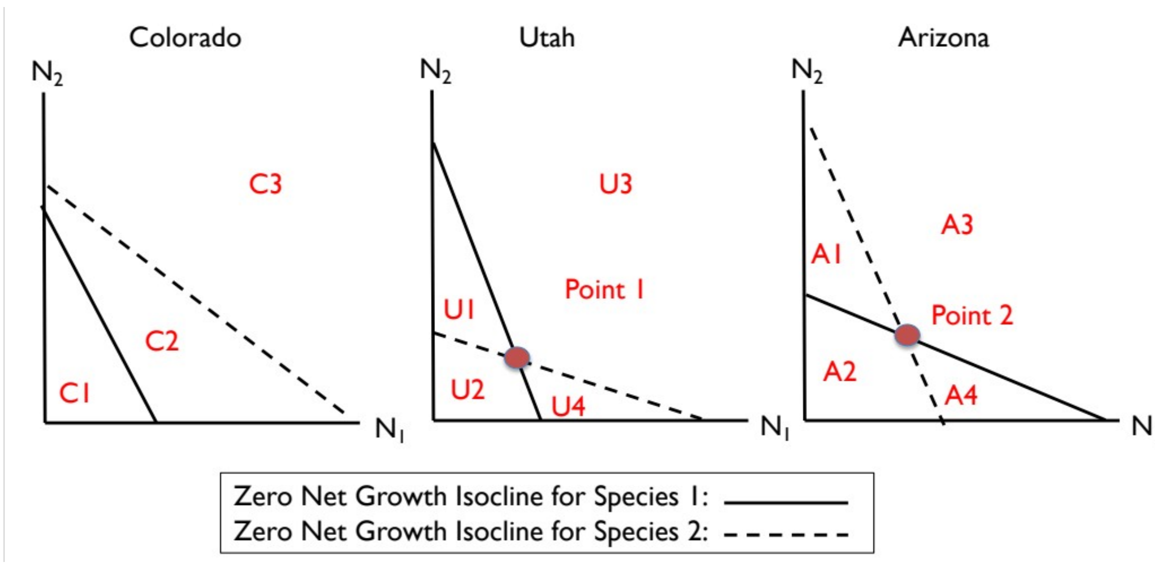
Environments are intrinsically heterogenous and diverse in their resources, climates, topography, and other facets. Effects of this widespread diversity can be noticed in nearly every scale of organization. Two particular scales are that of population ecology and species interactions.

Population ecology asks questions about the limits of population growth as well as the variation in population structures. The heterogenous nature of environments leads to an impact on the limits of population growth for species. With a large variety in species, many predators because generalists, eating more than one specific type of species. Their prey switching behavior of predators often causes them to focus on species that are more abundant on the landscape. This in turn, maintains heterogeneity as well as limits the population of the prey species from becoming too abundant and dominant. One specific example is that of two *Solanum* species. In an experiment of the two species grown together and exposed to a generalist herbivore, researchers found that predation on a species was positively correlated with how common the species was in the treatment. This helps prove that prey switching is a behavior allowed by diversity that limits populations of species.

A larger scale of ecology organization is species interactions. The study of species interactions includes questions on the effects of species on one another as well as how these interactions change in different environments. Along with heterogeneity comes species that are each specialized in their own ways and functions. An important consequence of heterogeneity is the competitive exclusion principle and creation of niches. Without a broad, interpretable variety of resources, competitors would not be able to coexist and carve out their role in an ecosystem.

Section 1.C Quantitative reasoning. Please answer all parts (20 points)

1.C.i Two species of grass compete in communities throughout the western USA. Your colleague has started competition isocline diagrams but has not finished them. Describe the trajectory of the populations of species 1 and 2 in each of the labeled phase spaces (e.g. C1, C2, etc) in each plot by completing the table below. U2 and A2 have been done for you as an example. (5 points)



label	***Sp. 1 trajectory***	***Sp. 2 trajectory***
C1	increasing	increasing
C2	decreasing	decreasing
C3	decreasing	decreasing

label	***Sp. 1 trajectory***	***Sp. 2 trajectory***
U1	increasing	decreasing
U2	increasing	increasing
U3	decreasing	decreasing
U4	decreasing	increasing
Point 1	stable coexistence	stable coexistence

label	***Sp. 1 trajectory***	***Sp. 2 trajectory***
A1	decreasing	increasing
A2	increasing	increasing
A3	decreasing	decreasing
A4	increasing	decreasing
Point 2	saddle point	saddle point

