Draft Syllabus

BIOHOPK 143H-243H
EARTHSYS 143H-243H
CEE 164H-264H

Quantitative methods for marine ecology and conservation

Units: 4

Winter Quarter
Jan 4th -March 10th 2022

Class in person @ Lathrop 299 on campus
(with opportunity to zoom in)
Tuesday 11:00am -1:00pm
Wednesday 10:00am -12:00pm
Thursday 11:00am -1:00pm

Hopkins Marine Station resident students will be able to join classes also via Zoom

Instructors:

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93950 Pacific Grove, CA (USA)  Lab web site: https://deleolab.stanford.edu/

Richard Ernest Grewelle IV (co-instructor, Evolution & Adaptation)
Dept. of Biology, SU campus, Email: regrew@stanford.edu

Maurice Goodman (co-instructor statistical data analysis)
Hopkins Marine Station, Email: maurice.goodman@stanford.edu

Gianalberto Losapio (EcoEvo), PhD. (co-instructor, food webs structure and dynamics)
Ecology and Evolution group, Dept. of Biology, Stanford University

Shaili Mathur (1st year graduate student in Biology, Teaching Fellow, Agent Based Models)
Dept. of Biology, SU campus, email: shailim@stanford.edu

and invited seminars by: Mikaela Provost (HMS, fishery reference points), Robin Elahi (climate change and body size), Tim White (Global Fishing Watch, HMS alumni, Automatic Identification System), and Elliott Hazen (NOAA, HMS adjunct faculty, Dynamic Ocean Management)
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WAYS OF THINKING/WAYS OF DOING requirement

The course has been certified for the following WAYS:

· Applied Quantitative Reasoning
· Formal Reasoning

MEETING TIMES AND CLASSROOM

- Taught in person and synchronously in Lathro-299 (TBC)
- 3 days a week, 2h each time on Tuesday, Wednesday and Thursday
- Flipped class: pre-recorded online lectures, in person time for problem solving

OFFICE HOURS

- De Leo, by appointment, and Wednesday, 1:00-2:00pm (either on Zoom or in person when on campus)
- Shaili Mathur (shailim@stanford.edu), TBD

CATALOG DESCRIPTION

The goal of this course is to learn the foundations of ecological, evolution and statistical modelling with a specific (but not exclusive) focus on marine conservation and sustainable exploitation of renewable resources. Students will be introduced to a range of methods – from basic to advanced – to characterize population structure, conduct demographic analyses, estimate extinction risk, identify temporal trends and spatial patterns, quantify the effect of environmental determinants and anthropogenic pressures on the dynamics of marine populations, describe the potential for adaptation to climate change. This course will emphasize learning by doing, and will rely heavily on practical computer laboratories, in R and/or Phyton, based on data from our own research activities or peer reviewed publications. Students with a background knowledge of statistics, programming and
calculus will be most welcome. This is a flipped class: students will have access to pre-recorded online lectures, in person time for problem solving

**Prerequisite**

Although the course does not have any formal prerequisite, it assumes that participants have (1) a good foundation of calculus and statistics and (2) have some experience with computer programming (any language), i.e., basic knowledge of conditional statements, for loops, plotting, etc.

All the examples and computer labs will be developed in R ([RStudio](https://www.rstudio.com)) and [Rmarkdown](https://rmarkdown.rstudio.com) as programming environment, tutorial will be offered for those who are not familiar with the programming environment.

