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Development of an Active-Learning Lesson that Targets Student Understanding of Population Growth in Ecology

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DEVELOPMENT OF AN ACTIVE-LEARNING LESSON THAT TARGETS STUDENT UNDERSTANDING OF POPULATION GROWTH IN ECOLOGY

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A THESIS
Submitted in Partial Fulfillment of the
Requirements for the Degree of
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May 2017

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DEVELOPMENT OF AN ACTIVE-LEARNING LESSON THAT TARGETS STUDENT UNDERSTANDING OF POPULATION GROWTH IN ECOLOGY

By Elizabeth Trenckmann

Thesis Advisor: Dr. Michelle K. Smith

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirement for the
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Integrating quantitative literacy skills into the undergraduate biology curriculum has been advocated as a way to better reflect the tools and practices used by scientists. One area where students often need and can develop quantitative skills is population ecology, and previous studies have shown that students often have conceptual difficulties in this area. The focus of this thesis project was to explore student thinking about population ecology and develop an in-class active-learning lesson that incorporates quantitative skills for use in large-enrollment undergraduate biology courses. The development of this lesson was guided by in depth reviews of literature, textbooks, and online teaching materials and data gathered from assessment instruments. The lesson was designed using an iterative process involving feedback from faculty and student learning data. The result of this process was a lesson that asks students to "engage like scientists" as they make predictions, plot data, perform calculations, and interpret information to investigate how ecologists measure and model population size. The final version of the lesson was taught in three sections of a large enrollment undergraduate class at the University of Maine. The impact of the lesson was assessed using formative and summative assessments including a pre/post-test, clicker-based questions, and multiple-choice exam questions. Student performance increased following peer discussion and on post-test questions. Students also performed well on end-of-unit exam questions targeting similar concepts.

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LITERATURE REVIEW ON THE IMPORTANCE OF ACTIVE LEARNING AND ON STUDENT CONCEPTUAL DIFFICULTIES IN ECOLOGY

1.1 Overview

This thesis focuses on improving undergraduate student understanding of population growth in ecology, increasing students' quantitative reasoning skills, and developing classroom activities and assessments that instructors can use in large-enrollment biology classes. Chapter 1 describes the background research conducted to develop a lesson that is inclusive, valuable, and addresses important content areas where students have been shown to struggle.

1.2 Active learning and its importance in the classroom

1.2.1 Inclusive teaching

It is important that the pedagogical strategies employed in undergraduate classrooms reflect an understanding of students' needs and diverse backgrounds, learning styles, and abilities (Ambrose et al., 2010). By implementing inclusive teaching strategies, instructors 1) provide multiple opportunities for students to engage with and learn important content, 2) help students connect with the course material in relevant and meaningful ways, and 3) allow students to feel comfortable (Inclusive Teaching, 2016).

To implement inclusive teaching strategies in the classroom, instructors can use different teaching approaches, activities, and assignments that can accommodate the needs of students and provide flexibility in how students demonstrate content knowledge (Lage et al., 2000). For example, by making content available through multiple mediums (e.g., on projected slides, on a worksheet, verbally stated by peers/instructor) the instructor can optimize student success by ensuring the students are receiving the information, regardless of how they best learn. Additionally, by providing opportunities for both individual and group work to take place in the classroom, the instructor allows students to learn in scenarios in which they are most comfortable.

1.2.2 What is active learning?

Over the past decade, the focus of the university classroom has shifted away from the traditional lecture based approach to a blend of pedagogical approaches that involve the student in the learning process (Barr & Tagg, 1995). Inclusive teaching practices now include the use of active-learning strategies such as asking students to answer questions and discuss their thinking with classmates (Crouch and Mazur, 2001; Smith et al., 2009; Smith et al., 2011). Through this student-centered approach the instructor can both increase student success and gain useful information on student understanding (Singer et al., 2012). Such methods, which engage the students in activities rather than passively listening to the instructor, are considered active learning techniques (Faust and Paulson, 1998; Silberman, 1996). Below I discuss several strategies regularly used in undergraduate classrooms to provide an idea of the diversity of active learning techniques used by instructors.

1.2.2.1 Questioning techniques

An approach known as “questioning techniques” encourages the instructor to ask students challenging questions that require the application of the concepts covered throughout the lecture

(Singer et al., 2012). For example, in a population ecology course the instructor can ask the students to name abiotic and biotic factors that affect a population of barnacles. This method can be employed to increase student involvement and interest in the classroom, even when lecture is the primary content delivery method.

1.2.2.2 Individual techniques

Individual techniques, such as having students write a “one-minute paper” allow students to be individually engaged in the learning process. This technique, originally reported by Angelo and Cross (1993), helps instructors monitor student progress and provides students with a consistent means of communicating with instructors. To implement, the instructor pauses class during a lecture, poses a specific question, and provides time for the students to answer the question in written format. Depending on the instructor’s objectives, this technique can be done anonymously or with the student’s names attached.

1.2.2.3 Cooperative learning techniques

Cooperative learning is a subset of active learning that allows students to work together in groups of three or more (Faust and Paulson, 1998). Groups work towards a common goal as they complete tasks such as multiple step exercises, research projects, or presentations. Many different types of cooperative learning techniques exist (examples 1-5):

1. Think-pair-share (TPS)- To implement TPS, the instructor poses a problem and students think about the problem individually, work together to solve the problem, and finally share their ideas with the entire class (Lyman, 1987; Kothiyal et al., 2013). Through this model, students can individually think about the posed question, reflect on

their own thinking, and obtain immediate feedback from both the instructor as well as their peers (Lyman, 1987).

2. Peer Instruction (PI)- Peer instruction is a cooperative learning technique that is closely related to TPS (Lyman, 1992), but it is enhanced with the use of personal response systems (clickers) which provide immediate assessment feedback (Duncan, 2006; Knight and Wood, 2005; Smith et al., 2009). Clickers are remote control devices where students typically respond to multiple choice questions, allowing the instructor to see student responses in real-time. The use of clickers promotes anonymity, which can reduce student discomfort in the classroom (Martyn, 2007). To use this instructional technique the following steps can be used: 1) the instructor poses a thought-provoking multiple choice question with multiple plausible incorrect answers, 2) students reflect on the question, 3) students commit to an individual question, 4) the instructor reviews student responses, 5) students discuss their thinking and answer choice with their partners, and 6) the instructor reviews student responses and decides whether more explanation is needed before moving onto the next concept (Mazur, 1997; Crouch and Mazur, 2001).

Research indicates that the use of PI in the classroom increases conceptual understanding in a variety of science, technology, engineering, and mathematics (STEM) courses (Crouch and Mazur, 2001; Simkins and Maler, 2009; McConnell et al., 2006; Mora, 2010; Cortright et al., 2005). In a study conducted by Crouch and Mazur (2001), student learning gains in a traditional lecture and PI-based physics courses were compared by administering a conceptual test, the Force Concept Inventory (FCI; Hestenes et al., 1992) to the students at the beginning and end of each semester. The authors compared the results from PI classes to

10 years of historic data and found that the observed learning gains of students in the PI instruction were twice as large as those observed in the traditional lecture (Crouch and Mazur, 2001). Similarly, in a study conducted by McConnell et al. (2006), the average differences between post and pre-test scores on the Geosciences Concepts Inventory (GCI; Libarkin and Anderson, 2005) were greater in courses where PI was implemented.

The use of PI has also been shown to increase student understanding. For example, in a study conducted to investigate how much students learned from peer discussion in a genetics course, students answered paired sets of similar clicker questions throughout the semester (Smith et al., 2009). Students were asked to answer one question individually (Q1), discuss their thinking with their neighbors, and revote on the same question (Q1 after discussion). Subsequent to this vote, the same students were asked a similar question (Q2) where no discussion followed the individual vote. Results from this study indicate that most students learned from the discussion of Q1, as the average percentage correct for Q2 was significantly higher than for Q1 and Q1 after discussion (Smith et al., 2009). To compare the effectiveness of three different approaches of using clickers (individual answer only, peer discussion only, and peer discussion and instructor explanation combination), pairs of similar clicker questions were given to students in majors' and non-majors' genetics courses (Smith et al., 2011). The combination of peer discussion followed by instructor explanation resulted in significantly higher learning gains when compared with their peer discussion or instructor explanation alone (as measured by normalized change in scores between Q1 and Q2) (Smith et al., 2011).

Research has also demonstrated the positive impact of PI on students' problem solving skills. In a study conducted to investigate students' ability to transfer knowledge in an exercise physiology course, students in the PI course were found to be significantly (p=0.02) more likely to answer questions designed to measure mastery of the material correctly (Giuldiodori et al., 2006). Likewise, the number of students correctly solving problems requiring qualitative predictions improved significantly with the use of PI (Giuldiodori et al., 2006).

3. Peer evaluation- Allowing students to evaluate the work of their peers in class can help students internalize the characteristic of quality work and encourage involvement and responsibility. Furthermore, peer evaluation can help improve student performance for the reviewer and the student being reviewed (Lundstrom and Baker, 2009). For example, in a study conducted by Lunstrom and Baker (2009) that investigated the benefits of peer evaluation, students were divided into a control group (students who received feedback) and the experimental group (students who provided feedback). Throughout the semester, students were given training on peer review (how to use feedback to revise a paper and how to provide feedback), and at the beginning and end of the semester students wrote a thirty-minute timed essay (Lundstrom and Baker, 2009). The essays were rated by teachers working at the Brigham University English language institute, and seven writing aspects were critiqued: overall, organization, development, cohesion, vocabulary, mechanics, and grammar. Results from this study suggested that both groups had gains in most of the writing aspects pre-test to post-test (Lunstrom and Baker, 2009). Instructors can implement this technique by providing students in-class opportunities to give other students feedback and suggestions.
4. In class debates- Allowing students to have structured discussions about material covered in class is another useful technique for fostering student engagement (Fredrick, 2002). To implement, instructors can divide the class into two or more groups, provide students

with a discussion prompt, and ask each group for statements supporting their side of the issue (Singer et al., 2012). Research has shown that in-class debates cultivate the active engagement of students by placing the responsibility of comprehension on the students (Snider and Schnurer, 2002).