1.C.ii If you needed to collect samples from both species but could only visit one community in one state, which state should you choose? Why? (5 points) (should take a few sentences)

I would travel to the plant community in Utah. The reason I would travel to Utah is because the community in Utah will reach a stable coexistence. In Colorado, Species 2 will end up dominating while Species 1 will die out due to the competition. Arizona on the other hand will have an unstable equilibrium at the saddle point where if the equilibrium is altered at all, one species will end up dominating.

1.C.iii What does the model predict will happen in Arizona? Discuss how reasonable this prediction is. What might you expect to see if you visited 10 communities in this state? (5 points) (should take a few sentences)

The model predicts that in Arizona if both the populations are equally too abundant or if both are equally rare, then both species approach the equilibrium point. However, if either of the populations grew too fast or slow and fell off the path to the equilibrium point, then the populations would not be able to coexist and only one species would survive. This is the nature of an unstable saddle point in the Lotka-Volterra model.

1.C.iv Coexistence of competitors in the Lotka-Volterra model requires that $\alpha\beta<1$. Describe how this gives species an 'advantage when rare'. (5 points) (should take about 1 paragraph)

For coexistence to happen, the product of alpha and beta both have to be smaller than one. This means that coexistence of two species only happens when the effect of intraspecific competition is greater than the effect of interspecific competition. This goes hand-in-hand with the competitive exclusion principle that states that species coexisting have to be distinct from one another in the utilization of their resources, or some other way. This gives species an 'advantage when rare' because with their niche, they can avoid being outcompeted. This was proven in Levine's 2009 study in *Nature* when they removed niches and saw a large drop in diversity and the ability of rare species to succeed when competing for the same exact resources in the same way as abundant species.

CONTINUE TO SECTION 2.A

Part 2- Cumulative

Section 2A (*3 questions*, 5 points each): Short answer questions focused on key concepts (about 4 min each). *We expect each question to take a few sentences to complete.*

2A.i Your friend claims that the only way for species diversity to be maintained in a community is via ecology selection (*sensu* Vellend 2010). Offer your friend a counter-example.

Species diversity can also be maintained through drift. In drift, species can change in their relative abundance due to demographic stochasticity. Demographic stochasticity can cause the variation in population growth rates over time and is especially strong in small populations. An example of this is the basic reef fish lottery model. In this model, reef fish defend a small territory their entire life and when they die, new fish immigrate in to take over that territory. This leads to long-term maintenance with a balance of immigration and extinction. The number of species will be at an equilibrium but the identities of species in the community will be constantly changing.

2A.ii Imagine that you have access to a region with a range of soils that are young, very old, and some of intermediate ages, and all soil types are home to plants that form associations with mycorrhizal fungi. Which soils would be most likely to find examples of individual plants that are being **parasitized** by mycorrhizal fungi? Explain.

The soils that would be most likely to find individual plants that are being parasitized by mycorrhizal fungi are young soils. Younger soils tend to be richer in Phosphorus and other nutrients and be depleted over time as they age. When these younger soils have good nutrients and are rich in Phosphorus it is not beneficial to have mycorrhizae associations because the rich soil doesn't have much to gain compared to what the mycorrhizae is taking. This creates a parasitic, rather than mutualistic relationship between the plant and mycorrhizal fungi.

2A.iii Imagine a plant and natural enemy community in which **Prey Switching** is operating. Next, imagine that all of the natural enemies suddenly evolve to become specialists rather than generalists. What do you predict would happen long term to plant diversity in the community? Explain.

I would predict that the long-term plant diversity in the community would decrease. If all of the natural enemies suddenly evolved to be specialists, they would no longer control populations by focusing on the abundant species like they did when they were generalists. Instead, the natural enemies would each focus on a single plant species and likely decrease the numbers in those plant populations regardless of their abundancies. Similarly, plant species not targeted would be able to soar in their population numbers without a check on their populations and outcompete their competition that would've maintained diversity.