**Motivation**

Understanding the dynamics of marine resources is very important not only because of their fascinating life history strategies and capacity to adapt to very different environmental conditions, but also because marine life provides crucial ecosystem services, including seafood production and support to a lucrative eco-tourism industry. The majority of the conservation and management problems that polarize our society requires us to answer to questions formulated in terms of “what happens if…?”, i.e. what happens to the fish stock if we increase fishing effort by 10%? What happens if we use a smaller mesh size? What happens if the increase in seawater temperature causes a 10% decrease in survival in green abalone? Would the once sustainable harvesting effort still be sustainable and, if not, how much do we have to change it? To answer these questions, we could for instance proceed by trial and error, as humankind has done in the last 100 thousand years. Yet this would require a very long time to find out the best management and we often do not have this time because so many species over commercial interest are already over exploited. Even more importantly, if we screw up and wipe out the blue whale population, so to speak, this is going to be *very* bad, as once a species is gone, it is gone forever… (or it would take years and often decades for the population to bounce back, as it occurred for the sardine fishery in the Monterey bay or the abalone fishery along the California coast). A much more effective and safe approach is to explore possible management strategies by using mathematical models mimicking the dynamics of the target species. In such a way, there is no risk to explore a wide range of management and conservation policies along with alternative scenarios of climate change. What is going to help us was already recognized four centuries ago by Galileo Galilei in the Assayer (1623): nature “is written in this grand book […] which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering around in a dark labyrinth.” We will start to explore this labyrinth by learning the foundation of population biology, how fast populations grow or recover from an environmental or anthropogenic shock, what limits their growth, what is the effect of harvesting and why we invariably end up in overexploiting renewable resources in the absence of regulations and cooperation, what can be done to reduce or avoid the risk of overexploitation or to increase the resiliency of the system. While most of population ecology is still limited by the paucity of ecological data available, we are entering an era of big data, where more and more data from animal-borne biologging tags, satellite images, acoustic stock assessment, genetic and genomic analyses are increasingly available.

**Teaching Philosophy**

My teaching philosophy can be summarized in the following main points:

- **Start simple**, even very simple, and then build up complexity by incrementally adding relevant details in a stepping stone approach. This specific course is aimed at familiarizing students with ecological modelling and a specific focus on population dynamics and management and modelling. We will keep the mathematics as simple as possible. For instance, I might not treat rigorously the mathematical theory of equilibrium stability, but give references for interested students.
- **Learn by doing:** As stated by Confucius, “I hear I forget, I see I remember, I do I understand”. There is no other way to learn to model natural resources than to try to develop your own simple model starting from very simple and possibly analytically tractable problems. Computer simulations of course help a lot, but sometimes we get lost in the programming technicalities rather than in trying to understand the role and importance of specific management and ecological processes. So, let’s play with models, learn how to build them up and how to explore the consequences of different management strategies and keep focusing on the questions of ecological or conservation relevance. We will do it both by working on assigned problems and developing your own specific independent project.

- **Class interaction:** do not be shy if you do not understand or if you feel lost: please stop us, feel free to interrupt, make any comments from your own personal experience or from what you have read - this is going to make classes so much more interesting and fun. You’re also welcome to message the TA’s or the instructor with questions, both during and outside of class hours. To the extent it is possible, we will try to flip the class as much as possible: this means that we will usually record lectures in advance, and expect you to have watched them before meeting in class, so that we can use live class time to solve exercises and run simulations.

**Teaching goals**

Students will learn to:

1) Become familiar with the basic theory of population dynamics, including mathematical derivations of basic population models for Malthusian growth, density dependent growth, and accounting for species interactions.

2) Develop an understanding of the relative importance of different biological processes in explaining the dynamics of essential “population level” characteristics; Understand the relationship between biological/fisheries processes and their mathematical formulation, and how they function in population dynamics.

3) Develop an understanding of the potential impact of fishing and the ecosystem on the dynamics of marine populations.

4) Familiarize with the basic concepts required to support single species management, such as maximum sustainable yield, maximum sustainable profit, Gordon theory of bioeconomic management of renewable resources, etc.

5) Apply statistical tools and concepts to fit basic mathematical models for populations to empirical data on biomass, growth, and reproduction, and understand how these data are used in managing harvested populations. Develop a broad understanding of different statistical techniques available for fitting population models in space and time.

6) Read and understand journal articles on basic level population dynamics models that may contain previously unfamiliar equations and/or symbols; Read and discuss contemporary articles recommended by the instructor and selected by the students themselves; Evaluate potential contributions and possible improvement in these journal articles.

