# ***Transforming an Ecology Class to Focus on Key Ecology Concepts and Practices using an Assessment-Driven Design Approach***

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# Executive Summary

## Rationale and Process for Transforming Ecology (BIOE 107) Course

Ecology (BIOE 107) is a required upper division course for all Ecology and Evolutionary Biology majors. Through readings of primary literature on science education, discussions with professors who have taught this course, and my own experiences as a teaching assistant it became clear that students often find modelling to be the toughest aspect of Ecology. Particularly they struggle with using ecological models to describe and predict population dynamics. They are further challenged when asked to interpret and explain their model out-puts in a scientific argument. Therefore, the following four learning outcomes were the foundation for my curriculum development:

1. Use ecological models to describe and predict population dynamics
2. Interpret and explain primary data
3. Construct scientific arguments using evidence
4. Utilize peer editing to improve scientific writing

These are scientific practices that most instructors would agree are fundamental to scientific investigation. After I settled on my learning objectives, I began to tackle the question, how will I know my students have achieved my learning objectives? This required that learning objectives and assessment be tightly linked—all of my assessments (i.e. in-class assignments, midterms, and homework) must be critically connected to my learning objectives. Lastly, I began planning my course curriculum, incorporating many active learning strategies, including student inquiry (authentic scientific investigation), to achieve my ultimate learning objectives. The specific active learning strategy I decided on was having students work in groups of approximately four students to solve ecological "case studies." During case studies students determined the appropriate ecological model to use given known data, and then manipulated the model to make predictions about population dynamics. At the end of each case study I posted a "synthesis" prompt for students to answer independently (i.e. not as a group). Syntheses asked students to interpret their results from the case study and transfer their understanding of the model out-put to a conservation or management strategy. Overall, syntheses gave students time to reflect on their learning and develop their reasoning and logic skills independently, additionally, syntheses allowed me to assess (grade) students individually.

## Description of Class Time

Classes were held twice a week, for 5 weeks and were 3.5 hours long. In a typical class period students were required to complete ~3-4 case studies and syntheses of their results from each investigation. During investigations students learned how to use ecological models and then for the syntheses students learned how to interpret and context their results. For example, in one investigation students were given abundance data for a population of North American Wood Thrushes over time. I then prompted the students to answer the following questions: Will the Wood Thrush go extinct? If so, when? These questions required that the students utilize a basic exponential population growth model, and the given population abundance data, to graph and make predictions about future population sizes. Throughout the investigation phase of the class, the teaching assistant and I would move among the groups to "facilitate" student learning. By facilitate, I mean we asked students to explain their choice and use of a model, encouraged thoughtful examination of alternative problem solving strategies, and paid careful attention to the social dynamics to keep interactions among students equitable and productive. For the synthesis students were asked: Based on your model when will the Wood Thrush population go extinct? Is it possible for a population to be extinct before zero individuals are left? What other data (behavior, life history, etc.) would you need to determine when a population is "functionally" extinct? This synthesis required students to give a prediction for when the Wood Thrush population would equal zero, and then asked them to think critically about what it means ,biologically, for a population to be "extinct." Near the end of each class I posted an end of day reflection prompt (i.e. a metacognition exercise), which was designed to help students reflect on the days discussions, ecological topics, and potential future applications of the days learnings. Finally, at the end of each class students were responsible for turning in answers to the syntheses and the end of day reflection for their in-class participation grade.

## Overall Course Assessment

At the end of the course, I designed assessment (grading) rubrics for three problems on the final exam which evaluated student mastery of learning objects 1-3. I also collected student self-evaluations of their skills and their feedback on the course via an online survey. My standard for successful comprehension of my course learning outcomes was 75% of students meeting or exceeding expectations.

## Results

1. **Students' demonstrated abilities to use ecological models** was evaluated using 2 criteria: determining appropriate model and then using the model to solve for a solution.
   - The majority (83%) of students' met or exceeded expectations for using known variables to determine best fitting ecological model (Table 1 & Fig. 1).
   - However, only 74% of students met or exceeded expectations for manipulating model to determine answer (Fig. 1 & Table 1).