5. Process Oriented Guided Inquiry Learning (POGIL)- To implement this student-centered teaching strategy, instructors allow students to work in small groups with individual roles to ensure that all students are fully engaged in the learning process (Moog and Spencer, 2008). POGIL activities focus on core concepts and encourage a deep understanding of the course material while developing higher-order thinking skills such as critical thinking, problem solving, and communication (Moog and Spencer, 2008). POGIL activities provide students with data or information and ask leading questions that are designed to guide students toward formulation of valid conclusions (POGIL, 2016). During POGIL, the instructor takes a new role as they act as a facilitator throughout the activity, observing and periodically addressing individual and classroom-wide needs (POGIL, 2016).

1.2.3 Benefits of active learning

As seen above, a number of techniques are available for instructors to actively engage students in the classroom. These techniques have become increasingly popular due to the evidence of the benefits of using such techniques in the classroom (Eagan et al., 2014). There is strong empirical evidence that active involvement in the learning process is beneficial for: 1) the mastery of skills, such as critical thinking and problem solving and 2) contributing to the student’s likelihood of persisting to the program completion (McCarthy and Anderson 2000; Braxton et al., 2008; Prince, 2004; Freeman et al., 2014).

Freeman and colleagues (2014) conducted a meta-analysis of 225 studies reporting data on examination scores or failure rates when comparing student performance in undergraduate science, technology, engineering, and mathematics (STEM) courses under traditional lecturing versus active learning. Results of this study showed that on average, student performance on examinations and concept inventories increased by roughly half a letter grade (0.47 SDs) with active learning (n=158 studies). On average examination scores improved by almost 6% in active learning sections, and students in traditional lecture were 1.5 times more likely to fail than students in classes with active learning. Miller and Grocchia (1997) compared standard lecture format and cooperative learning in an introductory college level biology course. Students taking the cooperative learning format option indicated significantly higher levels of satisfaction with the course than those taking the traditional format option. Similar results were supported in Montgomery, Brown, and Deery (1997). These studies indicate that active learning strategies help create a more stimulating and enjoyable classroom environment for students as well as improve their chances of being successful in the classroom.

Research has also shown that students benefit from highly structured active learning environments where instructors incentivize student engagement, such as with the use of participation points, particularly for students who are at high risk of failing. For example, in a study conducted by Freeman et al. (2007), five course designs that varied in the structure of daily and weekly active-learning exercises were examined in an introductory biology course. Significant gains in student achievement suggest that students benefit from active learning exercises when they are encouraged with points as opposed to being voluntary. Additionally, failure rates were significantly lower and exam points and attendance were higher when participation points were awarded to students. Therefore, if more introductory courses are designed in a way that advocates student participation and practice, it is likely that the success of students, especially those that are at a high risk of failing, will increase.

1.3 Persistent conceptual difficulties in ecology

1.3.1. Importance of ecology in undergraduate education

Biology faculty are beginning to use active learning in their classrooms with increasing frequency (Eagan et al., 2014), but to help more faculty adopt these practices it is important to provide them with lessons that can be used in the classroom. One area of biology where more lessons are needed is ecology. The American Association for the Advancement of Science (AAAS) *Vision and Change* report identified understanding ecology as one of the core concepts for biological literacy for undergraduate biology education, and the ability to use quantitative reasoning as a core competency and disciplinary practice (AAAS, 2011). Population ecology involves several quantitative approaches to examining population dynamics that require sophisticated modeling. Additionally, population ecology is an important part of the K-12 curriculum. For example, the Next Generation Science Standards (NGSS) middle school learning outcomes include Ecosystems: Interactions, Energy, and Dynamics of states that students should be able to analyze and interpret data to provide evidence for the effects of resource availability on populations of organisms in an ecosystem (NGSS, 2013).

1.3.2 Literature review of student understanding of population growth

Despite the importance of population ecology, there are limited studies available investigating conceptual difficulties of undergraduate students in this area. A current understanding of student conceptual difficulties in population ecology from elementary school to upper division college is shown in Table 1.1. For example, in a study conducted by Brody & Koch (1989), 226 students from 12 schools in Maine (grades 4th, 8th, and 11th) were interviewed using a set of questions that probed their understanding of marine science, natural resources, and decision-making concepts and principals. Following the interview, student knowledge was classified according to correct concepts, missing concepts, and conceptual difficulties. Of the conceptual difficulties reported, one pertained to directly to population ecology: students thinking that ecosystems are limitless resources and provide an opportunity for limitless growth (Table 1.1). Students who stated this were not considering the different abiotic and biotic factors that limit the population size for any given species.

In a similar study, a diagnostic test was developed to assess students understanding of natural selection, consisting of 20 multiple choice questions employing common alternative conceptions as distractors (Anderson et al., 2002). This assessment was given to 206 students in a non-majors biology course. From this assessment, conceptual difficulties were identified in: 1) population stability - students thought that not all populations can exhibit exponential growth under ideal conditions and that all populations grow over time; 2) competition - students thought that organisms would work together (cooperate) (e.g., stating that if food was limiting in a population of lizards, the organisms would share what food was available to ensure all survive); and 3) natural resources - students thought that organisms can always obtain the resources they need to survive (Anderson et al., 2002) (Table 1.1).

Learning Target	Example of Correct Student Thinking	Example of Context Specific Incorrect Student Thinking	Grade level studied
Population stability	Populations exist in a state of dynamic equilibrium, fluctuating around an average population size.	Populations exist in states of either constant growth or decline depending on their position in the food chain.	4th to upper division college *(Munson, 1994)*
	All species have such great potential and fertility that their population size would increase exponentially if all individuals that were born would again reproduce successfully.	Not all organisms can achieve exponential population growth.	Community college non-majors *(Anderson et al., 2002)*
	Most populations are normally stable in size except for seasonal fluctuations.	All populations grow over time.	Community college non-majors *(Anderson et al., 2002)*
Competition	Production of more individuals than the environment can support leads to a struggle for existence among individuals of a population, with only a fraction surviving each generation.	Organisms work together (cooperate) and do not compete.	Community college non-majors *(Anderson et al., 2002)*
Natural resources	Biotic and abiotic factors in an ecosystem are limited and affect the carrying capacity for any given species.	Some ecosystems are limitless resources and provide an opportunity for limitless growth of a population.	4th, 9th, and 11th grade students *(Brody and Koch, 1989)*
	Natural resources are limited; nutrients, water, oxygen, etc. necessary for living are limited in supply at any given time.	Organisms can always obtain what they need to survive.	Community college non-majors *(Anderson et al., 2002)*

Table 1.1: Conceptual difficulty topics in population ecology. Conceptual difficulty topics identified through an in-depth literature review of student thinking in population ecology.

1.3.3 EcoEvo-MAPS assessment results

Student conceptual difficulties were also identified from results from over 80 student interviews and final implementation of EcoEvo-MAPS (Ecology and Evolution Measuring Achievement and Progress in Science), an assessment tool designed to measure student thinking in ecology and evolution (Summers et al., submitted). This assessment tool was given to over 3000 students from 34 different institutions (including associates, bachelors, masters, and doctoral granting institutions) (Summer et al., submitted). The assessment includes nine questions with 63 total likely/unlikely statements asking students to evaluate a series of predictions, conclusions, or interpretations as likely or unlikely to be true given a scenario with observations and evidence, four of these statements applied to student understanding of populations (Table 1.2).

Results from the EcoEvo-MAPS assessment suggest that students struggled when learning about population ecology, specifically when discussing intraspecific competition, density, carrying capacity, and population growth. For example, when asked about competition within a flask of bacteria, 37% of the undergraduate students incorrectly stated that competition would only occur between two different species of bacteria present. Furthermore, when presented with a figure showing population size over time, 39% of students incorrectly stated that more information was required to calculate density. In another question, when asked if a population of phytoplankton at carrying capacity, limited by phosphorous availability, would exhibit increased growth as a result of nitrogen run-off from an agricultural field, 41% of students incorrectly said that the population would likely increase. These results suggest students did not understand the influence of limiting factors on carrying capacity. Lastly, students were presented with a statement that said if a population of bacteria was placed in flask with unlimited food the population would grow linearly, and 45% of students incorrectly selected that this would be likely when in fact the growth would be exponential.

Learning Target	Example of Correct Student Thinking	Example of Incorrect Student Thinking	Percent Incorrect
Intraspecific competition	When there are more bacteria in the flask, they compete more with each other for resources and space.	There is more competition only where there are more of another species.	37%
Density	Density is measured and shown in the figure.	More information is required to calculate density.	39%
Carrying capacity	If at carrying capacity because of limited phosphorus - need addition of phosphorous for population to increase.	If more nitrogen, more growth because nitrogen and phosphorous cancel out.	41%
Population growth/decline	Would more likely grow exponentially while unlimited food and resources.	There is nothing to make the population decrease, so linear growth.	45%

Table 1.2: EcoEvo-MAPS identified conceptual difficulties. Conceptual difficulty topics identified from the results of EcoEvo-MAPS assessment. Table modified from Summers et al., submitted.