7) Learn the foundation of population genetics

**The ultimate, overarching goal is to train students to translate the verbal description of an ecological problem into its mathematical formulation and to use mathematical models to answer key conservation and management questions.** In particular, students will be able to:

- develop mathematical models to simulate population dynamics in a realistic fashion based on existing data and knowledge of organisms and specifically
- translate mathematical models into code, simulate model dynamics, and fit their parameters to data using a modern programming language such as R or Python
- predict outcomes from mathematical models and develop general expectations based on different input parameter values.
Reference books
Slides, videos, R-Script, exercise and notes will be distributed by the instructors, including copies of selected book chapters listed below. In case you are willing to invest in a textbook, please contact us and, among the great resources listed below (and more), we will be happy to suggest what you may best fit your specific needs.

General books on population dynamics and management
- Haddon, Using R for Modelling and Quantitative Methods in Fisheries, 2020, Chapman and Hall/CRC
- Soetart and Herman, A practical Guide to Ecological Modelling, 2010, Springer
- Stevens, A primer of Ecology with R, 2009 Springer
- McElreath, Statistical Rethinking, 2019
- Edge, Statistical Thinking from Scratch, 2019
- Bolker, Ecological Models and Data in R, 2017

Books and books chapter for review of applied mathematics and calculus useful for population dynamics

Books on fishery ecology and management
- Jennings, Kaiser and Reynold, Marine Fisheries Ecology, 2007, Blackwell science
- Anderson and Seijp, Bioeconomics of Fishery Management, 2010, Wiley Blackwell
- Haddon, Modelling and quantitative Methods in Fisheries, 2011 CRC Press

Lab activities
A crucial part of the learning process is to understand how to develop simple mathematical models to solve demographic or management problems. To this purpose, we will solve in class and as homework a substantial number of exercises that will be assigned on a weekly basis. Some these exercises can be and will be solved analytically without running simulations, for more complex exercises we will run R and python scripts. NB: to build up a model on the basis of the verbal description of an ecological problem and to analyze its dynamical properties will be by far the toughest but most exciting challenge of this course. Therefore, solving exercise, together in class or with fellow mates as homework is a fundamental part of the course.
Independent project

Students will have the opportunity to develop independent projects during the course. There are two types of projects: a) development of a brand new, independent statistical analysis or, in alternative, a demographic/management model for a system of interest; b) presentation of a statistical or modeling paper published in the scientific literature, as described here below. Students will have to submit a final report (as word file, PDF or Overleaf document) and if the number of students is limited, students will have the opportunity to offer a short class presentation including also a Q&A session.

In case (a), students will be requested to identify a marine system/species/queston of interest (from the charismatic macro fauna of the Monterey Bay, such as sharks, seals, whales, to species of commercial and/or conservation interest, such as the abalone or the squid fishery) and to develop statistical/demographic models by using data from the literature on their basic life history traits and/or data on temporal and spatial distribution when available. The analysis should be meant to address relevant questions for their conservation and/or management. In this case the challenge is to find literature support/evidence to provide a rough estimation of the basic demographic and management parameters, namely per-capita fecundity, reproductive success, natural mortality, sex ratio, potential undisturbed carrying capacity, fishing mortality; assess whether there is enough published data on the species of interest to develop an age- or size-structured model; in such a case identify further information on size/age-dependent demographic rates, age at first reproduction, age/size dependent catchability or fishing mortality. In the ideal case, it will be possible to identify a historical series of catch and effort data (or fishery independent data in the case, for instance, of species of conservation interest): in this case, these data could be used to estimate some of the unknown demographic parameters, such as the per capita population growth rate at low density, and/or the carrying capacity and/or fishing mortality/catchability. When data of the specific species of interest is not available for a particular demographic parameter, discuss whether a rough estimation can be derived based on analogy with life-history traits of very close species, allometric scaling with body size, etc. The ultimate goal is to derive simple exercises on the population dynamics and management of marine population similar to those that we will learn to solve in classes or as homework. I expect to see back-of-the envelop calculations and, possibly, derivation of analytical solutions. In addition, or in alternative in the case of more complex age/size structured and/or spatially explicit models, numerical simulations in R will be most welcome.

An alternative type of project (case b) is to identify and then present a published paper in the scientific literature that develops statistical or demographic models to address questions relative to conservation or management. Usually, these models are more complex than those that we learned to develop in our introductory course. Students will have to show critical thinking in presenting the paper, identify the research questions the authors wanted to answer, whether it is a purely theoretical or an applied work, the assumptions and data at the basis of the models, how demographic/management parameters were estimated, whether and how uncertainty and environmental variability were included, whether the paper present a sensitivity analysis, the techniques used for stability analysis (if any, of course), what are the main findings, potential caveats, limitations, of the work.