2. **Students' demonstrated abilities to interpret primary data** was evaluated using one criterion: detecting a slight though non-significant trend via graphical data.
   - The majority (78%) of students' met or exceeded expectation for interpreting primary data figures (Fig. 1 & Table 2).

3. **Students' demonstrated abilities to construct a scientific argument** was evaluated using 3 criteria: making a claim, using evidence to support claim, and linking the claim and evidence together in a concluding statement.

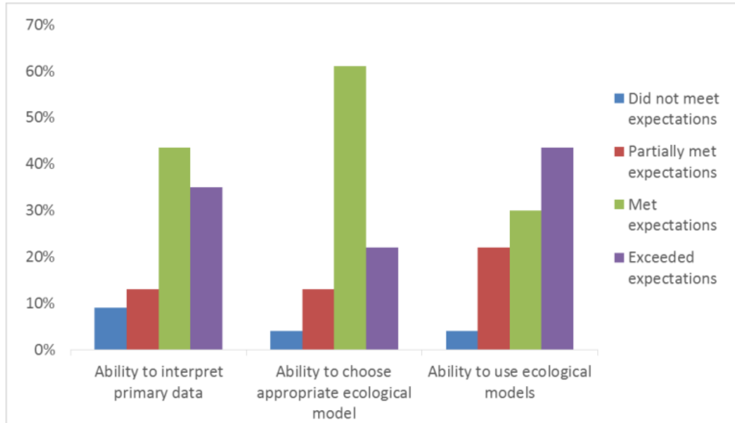



Figure 1. Direct evidence of students' demonstrated abilities to 1) interpret primary data, 2) choose appropriate ecological model and 3) utilize model to determine

- The majority (83%) of students, met or exceeded expectations by **providing evidence to support a claim** that was an accurate and logical interpretation of the data (Fig. 2 & Table 3).

- In contrast, only 43% of students, met or exceeded expectations by **designing a claim** that was accurate and logical (Fig. 2 & Table 3). Additionally, 39% of students made ecologically non-realistic claims and/or were unclear in their writing (partially met expectations; Table 3). Also of concern, is that 17% of students made a false or vague claim and thus failed to meet expectations (Table 3).

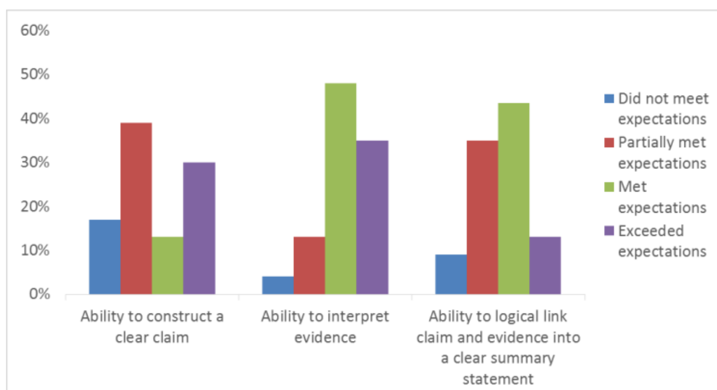



Figure 2. Direct evidence of students' demonstrated abilities to 1) construct a claim, 2) interpret evidence (data), and 3) logically link claim and evidence into a summary statement.

- Just over half (56%) of students, met or exceeded expectations by logically linking claim and evidence together in a **concluding sentence.** But 35% used illogical reasoning (partially met expectations) to link their claim and evidence (Fig. 2 & Table 3).

## Students' self-assessment of proficiency with scientific practices

**Students' self-assessment of abilities to use models.** Only 64% of students reported very good or excellent skills in using mathematical models at the end of the course (Supp. Fig. 1). However, overall, the vast majority (95%) of students saw improvement in their ability to use mathematical models to describe and predict population dynamics following this course (Table 4).

**Students' self-assessment of abilities to interpret primary data.** Again, only 67% of students rated their ability to interpret and draw conclusions from data (graphs and tables) as very good or excellent (Supp. Fig. 2). But the majority (81%) of students saw an improvement in their ability to interpret and draw conclusions from data following this course (Table 4).

