BI 519 Theoretical Evolutionary Ecology

CONTACT INFORMATION

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LECTURE
M, W, F, 11:15 – 12:05, Department of Biology, BRB 115.

COMPUTER LAB
Tu, 15:30 – 18:15, Department of Earth and Environment, CAS 435

OFFICE HOURS
Buston: M, W, F, 13:30 – 14:30, Department of Biology, BRB 531 (with exceptions)
Schlatter: M 9:30 – 11:00, Tu 10:30 – 12:00, Department of Biology, BRB 515 (or by appointment)

PREREQUISITES
One semester of biology (BI107) and one semester of calculus (MA123).

ENROLLMENT LIMIT
15

OBJECTIVES
The principal objective of this course is to familiarize students with theory of population ecology, microevolution, behavioral ecology, and how these theories are interlinked. Students gain enough background to read theoretical evolutionary ecology literature, do simple modeling, and springboard to more complex theory if desired. Students gain hands on experience through homeworks and computer labs. Students learn MATLAB and use it to program their own models and simulations during lab. This course builds on courses such as Ecology (BI 303) and Evolution (BI 309), and complements courses such as Evolution (BI 504), Behavioral Ecology (BI 508), and Metapopulation Ecology (BI 509) within the Department of Biology. This course can provide students in Math, Physics and Engineering an insight into how they might apply their skills in the fields of Ecology, Evolution, and Behavior.

BOOKS & OTHER MATERIALS
There is no perfect text for this course. I will provide comprehensive written lecture notes and all recommended readings (see weekly syllabus). The readings will provide a different perspective and additional context for the lecture notes. Students will have to pay for printing if they make hard copies of these electronic materials, but there are no books or other materials that have to be purchased. Most students find it useful to get a student license of MATLAB, which you do here: http://www.bu.edu/tech/services/cccs/desktop/distribution/mathsci/matlab/

INTERESTING BIOLOGY TEXTS – ON RESERVE.
Bulmer, M. 1994. Theoretical Evolutionary Ecology. Sinauer Associates, Sunderland, Massachusetts.
Case, T.J. 2000. An Illustrated Guide to Theoretical Ecology. Oxford University Press, New York.
Dugatkin L.A., Reeve, H.K. 1998. Game Theory and Animal Behavior. Oxford University Press, New York.
Edelstein-Keshet, L. 2005. Mathematical Models in Biology. SIAM, Philadelphia.
Gotelli, N.J. 2001. A Primer of Ecology, 3rd Edition. Sinauer Associates, Sunderland, Massachusetts.
Hastings, A. 1997. Population Biology: Concepts and Models. Springer-Verlag, New York.
Mangel M., Clark C.W. 1988. Dynamic Modeling in Behavioral Ecology. Princeton University Press, New Jersey.
Maynard Smith, J. 1982. Evolution and the theory of games. Cambridge University Press, Cambridge.
Murray, J.D. 2002. Mathematical Biology I, 3rd Edition. Springer-Verlag, New York.
Otto SP, Day T. 2007. A Biologist's Guide to Mathematical Modeling. Princeton University Press, New Jersey.

BACKGROUND BIOLOGY TEXTS – ON RESERVE.
Alcock, J. 2009. Animal Behavior, 9th edition. Sinauer.
Futuyma, DJ. 2009. Evolution, 2nd edition. Sinauer.
Molles, M.C., Jr. 2009. Ecology. 5th Edition. McGraw Hill, Boston

BACKGROUND MATHEMATICS & PROGRAMMING TEXTS – ON RESERVE.
Attaway, S. 2009. MATLAB: A practical Introduction to Programming and Problem Solving. Elsevier.
Lay, D. C. 2006. Linear Algebra and Its Applications. Pearson, Addison, Wesley.
Stewart, J. 2010. Calculus: Concepts and Contexts. Brooks / Cole, Cengage Learning.

HUB LEARNING OUTCOMES

Critical Thinking

The ability to think critically is the fundamental characteristic of an educated person. It is required for just, civil society and governance, prized by employers, and essential for the growth of wisdom. Critical thinking is what most people name first when asked about the essential components of a college education. From identifying and questioning assumptions, to weighing evidence before accepting an opinion or drawing a conclusion—all BU students will actively learn the habits of mind that characterize critical thinking, develop the self-discipline it requires, and practice it often, in varied contexts, across their education.

Courses and cocurricular activities in this area must have all outcomes.