This is the timeline for individual project development:
- Third week of the course: submit a one-page presentation on what species the student would like to work on and why; which type of problem or broad general questions would like to address (such as parameter estimation, management/conservation); which preliminary scientific literature and/or possible data sources (such as NOAA, Fishbase, other) were identified to support the possibility of estimating basic demographic parameters.
- Weeks 4 and 5 will be mostly dedicated to data digging. Weeks 6, 7 and 8 to model development and analysis; week 9 to wrap up the findings and to write a synthetic report with the list of the cited literature and data sources; week 10 to the PPT presentation.
- Every week students will have to submit a *very* synthetic bullet-list on updates, advances, criticalities

Possible topics for independent projects:
- To present the state of the art in stock assessment of the pacific sardines and its demographic models
To develop a demographic model of the great white shark along the California coast
- In relationship to the wasting diseases in starfish, develop a demographic model of one or more starfish species.
- Other research topics suggested by participants

Exams
There will be one midterm exam. The exam will last a couple of hours. It will cover the material presented and discussed in the lectures. It will consist of both short answer questions and longer calculations.

Evaluation

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<th>Component</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Class discussions and readings</td>
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<tr>
<td>Home work</td>
<td>25%</td>
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<tr>
<td>Midterm exam (5th week)</td>
<td>25%</td>
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<tr>
<td>Development of an independent project</td>
<td>25%</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
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Grades
Final grades will include a “+” and “−.” We feel that a “C” indicates adequate performance and that a “B” or an “A” indicate “good” and “superior” work. Your grades are determined independently, and you will not be competing against other students for the “curve.”

Absence policy
Students are expected to attend each class and lab. In general, no make-up lectures and labs will be given.

Changes to syllabus
The instructor reserves the right to make changes to the syllabus during the course. Any necessary changes will be announced in class and posted on the course website.

Overview of the main topics:
- Week 1-2: Population dynamics
- Week 3: Foundation of Fishery Management
- Week 4: Analysis of Food Web
- Week 5-7: Data analysis and model calibration
- Week 8-9: Population genetics and adaptation
- Week 10: Dynamic Ocean Management and more
**Agenda Winter 2022**

NB: the detailed agenda, share of time and cases used for each topic may be updated/adjusted based on contingent needs and/or students’ background knowledge in basic algebra and calculus.