CONTINUE TO SECTION 2.B

Section 2B (2 questions, 15 points each). In depth questions (12 min each).

2B.i Using your understanding of plant morphology and growth in relation to light, explain both the benefits and the costs of being a plant that reaches the canopy of a forest community. What might prevent these species from outcompeting understory species? Specifically, what advantages do shorter statured species in a forest have compared to tall competitors? (*answer should take 1-2 paragraphs*)

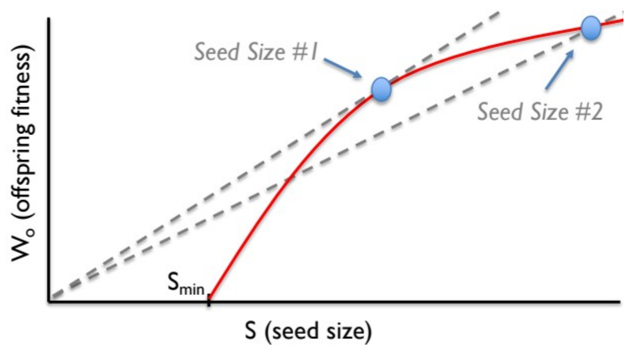
The canopy species have the obvious advantage of getting increased access to sunlight before it filters through any leaves. They use layers of leaves to increase their leaf area index (LAI), the leaf area divided by the canopy area. By increasing the LAI, the plant can increase its photosynthetic uptake. With this high LAI you are increasing the gross primary production (GPP), the total amount of carbon fixed by the autotroph. These advantages of the canopy species, however, do not come without their own consequences. With the leaves overlapping trying to grab as much sunlight as possible, there starts to be diminishing productivity returns. In addition, to create and maintain these leaves, it costs the plant energy and increases its respiration cost. The increased GPP is offset by the costs of respiration the plant faces. This is how the understory can compete with canopy species.

Although the canopy species works hard to grab as much of the light as possible, the understory species don't allocate all of their resources in the same pursuit. Due to their positioning, it wouldn't make sense for understory species to invest all of their energy into leaves for photosynthesis because they wouldn't be able to offset the high respiration costs. Instead, understory species can allocate their energy to invest in other structures. For example, a plant can offset its limits by building root biomass to capture more water or nutrients in an area that may be lacking it. By placing its focus on other biomass structures, a plant can boost its net primary production for building necessary structures without much sunlight.

2B.ii Smith and Fretwell developed a simple model to predict what the optimal seed size is from the perspective of a parent plant. The model has a number of core assumptions that form the foundation of the model. Please state one assumption of the model and then describe the ecological evidence that supports that assumption. (5 points) (should take about one paragraph)

One assumption of the model is that offspring fitness always increases with larger seed size, but there are diminishing returns on offspring fitness as seed size increases. The ecological reasoning behind this assumption is that at a certain point increasing the abundance of nutrients for the plant embryo at the same rate starts to have less of an effect. The effect will never be negative for the offspring but will matter less for their fitness.

Consider the Smith and Fretwell model at right. Which of the two labeled seed sizes is optimal from the parent's perspective? Explain why. Next, explain which seed size is better from the perspective of an individual offspring. If there is a difference, explain why. (5 points) (should take a few sentences)



Seed size #1 is optimal from the parent's perspective. This is because Seed size #2's isocline has a lower slope which translates into lower parental fitness defined by assumption #1 that parental fitness is inversely related with seed size.

Seed size #2 is better from the perspective of an individual offspring. This is because a larger seed size is always in the benefit of the individual offspring.

There is a difference because the offspring wants infinite nutrients for its benefit while the parent cannot allocate many of its resources to an individual offspring when it could use that energy to produce more offspring.

Assume that the plot above is for a pioneer tree growing in a light gap in a forest community. Use the model to predict how optimal seed size (from the parent's perspective) should differ for a late successional tree growing the closed canopy in the same forest. In the space below, describe what would change in the model for this species, and how optimal seed size might change. (5 points) (should take about one paragraph)

Seedlings grown from large seeds have reduced mortality in low light conditions. Therefore, the returns on offspring fitness would start to diminish further along the axis of seed size than it would normally. Optimal seed size would end up being a larger seed size.