1. Students will be able to identify key elements of critical thinking, such as habits of distinguishing deductive from inductive modes of inference, recognizing common logical fallacies and cognitive biases, translating ordinary language into formal argument, distinguishing empirical claims about matters of fact from normative or evaluative judgments, and recognizing the ways in which emotional responses can affect reasoning processes.

2. Students will be able to evaluate the validity of arguments, including their own.

Critical Thinking in the Context of BI519 Theoretical Evolutionary Ecology

1. *Students will be guided through a series of classical models in ecology, evolution, and behavior. For every model they will be presented with the assumptions, variables, parameters, and come to understand how the predictions of the models and conclusions that might be drawn are dependent on assumptions made. Students will learn how to convert verbal models into formal mathematical models.*

2. *Student will learn to evaluate what makes a good theoretical model. Students will come to recognize that the validity of their arguments depends upon the assumptions that they are making.*

* *Critical Thinking skills will be evaluated via a series of homeworks, exams, and labs (see below).*

Scientific Inquiry II

Many of the most vexing problems facing the contemporary world, from the global challenge of climate change to intimate decisions about our own health, demand the capacity to evaluate scientific claims, assess the strengths and weaknesses of prevailing theories, and discriminate between conflicting data and conclusions. Scientific literacy – both a basic understanding of major concepts in the natural sciences and a grasp of how scientific knowledge is produced and validated – is essential to responsible citizenship and personal autonomy. These outcomes foster the ability to understand scientific ideas, as well as the skills necessary to formulate working hypotheses, design experimental tests of these hypotheses, and evaluate experimental data.

While all courses in scientific inquiry involve the application of major concepts, learning experiences in this group require more advanced application of concepts and methods, including the analysis of data, to frame and address complex problems. It is assumed that courses incorporating Scientific Inquiry II build on previous college-level experience with scientific inquiry.

Courses in this area must have at least one of the following outcomes.

1. Students will apply principles and methods from the natural sciences based on collecting new or analyzing existing data in order to answer questions and/or solve problems. They will understand the nature of evidence employed in the natural sciences and will demonstrate a capacity to differentiate competing claims in such fields. This includes reflecting on and critically evaluating how natural scientists formulate hypotheses, gather empirical evidence of multiple sorts, and analyze and interpret this evidence.

2. Students will engage with issues of public policy, such as climate change, inequality, and health, that involve the intersection of perspectives from different disciplines. This would entail an ability to identify the evidentiary basis for scientific claims, the challenges to it, and the connections among the economic, social, and scientific factors that shape the creation and adoption of effective public policy.

Scientific Inquiry II in the Context of BI519 Theoretical Evolutionary Ecology

1. *Students will be familiarized with the classical theories of ecology, evolution, and behavior, and how these theories are interlinked. Students will gain enough background to read the theoretical evolutionary ecology literature, do simple modeling, and springboard to more complex theory if desired. Students will gain hands on experience through homeworks and computer labs. Students will learn MATLAB and use it to program their own models and simulations during lab. Students will learn how mathematical models can be used to formalize hypotheses, how to analyze these models, and how to interpret the models' predictions.*

* *Scientific Inquiry II skills will be evaluated via a series of homeworks, exams, and labs (see below).*

Quantitative Reasoning II

The contemporary world demands competence in a broad array of quantitative skills, including the ability to interpret evidence, model complex systems, and draw valid inferences from data. On a daily basis, people evaluate quantitative evidence and arguments, for example, to assess risks, maximize returns, evaluate change, and interpret statistical models. While these quantitative skills are acquired primarily through the study of mathematical, statistical, and computational methods, quantitative reasoning is ubiquitous in all fields of study and all aspects of life. Beyond skills and methods for problem solving, computational thinking has deep implications for understanding how the digital world works. Despite an ever-increasing potential for new insights and efficiency gains, algorithms—processes or sets of rules to be followed in calculations or other problem-solving operations, especially by a computer—can also amplify structural discrimination, produce errors that deny services to individuals, or mislead electorates. BU students should understand, use, and interpret the role that quantitative reasoning plays in shaping their personal, professional, and civic lives. They must possess a fundamental understanding of the tools of quantitative reasoning and the ability to apply them to marshal, interpret, and analyze data to answer complex questions across a variety of settings. Developing a capacity for quantitative reasoning is crucial for personal self-sufficiency, professional advancement, and responsible citizenship.