Review of the literature and EcoEvo-MAPS results directed the development of the lesson to focus on modeling and exploring population growth over time, as students struggled with determining the factors that can influence a population, understanding carrying capacity, calculating density, and investigating growth models.

1.4 Purpose of this study

As described above it is important for instructors to create learning environments where students' academic, social, and cultural backgrounds can be an asset to their learning (Inclusive Teaching, 2016). Achieving this inclusive learning environment can be done using a variety of different teaching methods in the classroom, including student centered learning practices, such as active learning. Many different forms of active learning exist, and there is strong support from the research literature about the benefits of such techniques (Freeman et al., 2014; Freeman et al., 2007; Miller and Grocchia, 1997; Brown, and Deery, 1997). This study builds on the research promoting the use of active learning in the classroom through the development of an active learning based lesson to target previously identified conceptual difficulties in population ecology (Munson, 1994; Summers et al., submitted; Anderson et al., 2002).

CHAPTER 2

ITERATIVE DEVELOPMENT OF AN ACTIVE-LEARNING BASED LESSON

2.1 Overview

The goal of this chapter is to describe the iterative process used to develop an active-learning based lesson to target conceptual difficulties in population ecology. This process consisted of conducting extensive background research on the topic through a review of available textbooks and online materials (including lessons and lectures) followed by the development of the lesson, which included multiple feedback opportunities from faculty and student learning data. Each step will be discussed in depth to give an indication of the process used to develop the final lesson. Finally, recommendations are provided for developing a successful lesson based on my experience.

2.2 Background of population ecology

2.2.1 Textbook review

Following the identification of the persistent conceptual difficulties students have when learning about population growth in ecology, an extensive textbook review was conducted to investigate the presentation of population ecology material to students. During this review, multiple textbooks were used to determine the important and reoccurring concepts covered in population ecology (repeated in every major textbook). A list of important terms and concepts was generated and used to guide the development of the lesson (Table 2.1).

	Dispersal	**Biotic and abiotic factors**	**Density**	**Immigration and emigration**	**Exponential and logistic growth models**	**Carrying capacity**	**Density dependence and independence**	**Intrinsic Rate of Increase**	**Competition**
Urry LA, Cain ML, Wasserman SA, Minorsky PV, Jackson RB, Reece JB. 2014. *Biology in focus*. Pearson. Chapter 40, 818-844.	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Sadava DE. 2011. *Life: the science of biology.* Sunderland. Chapter 55, 1167-1184.	**X**		**X**		**X**	**X**	**X**	**X**	**X**
Cotgreave P, Forseth I. 2009. *Introductory Ecology.* Wiley-Blackwell. Chapter 7.		**X**	**X**		**X**	**X**	**X**	**X**	**X**
Begon M, Townsend CR, Harper JL. 2005. *Ecology: from individuals to ecosystems.* Wiley-Blackwell. Chapter 21.	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Smith TM, Smith RL. 2009. *Elements of ecology.* Pearson Benjamin Cummings. Chapter 9.		**X**	**X**		**X**	**X**	**X**		**X**

Table 2.1: Textbook review concepts. Important ecology concepts identified from textbook review.

2.2.2 Review of available online materials

In addition to a review of the ecology and biology textbooks, an in-depth review of available online materials (including lesson and lectures) covering population ecology was conducted. Online lectures from Massachusetts Institute of Technology (MIT), Yale, and Harvard were viewed to determine the content covered, approach used by instructors to present that material, and skills needed for students to succeed (Table 2.2).

School Name	Lecture Title	Content Covered
MIT (http://ocw.mit.edu/courses/biology/7-014-introductory-biology-spring-2005/video-lectures/29-population-growth-i/)	Population Growth I & II	Properties of a population Measuring population growth Regulation of the density of a population Modeling population growth Distribution of populations Calculation of density and abundance Age structure Life table analysis Modeling exponential and logistic growth Feedback mechanisms in modeling
Yale (http://oyc.yale.edu/ecology-and-evolutionary-biology/eeb-122/lecture-26)	Population Growth: Density Effects	Density Growth Rate Age Structure Survivorship curves Life table analysis Density dependence Carrying Capacity
Harvard http://environment.harvard.edu/events/calendar/2009-10-14/biodiversity-ecology-and-global-change	Population Ecology	Density Distribution of populations Age structure Immigration, emigration, births, deaths, and their influence on a population Calculation of growth rate Modeling exponential and logistic growth Carrying Capacity Density dependence Survivorship curves Life table analysis Human population growth

Table 2.2: Review of undergraduate lectures. Summary of undergraduate lecture review. The content covered in all three lectures were similar to the content list generated from the textbook review.

A review of online lessons revealed the lack of resources available for instructor use at the undergraduate level. Of those available, most were better suited for high school level students or small-enrollment classes and were either computer or laboratory based (Table 2.3). Therefore, we decided to develop a lesson focused on quantitative skills in population ecology for large-enrollment undergraduate courses.

2.3 Iterative lesson development

2.3.1 Developing population growth lesson with multiple rounds of feedback

Using conceptual difficulty information obtained from the EcoEvo-MAPS assessment (Summers et al., submitted) and the literature, textbook, and online material reviews, we developed multiple versions (Lesson Versions 1-9) of a population ecology lesson for an introductory undergraduate classroom, and formative and summative assessment questions (Figure 2.1). As part of the iterative design process, we presented Versions 1-9 to a diverse group of faculty on campus multiple times to gain feedback on: 1) research methodology, from the Maine Center for Research in STEM Education (RiSE Center) and Smith Laboratory; 2) ecology content and level of difficulty, from the Ecology and Evolution from Everything Seminar (EEE); and 3) ecology student engagement and teaching clarity, from High School Instructors at the RiSE Center Conference (Figure 2.2). The iterative process of developing this lesson allowed us to strengthen the content, clarity, difficulty, and usefulness of the lesson. During each revision, the learning objectives were modified (Table 2.4), and the content shifted. Each version (1-9) of the lesson is discussed briefly below, including the main content areas, the number of clicker questions, and suggestions for revision.

Lesson Title	Education Level	Concepts Addressed	Skills needed	Teaching Methods	Reference
An Introduction to Population Ecology	Introductory undergraduate	Exponential population growth Doubling time Rate of growth	Use of exponential growth model to perform calculations	Computer based activity	Hale BM, McCarthy, ML. 2005. An introduction to population ecology, JOMA, 1. Retrieved October 21, 2008 from http://www.maa.org/press/periodicals/loci/joma/an-introduction-to-population-ecology
An Introduction to Population Ecology- The Logistic Growth Equation	Introductory undergraduate	Density-dependent forces Carrying capacity Logistic population growth	Use of logistic growth model to perform calculations	Computer based activity	Hale BM, McCarthy, ML. 2005. An introduction to population ecology- the logistic growth curve equation, JOMA, 1. Retrieved October 21, 2008 from http://www.maa.org/press/periodicals/loci/joma/an-introduction-to-population-ecology
Connecting Concepts: Interactive Lessons in Biology	Introductory undergraduate	Exponential and logistic mathematical models Measuring population size Population growth curves Logistic growth equation Growth rate	Graph development Data management Use of logistic growth model to perform calculations Density calculations	Computer based activity	Jeanne, R. (2003). Population ecology. Retrieved from Connecting concepts: interactive lessons in biology website: http://ats.doit.wisc.edu/biology/ec/pd/pd.htm
Exploring the population dynamics of wintering bald eagles through long term data	Upper division undergraduate	Modeling population growth Predicting population growth Graphing population growth	Data management Graph development Data analysis and interpretation	Computer based activity	Julie Beckstead, Alexandra N. Lagasse, and Scott R. Robinson. February 2011, posting date. Exploring the population dynamics of wintering bald eagles through long-term data. *Teaching Issues and Experiments in Ecology*, Vol. 7: Practice #1[online]. http://tiee.esa.org/vol/v7/issues/data_sets/beckstead/abstract.html

Table 2.3: Summary of available resources in ecology education.

Lesson Title	Education Level	Concepts Addressed	Skills needed	Teaching Methods	Reference
Teaching Exponential and Logistic Growth in a Variety of Classroom and Laboratory Settings	Introductory undergraduate	Logistic and exponential population growth Carrying Capacity Growth Rate	Data management Graph development	Laboratory or classroom setting	Barry Aronhime, Bret D. Elderd, Carol Wicks, Margaret McMichael, and Elizabeth Eich. 10 November 2013, posting date. Teaching Exponential and Logistic Growth in a Variety of Classroom and Laboratory Settings. *Teaching Issues and Experiments in Ecology*, Vol. 9: Experiment #4 [online]. http://tiee.esa.org/vol/v9/experiments/aronhime/abstract.html
Population Ecology: Experiments with Protistans	Introductory undergraduate	Birth and death rates Density-dependent forces Density-independent forces Modeling logistic population growth Competition Carrying Capacity Doubling Time Growth Curves	Graph development Calculations	Laboratory activity	Glase, J. C. (1991). *Population Ecology: experiments with protistans*. Retrieved from http://www.esa.org/tiee/vol/expv1/protist/protist.pdf
What limits the reproductive success of migratory birds?	Introductory undergraduate	Demography Population growth Density	Data management and interpretation Graph development	Computer based activity	Langin, K., Sofaer, H., & Sillett, S. (2009). Why study demography? Retrieved from Hubbard Brook Foundation website: http://hubbardbrookfoundation.org/migratory_birds/Pages/Background/Demography.html

Table 2.3: Continued.