**Students' self-assessment of abilities to construction scientific arguments.**

1. The majority (83%) of students also reported having very good or excellent skills in *providing evidence to support a claim* at the end of the course (Supp. Fig. 4).
2. The majority (77%) of students reported having very good or excellent skills in *designing a claim* following this course (Supp. Fig. 3).
3. Again, the majority (82%) of students reported having very good or excellent skills in *logically linking claim and evidence together in a concluding sentence* following this course (Supp. Fig. 5).

## Student Feedback

All respondents provided feedback on aspects of the course that had a strong impact. We identified the following course aspects (ranked in order of decreasing frequency) mentioned as having the **strongest impact** on their understanding of ecology:

1. In-class investigations.
2. Group work facilitated by instructors (See student quotes box).
3. Redwood forest survey (field trip) and accompanying data analysis.
4. Designing experiments in-class.
5. SimBio Virtual Lab Homework. Two online lab modules were assigned to facilitate exploration of ecological field methods, model manipulation, data collection, and data interpretation.

**Student Quotes:**

"The group work had the largest impact on my learning because it allowed for collaboration and helped to develop my critical thinking skills."

"Working and talking everything out with a group made learning more challenging but also way more effective."

"A little more preface before diving into the work might help us out a bit so we don't feel so lost initially. But other than that, I really liked the way this course was taught. Yeah, it took getting used to but I actually remember stuff past the final for the first time in four years at UCSC."

Again, all respondents provided feedback on aspects of the course that they felt could be improved. We identified the following course aspects (ranked in order of decreasing frequency) for **course improvements**:

1. Students wanted more lecture at the start of class clarifying (reiterating?) chapter reading (See student quotes box)
2. Lecture at the end of class with in-class investigation solutions
3. Practice problems with solutions for outside of class
4. More time with predation chapter (predation and life tables are the hardest chapters for students)

## Discussion

I developed tools for assessing student mastery of scientific practices that most instructors would agree are fundamental to scientific investigation, yet rarely explicitly taught or even assessed. My standard for successful comprehension of my course learning outcomes was 75% of students meeting or exceeding expectations. After analyzing the data, I conclude that this class met and even exceeded my standards in regard to two important course learning outcomes: interpreting data and using models (skills 1 and 2). However, this standard was not met for the third course learning outcome - construction of a scientific argument (skill 3). The data shows that it has remained challenging for many students to (1) develop and articulate clear claims and (2) use reason to logically link claim and evidence. This is not surprising because there is a wealth of literature on how difficult this skill is for students.

Overall, the students as a group tended to *over-estimate* their abilities to construct a scientific argument and *under-estimate* their abilities to use models and interpret data (Table 5). I think this self-assessment data shows how difficult it can be for people to evaluate their own competency. For example, it appears that the students' *over-estimated their abilities on topics that were new to them* (i.e. specific directions for constructing a scientific argument) and *under-estimated their abilities to do well known scientific practices* (i.e. model use and data analysis). The inaccuracy of student self-reports related to their skills is important to note, and instructors should use caution when using self-reports alone to evaluate students' scientific skills. However, there are still benefits to student self-assessments. For example, having students think about skills explicitly through surveys may have other benefits, such as helping students contextualize and reflect on the importance of learned skills. Additionally, instructors can use the surveys troubleshoot potential divergences between what students *think* they have mastered and what instructors believe students still need to improve.

The three assessment (scoring) rubrics I developed demonstrate that essential scientific practices can be successfully taught and assessed in a classroom setting. Additionally, instructors can use the assessment results to diagnose particular aspects of a course students still struggle with (e.g. connecting evidence to a claim with adequate reasoning). Student feedback on the active learning experience indicates that some may experience it as unusually challenging (see student quote box). Students have well-established routines and expectations when they enter a classroom, and can find it difficult to make the initial transition to an inquiry based and active learning environment. For example, in most labs there is a pre-lab lecture in which the instructor tells the students precisely what they will do in lab, even what results to expect. Consequently, when students enter an active learning classroom and are asked to conduct an authentic scientific investigation and exploration of a phenomenon, without being told the method or result beforehand, they can feel overwhelmed and underprepared. Therefore, even though students reported that they wanted more lecture at the beginning of class, it might just be that they expect it and were uncomfortable without it. Additionally, the fact that the top three aspects of the course that had the greatest impact on the students were all active learning techniques (i.e. in-class investigations, group work, and the field trip) indicates that the class was well-received by the majority of students, it just took some getting used to. In conclusion, this data supports continued transformation of higher education curriculum towards a focus on authentic student investigation and mastery of critical scientific practices.