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<th>#</th>
<th>Date</th>
<th>Topics</th>
<th>Primary reference:</th>
<th>Alternative reference</th>
<th>Optional Readings/notes</th>
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</table>
| 1   | Tu 1/4 | - Course presentation  
A taxonomy of models  
NB: For a review of basic calculus, it might help to read Ch 5 of Matthiopolous (2011) | -                                                                                  | -                     | - Monterey Weekly, Jan 1st 2014- “Is the end of sardines as we know it?”  
|     |      | 2 We-1/5  
Introduction to Malthusian growth:  
- discrete time models without and with overlapping generations and continuous time models;  
- estimation of the per capita growth rate  
Age and stage dependent demographic parameters.  
- The Leslie matrix.  
- Stable age distribution.  
- The Lotka-Euler equation and the computation of the finite growth rate  
- Sensitivity and Elasticity Analyses  
- Life tables and basic demographic parameters | Gotelli Ch. 1  
Gotelli Ch. 3 | - Hastings Ch. 2.1-2.2  
- Case, Ch. 1, 3 and 4 | - Crowder et al. 1994. Predicting the impact of turtle excluder devices on loggerhead sea turtle populations.  
Ecological Applications 4: 437 – 445  
- Lindegren et al. PNAS-2013-Climate, fishing, and fluctuations of sardine and anchovy in the California Current | |
| 3   | Th-1/6 | - Introduction to density dependent dynamics. Competition for space: the logistic equation  
- The Ricker model and the Beverton-holt model, determinist chaos  
- Models for intra-specific competition for limiting resources; scramble competition and context competition.  
- Inverse density-dependence: the Alee effect | Gotelli, Ch. 2 | | - Independent project: by Jan 31st, participants will send Maurice a brief update about data, problem formulation, etc. |
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<th>Alternative reference</th>
<th>Readings/notes</th>
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| 4 | Tu-1/11 | - The classic Lotka-Volterra Prey-Predator model  
- Other prey-predator models  
- Functional response of the predator and its effect on the population dynamics of its prey | Case, Ch. 5  
Gotelli, Ch. 6 pg. 125-133 | Hastings Ch 8.1-4  
- Shelton and Mangel (2011) Fluctuations of fish populations and the magnifying effects of fishing, PNAS |
<p>| 5 | We-1/12 | - Simple models for interspecific competition | - | - | TBA |
| 6 | Th-1/13 | - Stochastic dynamics (Shaili) | - | - | TBA |</p>
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| 7  | Tu-1/18| - Introduction to the exploitation of renewable resources: the fishermen dilemma  
- The maximum sustainable yield  
- Effect of Policies based on constant quotas, on constant exploitation effort, on constant escapement  
- Rossetto et al. 2015 No-take marine reserves can enhance population persistence and support the fishery of abalone. Canadian Journal of Fisheries and Aquatic Science. 72:1-15. |                                                                                  |
| 9  | Th-1/20| - Invited seminar: Automatic Identification Systems by Tim White  
*Global Fishing Watch*                                                                     | Gotelli, Ch. 6 pg. 134-154  | - Hastings Ch 8.6-7  
- Case, Ch. 13                                                                                  |                                                                                  |
<p>|    | F-1/21 | 1-page proposal for student’s project due                               |                             |                                                                                         |                                                                                  |</p>
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<tr>
<td>10</td>
<td>Tu-1/25</td>
<td>- The structure of marine food web</td>
<td></td>
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<td>- Yodzis 2001 Must top predators be culled for the sake of fisheries? TREE 16(2) 78-84</td>
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<td>11</td>
<td>We-1/26</td>
<td>- Secondary extinction in food webs</td>
<td></td>
<td></td>
<td>- Sanders et al. 2018 PNAS. Trophic redundancy reduces vulnerability to extinction cascades. <a href="https://www.pnas.org/content/115/10/2419">Link</a></td>
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<td>- Byrnes et al. 2007. Invasions and Extinctions Reshape Coastal Marine Food Webs. <a href="https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1808429/">Link</a></td>
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<td>12</td>
<td>Th-1/27</td>
<td>- Food web dynamics: the Ecopath with Ecosim approach</td>
<td><a href="https://ecopath.org/">Link</a></td>
<td></td>
<td>- Gerber et al. 2009. Should Whales Be Culled to Increase Fishery Yield? Science 323(5916): 880-881 (This link is this one)</td>
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<td>- Middle term exam</td>
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<td>13</td>
<td>Tu - 2/1</td>
<td>- <strong>Lab:</strong> Probability distributions &amp; central limit theorem</td>
<td>McElreath Chapter 4.1</td>
<td>Edge Chapter 4</td>
<td><strong>Before Class:</strong></td>
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<td>- Watch Maximum Likelihood Lecture Part 1</td>
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<td>- Read Edge Chapter 4.1-4.2, 4.4-4.6</td>
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<td>- Read McElreath Chapter 4.1</td>
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<tr>
<td>14</td>
<td>We - 2/2</td>
<td>- <strong>Lab:</strong> Intro to maximum likelihood estimation and with linear regression</td>
<td>Edge Chapter 9.1 and 8.2</td>
<td>- Bolker Chapter 6</td>
<td><strong>Before Class:</strong></td>
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<td>- Watch Maximum Likelihood Lecture Parts 2 &amp; 3</td>
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<td>15</td>
<td>Th - 2/3</td>
<td>- <strong>Lab:</strong> Fitting nonlinear models – stock-recruitment relationships &amp; functional responses</td>
<td>McElreath Chapter 10.2</td>
<td>- Bolker Chapter 6 &amp; 7</td>
<td><strong>Before Class:</strong></td>
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<td>- Read McElreath Chapter 10.2</td>
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<td>16</td>
<td>Tu - 2/8</td>
<td>- <strong>Lab:</strong> Fitting nonlinear models – stock-recruitment relationships &amp; functional responses (Continued)</td>
<td>- Due: Probability distributions lab</td>
<td>- Due: Intro to maximum likelihood lab</td>
<td><strong>Before Class:</strong></td>
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<td>- Due (end of class): Short group presentations on stock-recruitment or functional response lab</td>
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<td>- Complete Probability distributions lab</td>
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<td>- Complete Intro to maximum likelihood lab</td>
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<td>17</td>
<td>We - 2/9</td>
<td>- <strong>Lab:</strong> Fitting dynamic population models with maximum likelihood; non-independent errors; observation vs. process error</td>
<td>Bolker Chapter 11</td>
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<td><strong>Before Class:</strong></td>
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<td>- Read Bolker Chapter 11</td>
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<td>18</td>
<td>Th - 2/10</td>
<td>Lab: Spatiotemporal species distribution models with GAMs</td>
<td>Guisan et al 2002 - “Generalized linear and generalized additive models in studies of species distributions”</td>
<td></td>
<td>Before Class: Watch Lecture on implementation of correlative species distribution modeling with GAMs</td>
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<td>Fr – 2/11</td>
<td>Final Project Check-in</td>
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<td>19</td>
<td>Tu - 2/15</td>
<td>Lab: Spatiotemporal species distribution models with GAMs (continued)</td>
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<td>Due (end of class): Short group presentations on spatiotemporal species distribution models</td>
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<td>20</td>
<td>We - 2/16</td>
<td>Lab: Forecasting species ranges with correlative species distribution models</td>
<td>Dormann et al. 2012 - “Correlation and process in species distribution models: Bridging a dichotomy”</td>
<td></td>
<td>Before Class: Watch Lecture on theory of correlative species distribution models</td>
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### Week 8 - Applying evolution to the marine environment (Grewelle)