Lesson Version	Learning Objective 1	Learning Objective 2	Learning Objective 3	Learning Objective 4
1	Generate graphs	Interpret graphs	Develop hypotheses and experimental designs	-
2	Predict population growth	Identify and investigate factors that influence population growth	Distinguish between density dependence and independence	-
3	Predict population growth	Identify and investigate factors that influence population growth	Predict the effect of factors on population growth	-
4	Investigate population growth trends	Identify and investigate factors that influence population growth	Distinguish between density dependence and independence	-
5	Identify the change in rates of population growth and decline of a population	Distinguish between density dependence and independence	Develop hypotheses and experimental designs	-
6	Interpret graphs to predict how population size varies over time	Identify how the rates of population growth and decline change over time in a population.	Develop hypotheses and experimental designs	Evaluate how mechanisms influence changes in population size and carrying capacity.
7	Interpret graphs to describe population growth	Identify how the rates of population growth and decline change over time in a population using a mathematical equation	Identify and investigate factors that influence population growth	Develop hypotheses and experimental designs
8	Identify and investigate the measures of population growth using population growth curves and/or equations	Identify how the rates of population growth and decline change over time in a population using a mathematical equation	-	-
9	Compare the density versus abundance of two different populations.	Calculate and graph the density and abundance of a population.	Identify whether a growth curve describes exponential, linear, and or/logistic growth.	Calculate how the growth rate of a population changes over time.

Table 2.4: Summary of learning objectives used in the lesson. Summary of the learning objectives of the lesson over the course of the iterative design process.

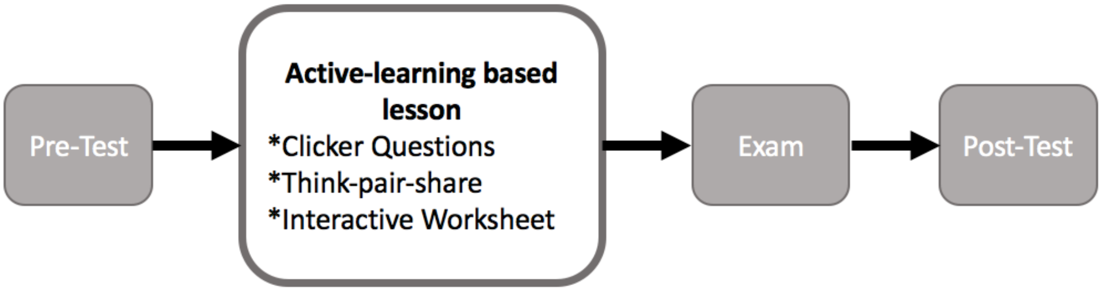


Figure 2.1: Structure of the active-learning based lesson. Structure of the active-learning based lesson developed to target student understanding in population ecology.

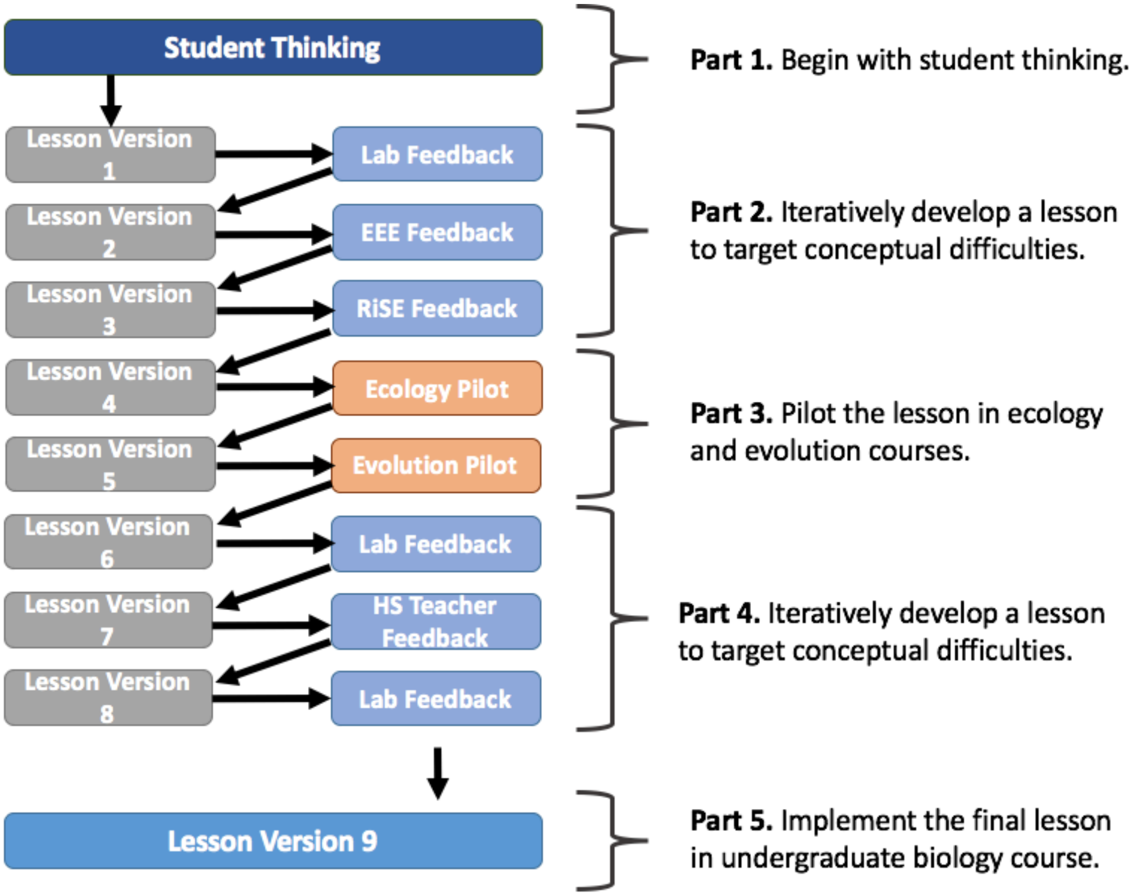


Figure 2.2. Iterative design process of the lesson development. The iterative process of developing the active learning based population ecology lesson with multiple rounds of feedback. EEE= Ecology and Evolution of Everything seminar; RiSE= Maine Center for Research in STEM Education; HS= High School.

2.3.1.1 Lesson version 1: Intraspecific competition

The first version of the lesson used a handout and focused on introducing intraspecific competition through two separate case studies. Case Study 1 focused on the effect of different densities on the growth and survivability of the plants while Case Study 2 focused on the effects of different nutrient concentrations on plant growth and amount of competition.

Case Study 1:

To begin the lesson, students were presented with background information on an experiment about the effect of growing plants in different densities (Lentz, 1998). In this experiment, Northeastern Bulrush, *Scirpus ancistrochaetus* Schuyler *(*Cyperaceae*)* seedlings were placed in four different pots with the following densities: 1 seedling per pot, 10 seedlings per pot, 25 seedlings per pot, and 50 seedlings per pot, and plant growth was measured over time. Following this introduction, students were asked to make predictions of the growth and survivability of the plants in each density. Next, students were given the data from the experiment and asked to construct graphs showing the following for each plant density: 1) final average plant height, 2) average final plant mass, and 3) final root to shoot ratio. Students then used the generated graphs to answer questions about the conclusions that can be drawn from the experiment and compare the results with their initial predictions.

Case Study 2:

Similarly to Case Study 1, students were given the experimental design used to investigate the effect of varying nutrient concentrations on the growth of plants (Lentz, 1998). In this experiment, plants were fertilized with a nutrient solution of 3%, 25%, or 50% of full strength Peter’s 20-20-20 N-P-K soluble fertilizer and one of the four densities described in Case Study 1. Students were asked to make predictions about plant growth and the level of competition present in each pot as a result of the different nutrient concentrations. Next students generated graphs of the each of the following using provided data from the actual study: 1) final average plant height, 2) final average plant mass, and 3) final root to shoot ratio. Following the generation of the graphs students answered questions about the conclusions that can be drawn from the experiment and compared the results of the study to their initial predictions.

To conclude the activity, students were asked to design an experiment to test the effects of intraspecific competition in a different ecological setting than the terrestrial plant setting covered in class. Students were presented with three scenarios (including barnacles in the intertidal zone, paramecium, and stickleback fishes) to choose from. After selecting their ecological scenario, students were given guiding questions to answer through the development of an experimental study. For example, if a student chose to develop a study to investigate barnacles in the intertidal zone, they were provided with the following guiding prompts: 1) How can you and your group determine if decreased survival in adult barnacles is a result of increased density? 2) Make a hypothesis about what you think will influence the growth and survivorship of the barnacles. 3) Describe how you would set this experiment up and what you will be testing-discuss the measurements that will be taken, the controls and treatments, and what graph you will include to show your results.

Version 1 of the lesson was presented to Smith laboratory for feedback. Feedback from this meeting suggested that the graphing portion of the lesson was tedious and time consuming, and the focus on intraspecific competition was too narrow for a full lesson. Furthermore, the use of a paper-based handout was impractical for use in large-enrollment undergraduate classrooms. Suggestions from this meeting included broadening the topic, creating a PowerPoint based lesson, and introducing clicker questions as a mode of assessing student learning throughout the lesson.