Learning experiences in this area enable students to frame and address complex problems using quantitative reasoning. It is assumed that courses incorporating Quantitative Reasoning II build on previous college-level experience using quantitative reasoning.

Courses and cocurricular activities in this area must have all outcomes.

1. Students will frame and solve complex problems using quantitative tools, such as analytical, statistical, or computational methods.
2. Students will apply quantitative tools in diverse settings to answer discipline-specific questions or to engage societal questions and debates.
3. Students will formulate, and test an argument by marshaling and analyzing quantitative evidence.
4. Students will communicate quantitative information symbolically, visually, numerically, or verbally.
5. Students will recognize and articulate the capacity and limitations of quantitative methods and the risks of using them improperly.

Quantitative Reasoning II in the Context of BI519 Theoretical Evolutionary Ecology

1. *Students will learn to frame and solve complex problems of evolutionary ecology, using mathematical and computational methods.*
2. *Students will apply quantitative tools to problems in population ecology, evolutionary ecology, and behavioral ecology — three sub-fields of biology, each with their own modeling approach*
3. *Students will learn to develop models, identifying assumptions, variables, and parameters, and analyzing the predictions of those models.*
4. *Students will communicate using mathematics and MATLAB, together with figures and text.*
5. *Students will learn to recognize the strengths and weaknesses of various models and that model predictions are contingent on model assumptions..*

* *Quantitative Reasoning II skills will be evaluated via a series of homeworks, exams, and labs (see below).*

COURSE POLICIES: grading, absences, make-ups, workload

Grading

Lecture series (41 lectures)

Homeworks from lecture (10)	30%	(2 lowest can be dropped)
Mid-term exams (2)	30%	
Final exam (1)	20%	

The homeworks explore the students' understanding of Theoretical Evolutionary Ecology concepts, especially the intersection of ecology and mathematics, as well as skills associated with Critical Thinking, Scientific Inquiry II, and Quantitative Reasoning II. The homeworks and exams are graded on a point or percentage basis. The course isn't curved, i.e., your final grade depends solely on your performance, rather than the performance of everybody else.

Lab series (13 labs)

Lab write ups, including figures and text (11)	15%	(2 lowest can be dropped)
Matlab code included in weekly write-ups (8)	5%	

The labs explore the students' understanding of Theoretical Evolutionary Ecology concepts, especially the intersection of ecology and programming, as well as skills associated with Critical Thinking, Scientific Inquiry II, and Quantitative Reasoning II. The lab write-ups and code are graded check, check + or check -. If you receive all checks, you will get all of the points. Check plus is given for doing something additional in terms of coding or exploration of the problem.

Graduate component

Work associated with Lecture series and Lab series (described above) becomes	80%
Thesis or dissertation modules (literature review or modeling project) an additional	20%

Note that 8 labs have a question for graduate students. You are expected to tackle at least 5 of these questions in the lab write-ups. As you might imagine, the questions get harder as the semester proceeds.

Absences

Non-attendance is not penalized directly. However, in the past, students that did not attend found it hard to keep up with the course material. Attendance and catching up on missed material is your responsibility.

Make-ups & Late work

There will be no opportunities for make-ups that are not well justified. Similarly, late work will not be accepted if it is not well justified. If you have questions regarding the grading of problem sets or tests, you must resolve the issue within two weeks. For tests, please provide written justification for why you believe your answer was correct. Some "extra credit" questions will be asked on exams, but otherwise extra credit is not available.

Workload

This is a 4 credit course, so you should anticipate spending 8-12 hours per week outside of class time on this course. Students report averaging 4-5 hours per homework (range 2-10 hours depending on student and which homework), 1-2 hours on lab write ups (range 1-4 hours), and 0-2 hours on reading and reviewing lecture material. Students who spent more time reviewing spent less time on homeworks. Students report the workload as heavy, but manageable. More importantly, students also report that they are satisfied with the amount that they learn in the course given the workload. We will work hard, cover a lot of material, and most students learn A LOT!

Conduct

All undergraduate students are expected to know and understand the provisions of the CAS Academic Conduct Code (https://www.bu.edu/academics/policies/academic-conduct-code/).

All graduate students are expected to know and understand the provisions of the Academic Discipline Procedures (http://www.bu.edu/cas/files/2017/02/GRS-Academic-Conduct-Code-Final.pdf).

Cases of suspected academic misconduct will be referred to the Dean's Office.