## Tables

Table 1. Direct evidence of students' abilities to utilize population models.

| | **Did not meet expectations** | | **Partially met expectations** | | **Met expectations** | | **Exceeded expectations** | | **Met or exceeded expectations** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Criteria | Count | % | Count | % | Count | % | Count | % | Count | % | **Total N** |
| Use known variables to determine best fitting ecological model | Did not choose correct mathematical model<br>1 | 4% | determined the correct model but logic was incorrect<br>3 | 13% | determined correct model and logic was correct<br>14 | **61%** | determined correct model and logic was correct + exceptional reasoning skills developed in writing<br>5 | **22%** | 19 | **83%** | 23 |
| Determine correct mathematical models to use and then manipulate model to determine answer | Did not choose correct model and got incorrect answer<br>1 | 4% | Determined at least one correct model, showed their work but did not correctly solve for unknown variables and got incorrect answer<br>5 | 22% | Determined the correct model. Used known variables to correctly solve for unknown variables. Showed their work but made a slight mathematical error and therefore did not get correct numerical answer (or did not fully solve for t)<br>7 | **30%** | Determined the correct model. Used known variables to solve for unknown variables. Showed their work and solved for correct numerical answer<br>10 | **43%** | 17 | **74%** | 23 |

Table 2. Direct evidence of students' abilities to interpret and explain primary data.

| | Did not meet expectations | | Partially met expectations | | Met expectations | | Exceeded expectations | | Met or exceeded expectations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Criteria | Count | % | Count | % | Count | % | Count | % | Count | % | **Total N** |
| Interpret data table | Reported a significant effect of fertilizer on crop yield or did not respond | | Detected no significant effect of fertilizer at low concentrations but reported an effect at high fertilizer concentration | | Detected no significant effect of fertilizer on crop yield but logic or writing is somewhat difficult to interpret | | Detected and logically explained no significant effect of fertilizer on crop yield. Plus possibly detected slight though non-significant trends for each strain of corn | | | | |
| | 2 | 9% | 3 | 13% | 10 | **43%** | 8 | **35%** | 18 | **78%** | 23 |

Table 3. Direct evidence of students' abilities to construct scientific arguments using evidence.

| | **Did not meet expectations** | | **Partially met expectations** | | **Met expectations** | | **Exceeded expectations** | | **Met or exceeded expectations** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Criteria | Count | % | Count | % | Count | % | Count | % | Count | % | **Total N** |
| Design a claim for observed data | Claim is false, vague, or not present<br>4 | 17% | Claim is accurate but not ecologically realistic and writing lacks clarity<br>9 | 39% | Claim is accurate and logical but more subtle elements are ignored<br>3 | **13%** | Claim is accurate, logical and well developed<br>7 | **30%** | 10 | 43% | 23 |
| Provide evidence to support claim | Evidence is inaccurate, vague, or not provided<br>1 | 4% | Evidence is accurate but interpretation is inaccurate (e.g. not ecologically adequate or realistic)<br>3 | 13% | Evidence is accurate and logical but sentence structure is somewhat difficult to read<br>11 | **48%** | Evidence is accurate, logical and explained properly<br>8 | **35%** | 19 | 83% | 23 |
| Use reasoning to link claim and evidence together | Reasoning for why evidence supports claim is vague, inaccurate, or missing<br>2 | 9% | Reasoning links evidence to claim but is illogical<br>8 | 35% | Reasoning links or explains why evidence supports claim but sentence structure is somewhat difficult to read<br>10 | **43%** | Reasoning links or explains why evidence supports claim accurately and logically<br>3 | **13%** | 13 | 56% | 23 |