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<tbody>
<tr>
<td>22</td>
<td>M-2/22</td>
<td>Lecture: selection and scales big and small. How do we measure selection? Genes, the environment, and plasticity.</td>
<td>Reading materials, slides and R-Markdown scripts reported on canvas</td>
</tr>
<tr>
<td>23</td>
<td>W-2/23</td>
<td>Lab: life history and the capacity to evolve. How does an organism’s genetic make-up determine the speed at which the population can change? Studies in inbreeding (marine snails and marine mammals). Introduction to Markov processes for genetics.</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>F-2/24</td>
<td>Lecture: measuring diversity in the ocean. How does genetic diversity contribute to the maintenance of evolving populations? What kind of diversity matters?</td>
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</tr>
</tbody>
</table>

### Week 9 - Adapting to climate in a changing seascape (Grewelle)

<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Topics</th>
<th>Primary reference:</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>M-3/1</td>
<td>Lab: Genetic diversity and evolvability of abalone endangered by falling pH. Gene number and quantitative traits. Intro to the statistics of QTL.</td>
<td>Reported on CANVAS</td>
</tr>
<tr>
<td>26</td>
<td>W-3/2</td>
<td>Lecture: Pushing back on the wave of extinction. How do marine populations prevent genetic extinction? The mathematics of extinction risk.</td>
<td>Reported on CANVAS</td>
</tr>
<tr>
<td>27</td>
<td>F-3/3</td>
<td>Lab: Extinction or recovery of abalone? Optimizing genetic survival.</td>
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<td>S-3/4</td>
<td>Final project due</td>
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<tr>
<td>#</td>
<td>Date</td>
<td>Topics</td>
<td>Primary reference:</td>
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<tr>
<td>28</td>
<td>Tu-3/9</td>
<td>Invited seminar on Dynamic Ocean Management</td>
<td>NOAA Elliott Hazen</td>
</tr>
<tr>
<td>29</td>
<td>We-3/9</td>
<td>-</td>
<td>Robin Elahi or Shaili?</td>
</tr>
<tr>
<td>30</td>
<td>Th-3/10</td>
<td>Project presentations</td>
<td>Students</td>
</tr>
</tbody>
</table>