2.3.1.2 Lesson version 2: Modeling and exploring population size over time

The second version of the lesson integrated the feedback from the Smith laboratory and was changed to a PowerPoint based lesson with three clicker questions to assess student understanding. This version focused on exploring how populations change over time and integrating multiple concepts. Additionally, the focus of the lesson shifted from graph creation to graph interpretation and making predictions.

In this version, students were provided background information on barnacles and presented with the experimental design used in a seminal study to observe barnacle population growth in the intertidal zone (Connell, 1961). In this study, empty rocks were placed in the intertidal zone and the settlement and growth of barnacles were measured for a month. Cages were placed around the rocks to prevent predators and other organisms from settling on the rock. After hearing this introduction, students were asked to predict the population growth of the barnacles over time on a blank graph with pre-made x-and y- axes. Following this prediction, the students were asked to select the graph, from four growth curves (linear, exponential, logistic, and a stair-step curve) that most resembled their prediction. Next, students were presented with the graph generated from the actual data (forming a logistic growth curve) and asked to select the most likely explanation for the observed change in growth rate between the first portion of the graph (exhibiting exponential-like growth) and the second portion of the graph (where the population size stabilizes). After concluding that the growth rate has slowed as the population stabilizes, the students were presented with different factors (limited space, predation, desiccation, and increased wave exposure) that can influence the barnacle population's growth rate over time, resulting in the decrease in growth rate over time. In groups, students separated these factors into two categories: whether they influenced the population based on size (density-dependent) or whether they influenced the population regardless of population size (density-independent). Lastly, students were asked to outline an experimental design that could be used to isolate and study the effects one of the discussed factors.

Version 2 of the lesson was presented to the Ecology and Evolution of Everything (EEE) Seminar, a group comprised of faculty and graduate students from the Biology & Ecology, Economics, and Wildlife Ecology programs at the University of Maine. This diverse group of ecology experts provided feedback on the ecology content and level of difficulty of the lesson. Feedback from EEE was promising, the faculty supported the use of this type of lesson in the classroom and confirmed that their students succeed when interacting with material in this fashion. Suggestions from this group included simplifying the graphs used throughout the lesson, integrating more background information on the intertidal zone, and simplifying the density-dependent and density-independent section of the lesson.

2.3.1.3 Lesson version 3: Modeling and exploring population size over time

The third version of the lesson was similar to Version 2 and contained five clicker questions. Students were presented with background information about barnacles, along with a more in-depth introduction to the intertidal zone. Students were given the same the background information on the experimental design used to study barnacles in the intertidal zone (Connell, 1961) and asked to make a prediction of the barnacle growth over time and select the graph that most resembled their prediction from four growth curves (linear, exponential, logistic, and a stair-step curve). Students were then asked to select the point on a logistic growth curve where the population was growing the fastest, followed by the clicker question from Version 2 of the lesson asking students to select the most likely explanation for the change in growth rate between the two different portions of the population growth curve.

Next students were asked a clicker question that asked them to identify the graph that would likely show the results of ecologists plotting the number of individuals on three different sized rocks (to show that increased space availability allows for more individuals to settle). The second portion of Version 3 of the lesson was identical to Version 2, where students separated the different factors that can affect a barnacle population into two categories based on whether they are density-dependent or density-independent. To end the lesson students were asked to outline an experimental design that could be used to isolate and study the effects one of the discussed factors, similarly to before.

This version of the lesson was presented to the RiSE Center research group that includes education faculty, discipline-based education faculty, and graduate students with diverse specialties (including physical science and life science education backgrounds). Suggestions from this group included incorporating a focus of carrying capacity and regulating mechanisms into the lesson.

2.3.1.4 Lesson version 4: Modeling and exploring how populations change over time

Version 4 included an introduction to the different ways populations lose or gain new individuals (through birth, death, immigration, and emigration). Following this introduction, the flow of the lesson was similar to Versions 2 and 3, where students predicted the barnacle population growth after hearing the experimental design used in the actual study (Connell, 1961), selected the graph that resembled their prediction from four growth curves (linear, exponential, logistic, and a stair-step curve), answered clicker questions addressing the change in growth rate observed in the barnacle population over time, and separated the factors affecting barnacle populations into two categories based on whether they were density-dependent and/or density independent. The last section of the lesson where students were asked develop an outline of an experiment to test the effects of one of the discussed factors on barnacle population size was simplified. Specifically, students were presented with three experimental questions and asked what they would change in the experimental design used to observe the effects of space limitation (as worked through in class) to observe the effects of predation, competition, and temperature on the barnacle population.

Version 4 was piloted in a General Ecology course at the University of Maine, Orono. This course examines a broad range of ecological processes, principles, and examples in ecology. Learning outcomes include: 1) describing abiotic and biotic factors that influence populations, 2) applying ecological perspectives to problem-solving and decisions, and 3) analyzing ecological and environmental problems to understand the roles of environmental drivers, biotic interactions, and human actions on current and further ecological conditions. The lesson was implemented mid-semester following discussion of population growth (carrying capacity and logistic growth were introduced) but prior to discussion of the specific interactions within populations responsible for such patterns in nature (i.e., intraspecific and interspecific competition). The class was a 50-minute-long class with 41 students present.

Implementing the lesson in a classroom provided information about how students interpreted the lesson and assessment questions. After the first round of piloting, it was apparent that certain areas of the lesson needed to be reworked or removed. For example, the portion of the lesson focusing on density-dependence and independence caused confusion among students. Additionally, there was a clear disconnect in the importance of ecologists conducting such experiments to determine how population growth is influenced in nature.

2.3.1.5 Lesson version 5: Modeling and exploring how populations change over time

Version 5 of this activity focused on growth curves, carrying capacity, regulating mechanisms, and the four mechanisms that cause population sizes to change (birth, death, immigration, and emigration), however the second half of the lesson was reworked to no longer include the separation of factors into two categories based on density-dependence and independence. Furthermore, a discussion of the importance of modeling and understanding population growth for ecologists was added.

In this version of the lesson, students predicted the barnacle population growth over time given the experimental design (Connell, 1961) and selected the graph that best depicted their prediction from four growth curves (linear, exponential, logistic, and a stair-step curve). The four potential graph choices were then individually discussed to highlight when populations in nature might exhibit that type of growth. Next, students were presented with the actual growth curve generated from the experimental data and asked to select the answer that best described what was happening to the rate of settlement between two points on a logistic growth curve. Following this, carrying capacity and the four mechanisms that cause population sizes to change (birth, death, immigration, and emigration) were introduced. Next, students were asked to list different abiotic and biotic factors that can influence those four mechanisms, such as competition, predation, disease, reproductive ability, space availability, etc. The instructor discussed each of the listed abiotic and biotic factors while keeping the experimental design in mind, to determine which factor most likely caused the growth observed in the barnacle population in the month-long study. For example, predation is a biotic factor that can influence the barnacle population, however because of the cages placed on the rocks to prevent predators in the experimental design, is not likely the cause of the observed barnacle population growth. Students were presented with the conclusion of the study, that space availability was likely the factor responsible for the barnacle populations exhibited growth. This version of the lesson ended with students outlining an experiment to determine how predation might influence the barnacle population.

Version 5 of the lesson was piloted in BIO 465, Evolution, at the University of Maine, Orono. This course investigated the origin and development of evolutionary theory and the mechanisms that bring about the genetic differentiation of groups of organisms. The lesson was implemented near the end of the semester and was presented to 71 students. This round of piloting revealed that the second half of the lesson was still weak. The discussion of the factors influencing barnacle population growth (birth, death, immigration, and emigration) was incomplete and the portion of the lesson asking students to design an experiment to test the effect of predation on the barnacle population was not well received in the classroom as a result of the lack of structure. For example, students were unsure of what information they were expected to include.

2.3.1.6 Lesson version 6: Modeling and exploring how populations grow over time

Version 6 of the lesson integrated feedback from the second pilot to continue to strengthen the content and flow of the lesson. In this version, background information on barnacles and the intertidal zone was covered, followed by the introduction of abundance and density (two measures used by ecologists to measure population size). Next students predicted the barnacle population growth over time given the experimental design (Connell, 1961) and selected the graph that best depicted their prediction from four growth curves (linear, exponential, logistic, and a stair-step curve). The four growth curves were discussed individually and students answered the same clicker question, selecting the answer that best described what was happening to the rate of settlement between two points on a logistic growth curve.

In this version of the lesson students were still presented with the four common influences on population growth (birth, death, immigration, and emigration), however after being introduced with the terms, the students were asked to generate an equation to calculate population size using the four influences. Following the development of the equation, students were asked to list different abiotic and biotic factors that affect each of the four influences. Similarly to the previous lesson, the instructor walked through the experimental design to discuss if each of the abiotic factors were likely responsible for the growth exhibited by the barnacles. Through this exploration of biotic and abiotic factors, the instructor guided students to the conclusion that space is likely responsible for the decrease in growth overtime for the barnacle population. The experimental design portion of the lesson was simplified, providing students with a breakdown of the experimental design used in the seminal barnacle population growth study to mirror, asking students to outline an experiment to investigate the effects of predation on barnacle population growth. To conclude, four growth curves (linear, exponential, logistic, and a stair-step curve) of organisms found in nature were presented to the students to highlight the importance of these growth curves.

This version of the lesson was presented to the Smith laboratory for feedback. Suggestions from this group included shortening the length of the lesson; adding additional clicker questions, particularly to assess student understanding of density and abundance; simplifying the generation of the equation to relate birth, death, immigration, and emigration; and lastly to strengthen the section on the importance for ecologists to study population dynamics.