LECTURE, READING, ASSIGNMENT & EXAM SCHEDULE (subject to change)

Date	**Lecture**	**Topic**	**Reading**	**Assignment**
Friday, January 21	*1. Introduction to modeling*	Why use quantitative approaches?	Stewart Chapter 1	
Ecological properties of populations I: single, unstructured populations				
Monday, January 24	2: *Density-independent growth in continuous time I: forced, non-autonomous systems.*	Dynamical systems, forced changes, main theorem of calculus, integration, rescaling.	Stewart Chapter 2	
Wednesday, January 26	3: *Density-independent growth in continuous time II: autonomous systems (exponential growth).*		Otto and Day 3.2.1, 5.3.1; Hastings 2.1. Stewart Chapter 3	
Friday, January 28	4: *Density-independent growth in continuous time II: autonomous systems (exponential growth).*		Otto and Day 3.2.1, 5.3.1; Hastings 2.1. Stewart Chapter 4	
Monday, January 31	*5: Density-dependent growth in continuous time I (logistic growth).*	Explicit solutions of autonomous equations, equilibria, linearization, and stability.	Otto and Day 3.2.2; Hastings sections 4.1, 4.2. Stewart Chapter 5	
Wednesday, February 2	*6: Density-dependent growth in continuous time II (logistic growth continued).*			
Friday, February 4	7: *Density-dependent growth in continuous time III (Allee effects).*	Bifurcation		
Monday, February 7	8: *Density-dependent growth in continuous time IV.*	In-class activity: harvesting problem.	Murray 1.6 on harvesting.	
Wednesday, February 9	9: *Density-independent growth in discrete time (geometric growth).*	Rescaling, equilibria, and stability in discrete time.	Murray 2.1 and 2.2.	Homework 1 due
Friday, February 11	10: *Density-dependent growth in discrete time I (discrete logistic model).*	Period-doubling and chaos.	Murray 2.2 and 2.3.	
Monday, February 14	11: *Density-dependent growth in discrete time II.*		Strogatz 10.2-10.7	

Ecological properties of populations II: single, structured populations				
Wednesday, February 16	12: *Single structured populations: two state populations I.*	Multiple, non-interacting variables, linear homogeneous systems, vectors, matrices	Strogatz 5.1-5.2	Homework 2 due
Friday, February 18	13: *Single structured populations: two state populations II.*	Eigenvalues, and eigenvectors.		
Monday, February 21	*Presidents' Day Holiday*			
Tuesday, February 22	14: Single structured population in discrete time: *Migration and multistate populations.*	Multiple, non-interacting variables, linear systems in discrete time.		
Wednesday, February 23	*15: Single structured populations: Age structure I.*	Life tables, Leslie matrices, estimating population growth rate, sensitivity analysis	Gotelli chapt. 3.	Homework 3 due
Friday, February 25	16: *Single structured populations: Age structure II*			
Ecological properties of populations III: interacting populations				
Monday, February 28	17: *Introduction to interacting populations I.*	Isoclines, equilibria, linearization, stability in 2 dimensions	Otto and Day 8.2.1, 8.2.2; Hastings chapt. 6.	
Wednesday, March 2	18: *Introduction to interacting populations II.*			Homework 4 due
Friday, March 4	19: *Lotka-Volterra competition I.*		Otto and Day 3.4.1, 4.2.4; Hastings sections 7.1-7.3.	
March 5 – March 13	*Spring Recess*			
Monday, March 14	20: *Lotka-Volterra competition II.*			
Wednesday, March 16	*21: Lotka-Volterra predator-prey.*	Structural instability. In-class activity: analyzing predator-prey models.	Otto and Day 3.4.2, pp. 307-308.	**Mid-term Exam 1 due**
Friday, March 18	*22: Predator-prey models with stability: one factor modifications*		Hastings 8.3-8.6.	
Monday, March 21	23: *Predator-prey models: two factor modifications*	Classification of stabilizing and destabilizing factors, limit cycles, Andronov-Hopf bifurcations.	Bazykin 3.3.	
Wednesday, March 23	24: *Predator-prey models: two factor modifications (continued)*			Homework 5 due