Table 4. Students' self-assessment of mastery of course learning outcomes before and after this course.

| | | Constructing a scientific argument | | | | | | Interpreting data | | Using mathematical models | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Design a Claim | | Use Evidence to support claim | | Logically link claim and evidence | | Detecting a significant trend | | Utilizing model to determine solution | |
| | | Count | % | Count | % | Count | % | Count | % | Count | % |
| Start of class | Very Good /Excellent | 2 | 9% | 4 | 18% | 4 | 18% | 1 | 4% | 1 | 4% |
| | Other responses | 20 | 91% | 18 | 82% | 18 | 82% | 21 | 96% | 21 | 96% |
| Current Levels | Very Good /Excellent | 17 | **77%** | 18 | **82%** | 18 | **82%** | 14 | **67%** | 14 | **64%** |
| | Other responses | 5 | 23% | 4 | 18% | 4 | 18% | 8 | 33% | 8 | 36% |
| Gain* | Improved | 18 | **82%** | 16 | **73%** | 16 | **73%** | 17 | **81%** | 20 | **95%** |
| | Stayed the same or decreased | 4 | 18% | 6 | 27% | 6 | 27 | 4 | 19% | 1 | 5% |

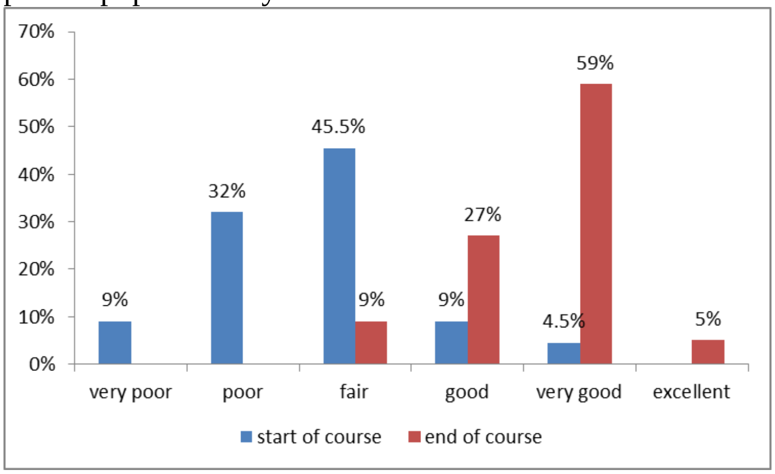
Table 5. Comparison direct versus indirect evidence of student mastery of course learning objectives. Table shows the percent of students' rating their understanding as "very good/excellent" compared to the percent of students "meeting/exceeding (instructor) expectations."

| *Skill* | *Student assessment* | *Direct evidence* |
|---|---|---|
| Clear claim | 78% | 43% |
| Interpret evidence | 83% | 83% |
| Reasoning | 83% | 56.5% |
| Interpret data | 67% | 78.5% |
| Choose correct model | | 83% |
| Use correct model | 64% | 73.5% |