2.3.1.7 Lesson version 7: Modeling and exploring how populations grow over time

Version 7 of the lesson focused on three main parts: 1) What affects the size of barnacle populations and how the grow over time? 2) Why is it important for ecologists to study population dynamics? and 3) What is the practical importance of population dynamics? Overall, the first portion of the lesson (what affects the size of barnacle populations and how they grow over time) remained the same as previous versions, however the introduction to barnacles and the intertidal zone was shortened and a clicker question was developed to assess student understanding of the measures of population size (density and abundance). Additionally, in this version of the lesson, the breakdown of each of the four growth curves (linear, exponential, logistic, and a stair-step curve) was removed. After introducing the four main influences on population size (birth, death, immigration, and emigration), students were asked to select from equations that best modeled changes in population size using those terms. This version of the lesson walked students through each of the potential factors that might influence birth, death, immigration, and emigration to determine why the barnacle population growth resulted in a logistic growth curve, similarly to previous lessons.

After determining the most likely cause of population stabilization over time, the focus of the lesson shifted to the importance of studying population dynamics. This portion of the lesson introduced endangered species and the importance of modeling those populations. By discussing three different success stories of endangered species, the instructor demonstrated the importance of understanding population dynamics for aiding in the rebound of those populations.

This version of the lesson was presented at the RiSE Center conference where over 50 high school teachers provided feedback. Feedback from this group was positive, most teachers stated that it was a lesson they would want to use in their classroom to teach their students about population growth. After receiving the feedback, it was decided the lesson was well suited for a high school classroom, however the content needed to be modified to increase difficulty before being implemented in an undergraduate classroom.

2.3.1.8 Lesson version 8: Describing and modeling populations over time

Version 8 of the lesson was modified to make the lesson better suited for an undergraduate classroom. The first part of the lesson remained the same- students were presented with the background information on seminal study used to measure barnacle population size (Connell, 1961) and were asked to make a prediction of barnacle population growth over time, however in this version of the lesson students were only given three graphs to choose from (linear, exponential, and logistic). Additionally, rather than giving the students the results from the experiment, students were given the data and asked to generate a graph to determine how the barnacle population changed over time.

Following the graphing exercise, students were presented with the equations used to calculate growth rate for each of the three main growth curves. Students then answered a clicker question targeting understanding of how the rate of growth changes over time in all three growth curves (linear, exponential, and logistic). Next, each growth curve and equation was broken down to discuss the similarities and differences between the three. In order to assess students' abilities to use the logistic growth curve to determine what happens to the growth rate as the population size approaches carrying capacity, students were presented with a clicker question. This version of the lesson focused on the importance of collecting and analyzing descriptive data, using mathematical models to simplify the complexity of ecology, and the implications of carrying capacity on population growth.

Version 8 of the lesson was presented to the Smith laboratory for one additional round of feedback before implementing it in the BIO 100 introductory biology course at the University of Maine. At this meeting the feedback was minor and focused mainly on small visual changes to slides.

2.3.1.9 Lesson version 9: Describing and modeling populations over time

The final lesson was implemented in an introductory biology course at the University of Maine, Orono where a total of 433 students participated in the pre-test, lesson implementation which includes several formative assessment clicker questions, exam equations, and a post-test. The format of the final lesson and results from this implementation are discussed in depth in Chapter 3.

2.4 Recommendations for developing lessons

The iterative process of developing this lesson provided me with knowledge and confidence in developing similar lessons in the future. This section highlights the important steps to follow to generate a lesson that targets student understanding in the classroom based on what I have learned through this process (Table 2.5).

Step	Description	Timeline
I. Identify an area where students struggle or where instructional material is needed.	This can be done through previous research, personal experience, review of the available educational literature, or a combination of the three.	4-7 days
II. Research student understanding of the topic and relevant skills.	Research educational literature on student thinking and conceptual difficulties when learning about the chosen topic.	4-6 days
III. Research the current materials available to teach the chosen topic.	Review the available textbooks, online lectures, and online lessons to determine how others approach teaching the topic.	4-7 days
IV. Develop learning outcomes for the lesson.	Think about what you want students to be able to do upon completion of the lesson.	2-5 days
V. Develop an assessment tool to assess student understanding of the learning outcomes.	Develop an assessment tool to successfully assess all learning outcomes.	2+ months
VI. Develop the lesson to target student understanding of the developed learning outcomes based on current knowledge of student thinking.	Using the information gained through the literature, textbook, online lesson, and online lecture review create a lesson to target the developed learning outcomes.	3+ months

Table 2.5: Timeline for the development of a lesson. Outline of the necessary steps to develop a lesson to address students' conceptual difficulties for a specific topic.

2.4.1 Important steps and timeline for development

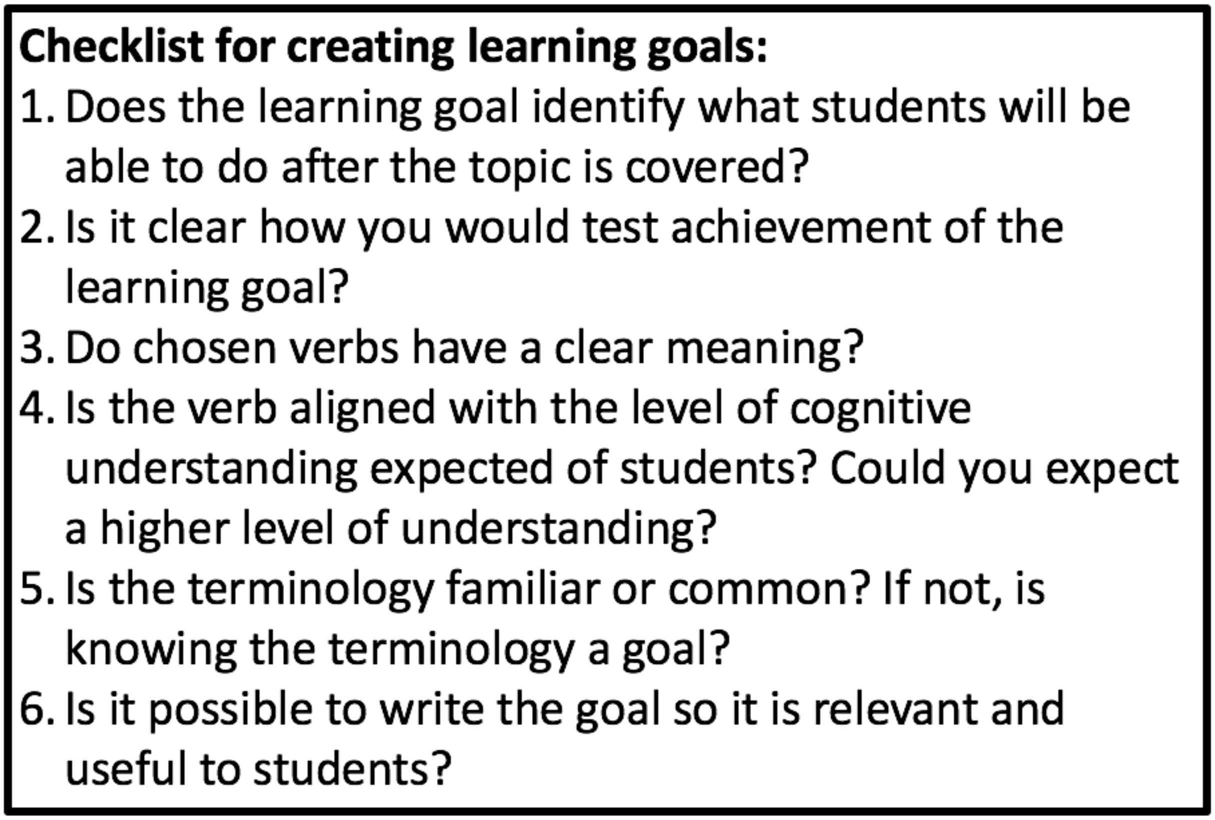
When developing a lesson to promote significant learning experiences for students, I recommend employing the "backwards design" process, which begins with a vision of the desired results in mind (Wiggins and McTighe, 1998). This process divides instructional planning into three stages: 1) identifying desired results, 2) determining what constitutes acceptable evidence of learning, and 3) planning the learning experiences and instruction (Wiggins and McTighe, 1998).

Identifying areas of persistent struggle for students and incorrect thinking students possess when learning helps to determine what is worthy of requiring student understanding (Stage 1; Wiggins and McTighe, 1998). There are several ways to identify where students persistently struggle. One is based on classroom experience and interactions with students.

Another is using the published literature, such as the information of particular areas where students struggle in population ecology (see Chapter 1).

Once the topic of the lesson has been determined, it is important to examine multiple textbooks to understand how others present the material, allowing you to gain a sense of the flow of the lesson as well as what terms and concepts should be stressed (Table 2.1). Furthermore, it is recommended to review available online lectures (Table 2.2.) and lessons (Table 2.3) covering the topic to observe how others are presenting this topic to their students. This step is crucial, as it allows you to see how others are taking the content in the textbook to teach the material.