Evolution: change in allele frequencies				
Friday, March 25	25: *Factors of microevolution.*	Space of genotypes, mutation, selection, sex, migration, and drift: history as initial conditions.	Hastings sections 3.1 and 3.2.	
Monday, March 28	26: *Selection and genetic load.*	Changes in allele frequencies, haploid selection model, relation to logistic model, multiplicative and additive fitness, fitness and stability surfaces.		
Wednesday, March 30	27: *Selection and segregation.*	Panmixia of zygotes and gametes, diploid selection model.	Otto and Day section 3.3. 4.2.3, 4.4.1; Hastings chapt. 3.4 pp. 48-64.	Homework 6 due
Friday, April 1	28: *Mutation and mutation-selection balance.*		Otto and Day pp. 181-183; Hastings 3.4 pp. 64-68.	
Monday, April 4	29: *Fisher's Fundamental Theorem and Wright's gradient equation.*		Hastings chapt. 3.5.	
Wednesday, April 6	30: *Evolution of quantitative traits.*	The gradient equation, Malthusian fitness.	Lande 1976 pp. 314-317 only.	Homework 7 due
Behavior: evolution of phenotypes				
Friday, April 8	*31: Hawk-dove game*	Evolutionary game theory: pairwise contests. ESS models, optimization, invasion theory.	Maynard Smith chapt. 2.	
Monday, April 11	*32: Mixed strategies and generalized two-player games*	Evolutionary game theory: games against the field		
Wednesday, April 13	*33: Evolutionary conflicts: foraging theory I*	Dynamic programming	Mangel and Clark chapt. 2.	Homework 8 due
Friday, April 15	*34: Evolutionary conflicts: foraging theory II*			
Monday, April 18	*Patriots' Day Holiday*			
Wednesday, April 20	*35: Evolutionary conflicts: parental allocation*		Mangel and Clark chapt. 6.	**Mid-term Exam 2 due**
Friday, April 22	*36: Age structure dynamics*	Iteroparity and semelparity and return to the Leslie matrix.		

Monday, April 25	*37: Selection in variable environments*	Arithmetic and geometric means.	Bulmer chapt. 5 pp. 89-93.	
Wednesday, April 27	*38: Evolution of dispersal*	In-class Activity: paper discussion.	Hamilton and May 1977.	Homework 9 due
Friday, April 29	*39. Evolution of dispersal II* (Guest Lecturer: E. Schlatter)		Shaw et al.	
Monday, May 2	*40. Grad Student Presentations*			
Wednesday, May 4	*41. Wrap-up and Review*			Homework 10 due
Friday, May 6	*Study Period*			
Monday, May 9	*Final Exam Due* *Final Project Due (Grads)*			Final Exam due (12:00 – 14:00) Final Project due (12:00 – 14:00)

COMPUTER LAB SCHEDULE

The goal of these labs is for you to explore the models and to learn how to program in MATLAB. In the past, most students were able to finish the entire lab and some of the write up in the time provided. As much as I want all of you to learn MATLAB programming, I also do not want it to get in the way of exploring the models. So, I will release a working version of the MATLAB code for the week in the last half hour of the lab. Part of your lab write-up grade is based on having a working code of your own, but students who use my code will receive credit for the rest of the write-up. If you need extra lab time to finish or for homeworks, MATLAB is available in certain computer labs on campus — you can also install on your own laptop for free. You should bring a memory stick to lab in order to save your programs for write-ups and use in later labs or you can e-mail them to yourself.

Tuesday, January 25, Lab 1: *Introduction to MATLAB*
Attaway: Chapter 1, Intro to MATLAB, pp 3-15 and pp 21-31; Chapter 2, Intro to Programming pp 45-57
No Assignment

Tuesday, February 1, Lab 2: *Exploring growth in single populations with continuous time*
Attaway: Chapter 2, Simple Plots, pp 58 - 63; Chapter 2, User-defined functions, pp 68 - 75
Code and Write up Assignment (Grad component available)

Tuesday, February 8, Lab 3: *Exploring the Allee effect and harvesting models*
Attaway: Chapter 3, Relational operators, Logical operators & Selection statements.
Code and Write up Assignment (Grad component available)

Tuesday, February 15, Lab 4: *Chaos in the discrete time logistic model*
Attaway: Chapter 4, For loops, nested for loops and while loops.
Code and Write up Assignment

Tuesday, February 22: No Lab: Monday Schedule

Tuesday, March 1, Lab 5: *Manipulation of Leslie matrices*
Attaway: Chapter 5, Vectorization of code.
Code and Write up Assignment (Grad component available)

Tuesday, March 8: No Lab: Spring Recess

Tuesday, March 15, Lab 6 (optional): *Review of Matlab and special projects*
No Assignment