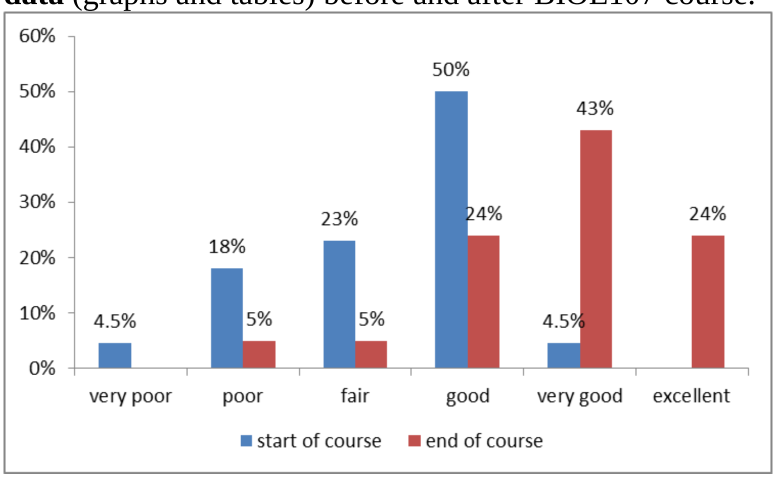
## Supplemental Data

### I. Figures of student self-assessment data

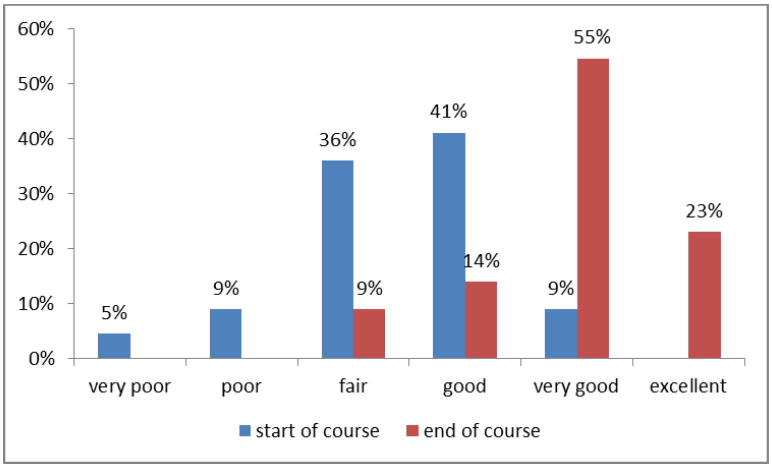
Supp. Figure 1. Student self-assessment of abilities to **use mathematical models** to describe and predict population dynamics before and after BIOE107 course.



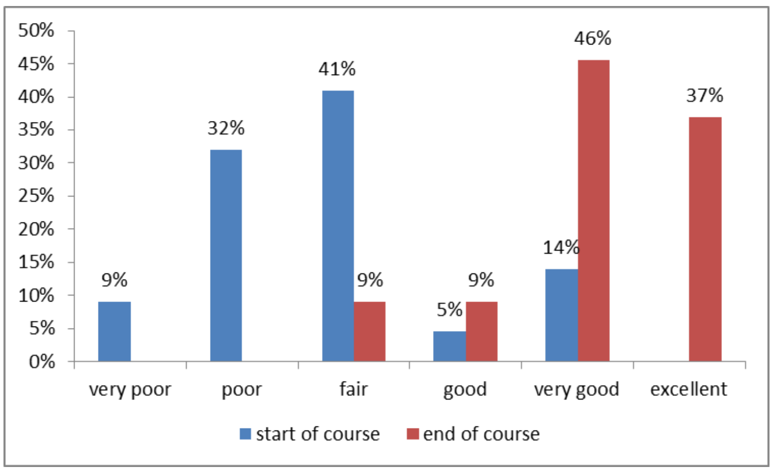

Supp. Figure 2. Student self-assessment of abilities to **interpret and draw conclusion from data** (graphs and tables) before and after BIOE107 course.



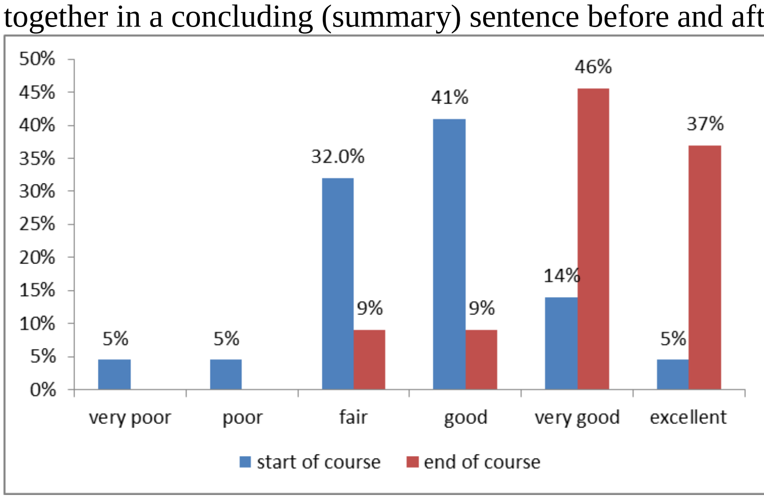
Supp. Figure 3. Student self-assessment of abilities to **develop a clear claim** from data before and after BIOE107 course.