Following the literature, textbook, and online lesson review, I recommend developing the learning outcomes: what do you want students to be able to do at the completion of the lesson? (Stage 2; Wiggins and McTighe, 1998). Learning goals are used to communicate the key ideas of a course/lecture/lesson and the level at which students should understand those ideas in operational terms (Smith and Perkins, 2010). Typically, learning goals take the form of "at the end of the course/lecture/lesson, students will be able to…" followed by a specific verb and task (Smith and Perkins, 2010). For example, a topic-level learning goal from an introductory genetics course at the University of Colorado (CU) was "At the end of this lesson, students will be able to distinguish between different modes of inheritance (Smith and Perkins, 2010). Based on experiences working in groups of faculty to formulate learning goals, Smith and Perkins (2010) suggest six steps for creating useful learning goals that are outlined in in Figure 2.3.



Checklist for creating learning goals:

1. Does the learning goal identify what students will be able to do after the topic is covered?
2. Is it clear how you would test achievement of the learning goal?
3. Do chosen verbs have a clear meaning?
4. Is the verb aligned with the level of cognitive understanding expected of students? Could you expect a higher level of understanding?
5. Is the terminology familiar or common? If not, is knowing the terminology a goal?
6. Is it possible to write the goal so it is relevant and useful to students?

Figure 2.3: Suggested checklist for developing useful learning goals (Smith and Perkins, 2010).

Research has revealed that learning goals are beneficial for students, instructors, and alignment of courses (Simon and Taylor, 2009; Smith and Perkins, 2010). For example, to explore the impact of learning goals on students and instructors in the classroom, instructors from three courses at the University of British Columbia wrote individual learning goals in the form of, “At the end of this lecture/ topic I will be able to…” and presented the learning goals to students as part of their lectures (Simon and Taylor, 2009). Following the lessons, students were asked to complete up to five copies of the sentence, “For me, the use of learning goals in this course is…” and student responses were analyzed and separated into categories such as Study, Exams, Lecture, General Positive, and Negative. Additionally, the instructors involved in the study were interviewed to examine their views of learning goals. Overall, results from the study suggest that there are benefits for writing and sharing learning goals. Responses from students showed that nearly all students involved in the study found learning goals to be valuable, with most mentioning the largest value being that they helped students "know what I need to know for a course." Similarly, results from instructor interviews suggest that learning goals enhanced communication, as instructors stated the learning goals provided a method to clearly outline the importance concepts and materials in the class for students.

After developing learning goals, instructors should determine how achievement of the learning goal will be assessed (Figure 2.3, step 2; Wigging and McTighe, 1998). It is important that the learning goals and assessments are aligned at a similar level of cognitive understanding expected of students (Smith and Perkins, 2010; Bloom and Krathwohl, 1956). For example, if the learning goal asks students to apply knowledge to unfamiliar situations, the assessment questions should assess students' ability to do just that. Instructors can use formative and summative assessments to monitor student success in the classroom. Formative assessment monitors student learning to provide feedback that can be used to improve instructors teaching methods and student learning (Yorke, 2008), while summative assessment evaluates student learning at the end of an instructional unit or course (Teaching excellence and education innovation, 2008). Formative assessments are typically low stakes and include but are not limited to using clicker questions, concept maps, and research proposals, while summative assessments are high stakes and can include midterm exams, final projects, and papers (Teaching excellence and education innovation, 2008).

Once useful learning goals and assessment tools have been created, the next step is to develop at lesson to promote understanding, interest, and competency in the subject matter is next (Stage 3; Wiggins and McTighe, 1998). The development of the lesson will be most successful if it goes through multiple rounds of edits. I recommend giving the lesson to colleagues and students, allowing for feedback on the content, level of difficulty, and effectiveness of the lesson. During this process, it is important to engage with content experts who provide feedback on the content covered and educational specialist who can give feedback on the success of the teaching methods used. During this process, I recommend presenting the lesson as if you were giving it to students in the classroom, allowing you as the developer to observe how the lesson is received, and allowing the participants to gain a greater understanding of student interaction with the material.

Prior to presenting the lesson for feedback it is important to have specific areas where you wish to receive feedback. Written and oral feedback are both beneficial, therefore I suggest using audio and/or video recordings and requesting written feedback from participants. To meet with a diverse set of faculty with busy schedules, I recommend requesting feedback during already established journal club/ seminar times or using an online poll system to determine the most convenient meeting time. After receiving such feedback, but prior to finalizing the lesson, piloting the lesson to students can allow for a deeper understanding of student interpretation and interaction with the material. After piloting the lesson, I suggest going through a final round of edits and feedback.

CHAPTER 3

AN ACTIVE-LEARNING LESSON THAT TARGETS STUDENT UNDERSTANDING OF POPULATION GROWTH IN ECOLOGY

3.1 Overview

As a part of this thesis project, the active-learning population ecology lesson has been submitted for publication in *CourseSource*, an open-access journal of peer-reviewed teaching resources for undergraduate biological sciences. This journal publishes articles that are organized around courses in biological disciplines and aligned with learning goals established by professional societies. The third chapter of this thesis is the manuscript submitted to *CourseSource*.

3.2 *CourseSource* abstract

Effective teaching and learning of population ecology requires integration of quantitative literacy skills. To facilitate student learning in population ecology and provide students with the opportunity to develop and apply quantitative skills, we designed a clicker-based lesson where students investigate how ecologists measure and model population size. This lesson asks students to "engage like scientists" as they make predictions, plot data, perform calculations, and evaluate evidence. The lesson was taught in three sections of a large enrollment undergraduate class and assessed using a pre/post-test, in-class clicker-based questions, and multiple-choice exam questions. Student performance increased following peer discussion of clicker questions and on post-test questions. Students also performed well on the end-of-unit exam questions.

3.3 Scientific teaching context

3.3.1 Learning goals

How do populations change over time? (from the CourseSource Ecology Learning Framework, http://www.coursesource.org/courses/ecology)

Students will know that many different growth curves and patterns exist for organisms in nature. They will understand that modeling helps to describe and predict population growth over time.

3.3.2 Learning objectives

Students will be able to:

- Calculate, graph, and compare the population density and abundance.
- Identify whether a growth curve describes exponential, linear, and/or logistic growth.
- Describe and calculate a population's growth rate using linear, exponential, and logistic models.
- Explain the influence of carrying capacity and population density on growth rate.

3.4 Introduction

Quantitative reasoning and literacy skills are essential for many careers, particularly those in biology where individuals encounter a diversity of challenges that require an application and integration of approaches NRC, 2003; AAAS, 2009). To prepare students to address these challenges, which span a variety of sectors including health, education, the environment, and complex social issues; biology education researchers have advocated integrating quantitative skills with biology content (Speth et al., 2010; Hester et al., 2014; Bravo et al., 2016). This integration gives students the opportunity to practice posing questions, analyzing and interpreting evidence, developing models, and generating testable predictions (NRC, 2002; NRC 2009). Previous studies have revealed that undergraduate biology students struggle with higher-order quantitative thinking (e.g., analyzing, evaluating, and drawing conclusions), particularly with generating graphs from raw data (Speth et al., 2010; Picone et al., 2007); interpreting bar graphs and scatterplots (Speth et al., 2010); understanding independent and dependent variables (Picone et al., 2007); summarizing trends from data with variation (Picone et al., 2007; Kitchen et al., 2003); and articulating data driven arguments (Speth et al., 2010). Introductory biology students also have difficulty performing simple calculations (such as calculating a mean) and representing calculations graphically (Speth et al., 2010).

Population ecology is a topic well-suited for the development of quantitative reasoning and literacy skills. At both the introductory and advanced levels, students are asked to model population growth using graphs, measure population size, and estimate carrying capacity (Urry et al., 2014; Cotgreave and Forseth, 2002). However, students often struggle with integrating quantitative skills with conceptual understanding and practical application (Urry et al., 2014; Cotgreave and Forseth, 2002). For example, undergraduate students have incorrectly predicted that a population would likely exceed carrying capacity if a non-limiting factor increased (Summers et al., *submitted*) and that all population sizes will level off regardless of the resources available (D'Avanzo, 2003). They have also explained that competition only occurs between organisms of the same species (Summers and Smith et al., *submitted*; Munson, 1994). Although instructional tools currently available target some of these persistent conceptual difficulties (Hale and McCarthy, 2016; Jeanne, 2003; Beckstead et al, 2011; Aronhime et al., 2013; Glase and Zimmerman, 1991; Langin et al., 2009), there is a need for materials explicitly designed to investigate student thinking and learning progressions. In additional, available instructional materials on this topic are also largely computer models and lab-based activities, leaving a need for tools that integrate quantitative skills in a large-enrollment format.

Here we describe an interactive in-class lesson that targets conceptual difficulties in population ecology and seeks to develop students' quantitative reasoning. This 50-minute clicker-based lesson focuses on exploring population growth in a barnacle population using authentic data from a seminal study in ecology (Connell, 1961). Throughout the lesson, students predict, plot, calculate, and interpret data to learn the methods used by ecologists to measure, describe, and model population growth.

3.5 Lesson background information

3.5.1 Intended audience

This lesson is intended for undergraduate introductory biology courses. It was given to students in a large enrollment Introductory Biology course at the University of Maine (n=766; students divided into three class sections). In this class, the mean SAT Math score was 525 (range from 320-770; 87% of students took the SAT) and mean ACT Math score was 23 (range 14-33; 18% of students took the ACT).

3.5.2 Required learning time

This lesson was designed for a 50-minute class period.

3.5.3 Pre-requisite student knowledge

Before participating in the lesson, students participated in one class where the following topics were discussed: abiotic and biotic factors responsible for determining population size, the definitions of carrying capacity and regulation, and different examples of populations that exhibit logistic and exponential growth. They were also asked to complete an assigned textbook reading (Urry et al., 2014) that introduced population ecology and an overview of biotic and abiotic factors, density, exponential population growth, logistic and exponential growth curves and equations, carrying capacity, and density-dependent regulation.