Tuesday, March 22, Lab 7: *Dynamics of a competition model*
Code and Write up Assignment (Grad component available)

Tuesday, March 29, Lab 8: *Analysis of the Lotka-Volterra predator-prey model and modifications*
The symbolic toolbox in MATLAB
Write up Assignment Only (Grad component available)

Tuesday, April 5, Lab 9: *Simulation of allele frequency changes and genetic load*
Code and Write up Assignment

Tuesday, April 12, Lab 10: *Evolution of a quantitative trait*
Code and Write up Assignment

Tuesday, April 19, Lab 11: *Simulation of 2 and 3 player games*
Code and Write up Assignment (Grad component available)

Tuesday, April 26, Lab 12: *Investigation of a dynamic state-variable model, patch selection*
Write up Assignment Only (Grad component available)

Tuesday, May 3, Lab 13: *Investigation of the Hamilton and May (1977) Dispersal in Stable Habitats model*
Required reading: Hamilton and May 1977
Write up Assignment Only (Grad component available)

BI519 Thesis or Dissertation Module (GRADUATE STUDENTS ONLY)

There are two choices of modules listed below. The goal of either module is to help you incorporate theory into your thesis or dissertation. **This project is 20% of your grade** and, as you can imagine, it will require effort.

Requirements: The completed module should be presented as a 6-10 page (single space) write up with appropriate references (minimum 8) and formatting for a scientific paper. A one page prospectus of your ideas will be due **Friday, April 1**. This will allow me time to give you feedback on your proposal before it is due. Students who have not turned in a prospectus have occasionally had problems at the end of the semester with the appropriateness of their project, so I encourage you to put some effort into the prospectus. The more you give me, the better feedback I can give you. The final write up will be due **Monday, May 9**.

Workload: In the past, students have spent 8-10 hours per week on the project during the last four weeks of classes. I usually meet with students regularly during this period to answer questions and discuss the direction of the project. Most students usually wish they had started their projects sooner, so I encourage you to start as early as possible. Please consider handing in your prospectus earlier than April 1. Some students have been caught unprepared in the final weeks of class when the presentation and write-up are due because there are also homeworks, in-class discussions, and labs due in those final weeks. Since students have the entire semester to work on the project and can drop 2 homeworks and 2 labs, I am not very sympathetic to this situation. Although, I hope overall that you will find me flexible and willing to meet with students and work with them on their projects.

Expectations: The best projects are ones that provide the seed for a portion of your thesis or dissertation or are something that eventually will be publishable. I do not expect you to complete a dissertation chapter for this course, but if you can outline an appropriate idea and do some work that shows it is feasible, you will receive an A for this module. I also want to make clear that if you are doing something completely theoretical for your dissertation/thesis work, it is NOT appropriate to turn in a summary of your overall project. I am looking for you to do something specific for this class.

Option 1: Literature review of models relevant to your area of research
Review, in detail, at least three different models that provide predictions or describe systems related to your area of research. This review should minimally include a description of the models and their biological interpretation, your critique of the models themselves and their assumptions (e.g., are they "good" models), and a discussion of how the models as a group can inform your research. I hope that this will help you develop the theory section of the literature review for your thesis or dissertation. In grading this option, I am looking for your ability to accurately and succinctly summarize other theory papers, synthesize the body of work, and explain the implications in the context of your work. The format will be flexible since review papers often use different formats. **Grading:** Summary of theory (40%), critique of theory (15%), synthesis of theory (15%), implications and links to your own work (20%), quality and clarity of writing (10%).

Option 2: Modeling project relevant to your area of research
Use what we have learned in class and your MATLAB skills to construct a simple model that you are interested in investigating for your research. Your write up should include the biological justification and interpretation of the model, a complete mathematical investigation of the model, and a discussion of how the model results can inform your research. I hope that you might use this option to begin developing a "modeling" chapter for your thesis or dissertation. In grading this option, I am looking for your ability to represent the biology of your system mathematically, clearly state assumptions and if they are realistic, analysis, and interpretation of results in the context of your work. The format should follow the usual scientific paper format (e.g., Introduction, Methods, Results, Discussion). **Grading:** Biological justification of model (20%), clarity of assumptions (15%), model formulation (i.e., does your model represent what you mean for it to, 15%), model analysis (20%), implications and links to your own work (20%), quality and clarity of writing (10%).

Please feel free to discuss your ideas with me ahead of time. I am happy to meet with you and/or give you feedback at any point during the semester.