Supp. Figure 4. Student self-assessment of abilities to **describe evidence** (verbally interpret data trends) to support claim before and after BIOE107 course.




Supp. Figure 5. Student self-assessment of abilities to **logically link claim and evidence** together in a concluding (summary) sentence before and after BIOE107 course.



## II. Rubrics used on final exam questions

Supp. Table 1. Assessment/grading rubric used to assess students' abilities to **use ecological models**. Students' abilities to build ecological models was evaluated using 2 criteria: (1) determining appropriate model and (2) using the model.

| Criteria | Did not meet expectations | Partially met expectations | Met expectations | Exceeded expectations |
|---|---|---|---|---|
| Use known variables to determine best fitting ecological model | Did not choose correct mathematical model | Determined the correct model but logic was incorrect | Determined correct model and underlying logic was correct but writing was difficult to interpret | Determined correct model and utilized exceptional reasoning/writing skills |
| points | 0 | 0.5 | 1 | 1 |
| Use model to determine answer | Did not show any of their work for solving for unknown variables and just wrote down incorrect values for unknown variables | Attempted to solve for unknown variables (r and t) but didn't show all their work and ultimately got incorrect answer | Used known variables to correctly solve for unknown variables (r and t). Showed their work but made a slight mathematical error and therefore did not get correct numerical answer (or did not fully solve for t) | Used known variables to solve for unknown variables. Showed their work and solved for correct numerical answer |
| points | 0 | 0.5 | 1 | 2 |

Supp. Table 2. Assessment/grading rubric used to assess students' abilities to **interpret primary data**. Students' abilities to interpret data was evaluated using one criterion - detecting a significant trend in a data table.

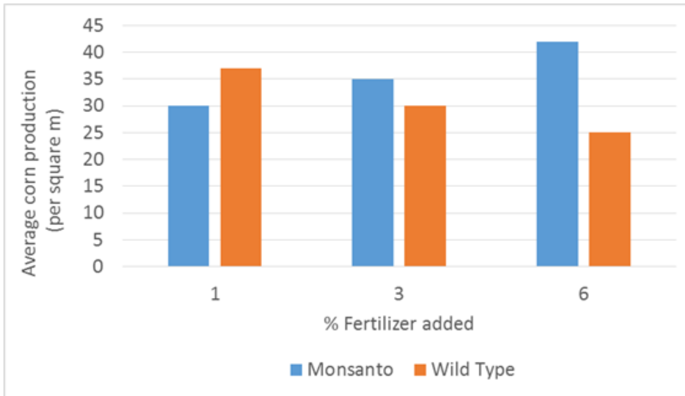
| Criteria | Did not meet expectations | Partially met expectations | Met expectations | Exceeded expectations |
|---|---|---|---|---|
| Interpret data | reported a significant effect of fertilizer on crop yield or did not respond | Detected no significant effect of fertilizer at low concentrations but reported an effect at high fertilizer concentration | Detected no significant effect of fertilizer on crop yield but logic or writing is somewhat difficult to interpret | Detected and logically explained no significant effect of fertilizer on crop yield. Plus possibly detected slight though non-significant trends for each strain of corn |
| points | 0 | 0.5 | 1 | 2 |

Supp. Table 3. Assessment/grading rubric used to assess students' abilities to **construct a scientific argument**. Students' abilities to construct a scientific argument was evaluated using 3 criteria: (1) making a claim, (2) using evidence to support claim, and (3) reasoning linking the claim and evidence together.