Section 2.C. Quantitative questions. Answer all parts; show all work (20 points).

2.C.i Calculate the intrinsic rate of growth for the population described in the lifetable below (4 points). (show calculations)

x	l_x	F_x
0	1	0
1	0.5	1
2	0.25	2
3	0.125	8

R_0 = sum (l_x *F_x)
= (1*0) + (0.5*1) + (0.25*2) + (0.125*8)
= 2
G = sum (l_x * F_x * x) / R_0
= [(1*0*0) + (0.5*1*1) + (0.25*2*2) + (0.125*8*3)] / 2
= 2.25
Lambda = $R_0^{(1/G)}$
= $2^{(1/2.25)}$
= 1.36

2.C.ii As a land manager, you have the opportunity to either double the survivorship of individuals entering year 3 or double the fecundity of one-year olds. Which is better for the growth of the population? Show your work. (6 points) (show calculations + 1-2 sentences)

As a land manager, the better choice for the growth of the population would be to double the survivorship of individuals entering year 3.

Calculations:
Double the survivorship of individuals entering year 3: l_x = 0.25 instead of 0.125
R_0 = sum (l_x * F_x)
= (1*0) + (0.5*1) + (0.25*2) + (0.25*8)
= 3
G = sum (l_x * F_x * x)/R_0
= [(1*0*0) + (0.5*1*1) + (0.25*2*2) + (0.25*8*3)] / 3
= 2.5
Lambda = $R_0^{(1/G)}$
= 1.55

Double the fecundity of one-year old's: F_x = 2 instead of 1
R_0 = sum (l_x * F_x)
= (1*0) + (0.5*2) + (0.25*2) + (0.125*8)
= 2.5
G = sum (l_x * F_x * x)/R_0
= [(1*0*0) + (0.5*2*1) + (0.25*2*2) + (0.125*8*3)] / 2.5

= 4.4
Lambda = $R_0^{(1/G)}$
= 1.23

2.C.iii Population growth rates for two populations are shown below. Assuming that both populations start at the same size, which one will be bigger in year 10? Why? (5 points) (should take a few sentences plus calculations)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Population 1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Population 2	1.5	2	1	1	2	1.5	1.5	1.5	1	2

Assuming both populations start at the same size, population 1 will be bigger in year 10. This is because when we calculate the population size from different growth rates in future years, we use the geometric mean instead of the arithmetic mean to calculate.

Let's say we hypothesize the starting population to be 10:
$N_{t+10} = N_0 * (\text{geo mean})^{10}$

Population 1:
Geometric mean = $(1.5^{10})^{(1/10)} = 1.5$
$N_{t+10} = 10 * 1.5^{10}$
= 577

Population 2:
Geometric mean = $(1.5*2*1*1*2*1.5*1.5*1.5*1*2)^{(1/10)} = 1.448$
$N_{t+10} = 10 * 1.448^{10}$
= 405

2.C.iv What, with reference to the underlying equations, is the connection between exponential growth, logistic growth and the Lotka-Volterra competition model? What are the main differences? (5 points) (should take 1-2 paragraphs)

Exponential growth is the pattern of growth of a population that experiences no limits to its rate of increase and does not vary with population density. The equation of exponential growth is ***dN/dt = rN*** and results in a J-shaped curve. In reality, growth is not unchecked by limited resources and space. Logistic growth takes the elementary idea of exponential growth and adds a parameter based on the species density as it approaches its environment's carrying capacity. The equation therefore expands to ***dN/dt = rN * (1 – (N/K))***. One thing that the logistic growth equation ignores its a species interaction with another species. The Lotka-Volterra competition model adds this factor onto the logistic growth model resulting in this equation for growth of Species 1: $dN_{,} / dt = r_1 N_1 * (1 – ((N_1 + \alpha N_2) / K_2)$

The connection between exponential growth, logistic growth, and the Lotka-Volterra competition model is that they are all used to evaluate population growth over time of a species. They differ in the factors that are taken into account in order to calculate the rate of change.

Have a safe and restful winter break!