| Criteria | Did not meet expectations | Partially met expectations | Met expectations | Exceeded expectations |
|---|---|---|---|---|
| points | 0 | 0.5 | 1 | 1 |
| Design a claim | Claim is false, vague, or not present | Claim is accurate but not ecologically realistic and writing lacks clarity | Claim is accurate and logical but more subtle elements are ignored | Claim is accurate, logical and well developed |
| Provide evidence to support claim | Evidence is inaccurate, vague, or not provided | Evidence is accurate but interpretation is inacurate (e.g. not ecologically adequate or realistic) | Evidence is accurate and logical but sentence structure is somewhat difficult to read | Evidence is accurate, logical and explained properly |
| Use reason to link claim and evidence together in a concluding sentence | Reasoning for why evidence supports claim is vague, inaccurate, or missing | Reasoning links evidence to claim but is illogical | Reasoning links or explains why evidence supports claim but sentence structure is somewhat difficult to read | Reasoning links or explains why evidence supports claim accurately and logically |

### III. Final exam questions used for assessment

1) Interpreting graphical data. You work for the USDA and have been tasked with testing the sensitivity of Monsanto and wild type corn to a new fertilizer. Because there will always be some random variability ("noise") in your data, we set our threshold for statistical significance if the crop yield changes by **greater than** 15 units as the amount of fertilizer used changes. Based on the data and our threshold significance level, determine whether the Monsanto and wild type strains of corn are sensitive to the new fertilizer? **Explain your logic. (2pts)**




2) Explain the following results (be sure to specify your **claim**, provide **evidence** to support your claim, and use reasoning to logically **link** your claim and evidence). **(3pts)**

| Abalone abundance | Otter abundance | Site | Year |
|---|---|---|---|
| 100 | 200 | Alaska | 1995 |
| 50 | 100 | Alaska | 2000 |
| 60 | 200 | California | 1995 |
| 120 | 400 | California | 2000 |

3) Comparing population growth models. You're studying a population of *Ensatina* salamanders in their native redwood habitat. The carrying capacity for this population is 500 individuals, the per capita birth rate is 1.5 and the per capita death rate is 0.75. Additionally, the initial population size in 2010 was 25 individuals.

   a. Given your known variables determine the appropriate population growth model (e.g. logistic or exponential growth model). Explain your logic. ***(1pt)***

   b. **Approximately**, when is the "carrying capacity" (AKA when N=500) for this population of salamanders reached when you use the exponential model to predict growth? And when **approximately** is the carrying capacity **first** reached when you use the logistic growth model? To aid number punching with this problem you do not need to go above t= 25 years ***(2pts)***

   c. Explain your understanding of **why** the model predictions differ? ***(1pt)***

## IV. Course syllabus

**Lecture schedule and readings for Gotelli:**

| Date | Topic | Read ***before*** lecture |
|---|---|---|
| **July** | | |
| Tue 28 | Introduction<br>Exponential and logistic population growth | Ch. 1: pgs 2-14<br>Ch. 2: pgs 26-37 |
| Thur 30 | Life tables | Ch. 3: pgs 50-65 & 74-79 |
| **August** | | |
| Tue 4 | Competition<br>**SimBio Isle Royale graded questions due online by 9pm**<br>**1st writing assignment due on eCommons by 9pm** | Ch. 5 |
| Thur 6 | Island Biogeography + Species Diversity<br>**Field trip to Redwood forest on campus—*wear appropriate clothing + shoes*** | Ch. 7<br>Ch. 9: pgs 204-208 & 219-223 |
| Tue 11 | MIDTERM (*includes material covered through Aug 6th*)<br>**2nd writing assignment due on eCommons by 9pm** | |
| Thur 13 | Writing workshop<br>**Bring hardcopy of writing assignment or computer to class for peer revision and discussion** | The Science of Scientific Writing PDF |
| Tue 18 | Predation | Ch. 6 |
| Thur 20 | Metapopulation dynamics<br>**Final writing assignment due on eCommons by 9pm** | Ch. 4 |
| Tue 25 | Succession<br>**SimBio Patchy Prairies Exercises 3 & 4 due in class** | Ch. 8 |
| Thur 27 | FINAL EXAM (*weighted more heavily on material covered after the midterm*) | |

**Grading:**

- 25% Lecture participation and preparedness—assessed by in-class assignments. *Note: I will drop your lowest score*
- 10% SimBio Homework
- 30% Midterm exam
- 35% Final exam
- P/NP writing assignment