3.5.4 Pre-requisite teacher knowledge

We recommend that instructors are familiar with how ecologists study population growth and the main concepts covered in the lesson (measurements of population size; the equations that describe linear, exponential, and logistic growth; the role of carrying capacity; and examples of different growth models and their applications). Instructors will also benefit from basic knowledge about barnacles and the intertidal zone. Information about each concept, barnacles, and the intertidal zone are included in the lesson slides (Appendix A). Recommended population ecology resources are also provided in Appendix B.

We also suggest that instructors familiarize themselves with common and persistent conceptual difficulties related to population growth. We used the Ecology and Evolution Measuring Achievement and Progress in Science or EcoEvo-MAPs assessment tool (Summer et al., *submitted*) at the beginning of this course to identify some of the ecology and evolution concepts that cause our students to struggle.

3.6 Scientific teaching themes used in the lesson

3.6.1 Active learning

Students are actively engaged in their learning throughout the lesson. Students make predictions, answer clicker questions, engage in peer discussion, participate in group problem-solving, answer questions in their own words on a worksheet, and respond to instructor questions. The instructor who taught this lesson was observed using the Classroom Observation Protocol for Undergraduate STEM (COPUS) (Smith et al., 2013). This observation protocol uses a series of codes to characterize instructor and student behavior in the classroom and documents those behaviors in two-minute intervals throughout the duration of the lesson (Smith et al., 2013; Smith et al., 2014). The summary of COPUS results (Figure 3.1) highlights the diversity of student-centered instructional practices and student participation in this lesson. For example, throughout the lesson more than 25% of the codes were "students talking to the class" (asking and answering questions) and more than 25% of the codes were "students working" (working individually, answering clicker questions, and working in groups). Similarly for the instructor, nearly 75% of the codes were "guiding" (posing questions to students, asking clicker questions, following up with students, and moving and guiding).

3.6.2 Assessment

Students were assessed using formative and summative questions aligned with the learning outcomes: quantifying population size, plotting and predicting population growth, calculating growth rate, and incorporating carrying capacity in logistic growth curves. We used clicker-based questions for formative real-time assessment of student understanding during the lesson. Student responses are included in the lesson plan and in Appendix C. Summative assessment of student understanding included a pre/post-test and exam questions. The pre- and post-test consisted of ten multiple-choice questions and were administered online. Students had one day to complete the pre-test immediately preceding the lesson. Students were given five days to complete the post-test, starting five days after the lesson. Pre/post-test questions are included in Appendix D. Students also answered three multiple-choice exam questions three days after the lesson. Multiple-choice exam questions are provided in Appendix E.

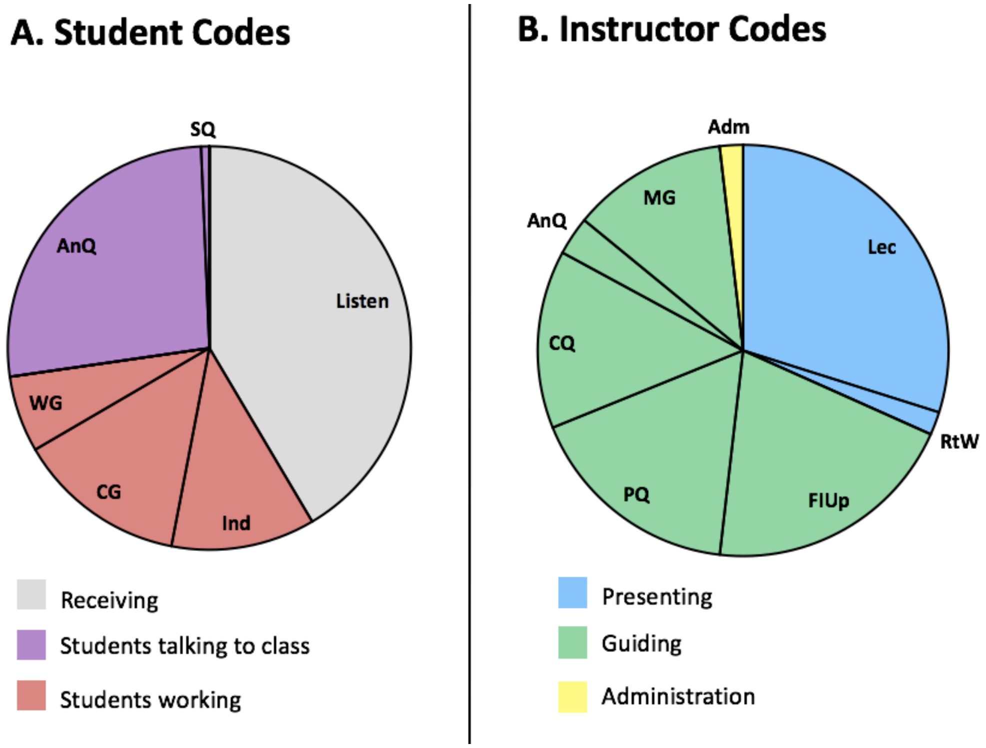


Figure 3.1: COPUS results from the lesson implementation. Average collapsed Classroom Observation Protocol for Undergraduate STEM (COPUS) (Smith et al., 2013; Smith et al., 2014) codes from three sections of a University of Maine introductory biology course in which this lesson was used. Collapsed student codes: Receiving (Listen- Listening), Students Working (Ind-Individual Work, CQ- Clicker Question Discussion, WG- Worksheet Group Work), Students Talking to Class (AnQ- Answering Question, SQ- Student Question). Collapsed instructor codes: Presenting (Lec- Lecturing, RtW- Real Time Writing), Guiding (FlUp-Follow-up, PQ- Posing Questions, CQ-Clicker Question, AQ-Answer Question, MG-Moving and Guiding), Administration (Adm- Administration).

3.6.3 Inclusive teaching

This lesson seeks to create a learning environment where students’ academic, social, and cultural backgrounds can be an asset to their learning. This inclusive teaching environment was fostered through incorporating a variety of different teaching methods to meet the needs of students with diverse learning styles, abilities, and backgrounds (Armstrong, 2011; Inclusive teaching strategies, 2016). For example, the concepts were presented and available to students on projected slides, the student worksheet, and through instructor and peer-led discussion. When questions were presented, students were given the opportunity to first think and write on their own, then discuss in small groups, and finally report out to the entire class. In addition, we used an anonymous response system (clickers) with peer discussion to reduce student discomfort (Martyn, 2007) and promote a collaborative learning environment (Crouch and Mazur, 2001; Smith et al., 2009; Smith et al., 2011).

3.7 Lesson plan

This lesson is designed for a 50-minute lecture and is intended to introduce students to quantitative skills used in population ecology, and can follow an introduction to population ecology (in a previous class or as a pre-class assignment). The progression of the clicker-based lesson with estimated timing is provided in Table 3.1.

Activity	Description	Estimated time
Preparation for Class		
Introduction to population ecology concepts and terminology	Prepare students to define and recall the following terms: a. Density a. Abundance b. Carrying Capacity c. Density dependence d. Linear, exponential, and logistic growth Prior to this lesson, students should be exposed to the concepts listed above either through reading or information presented in a previous class.	
Pre-test	Provide students with the pre-test to complete before the start of class.	~ 20 min
Class Session- Progressing through the Activity		
1. Introduction and assessing prior knowledge *Slides 1-5*	1. Provide background information on the intertidal zone and barnacles. 2. ***TPSQ1:*** Students brainstorm in small groups followed by a facilitated classroom discussion of abiotic and biotic influences on barnacle population size.	~10 min
2. Quantifying population size *Slides 6-10*	1. Introduce density and abundance as two ways that ecologists can measure population size. 2. ***CQ1:*** Students answer and discuss a clicker question that reinforces the difference between measuring density and abundance. Following facilitated group discussion, provide an explanation of how to calculate density and abundance.	~5 min
3. Predicting and plotting population growth *Slides 11-16*	1. Introduce the relevant methodology used in Connell, 1961 to study barnacle population size (Connell, 1961). 2. ***TSPQ2:*** Students graph their prediction of barnacle population growth over the 30-day experiment. 3. ***CQ2:*** Students answer and discuss a clicker question selecting the growth curve that most resembles their prediction of barnacle population growth. 4. ***TPSQ3:*** Students use data from the scientific study to plot barnacle population growth. 5. ***CQ3:*** Students answer a clicker question selecting the growth curve that most resembles the plot generated from the data.	~10 min

Table 3.1: Progression through the clicker based lesson. Progression through the clicker-based lesson with approximate time stamps. Each classroom-discussion open-response TPS question opportunity is identified by "TPSQ" and each Clicker Question TPS opportunity is abbreviated "CQ" for Clicker Question. Pre-test, lecture slides, and post-test are available in the Appendices A and D.

Activity	Description	Estimated time
4. Identifying and discussing growth rate *Slides 17-22*	1. Introduce growth rate and how it differs between linear, exponential, and logistic growth curves. 2. ***CQ4:*** Students answer and discuss a clicker question investigating how the growth rate is changing over time in all three growth curves. Expand on the discussion by showing the different equations used to describe the growth rate and emphasize how growth rate differs between each (constant over time in linear, increasing over time in exponential, and increasing initially, then decreasing in logistic). 3. Demonstrate how to calculate the growth rate at different time-points or population sizes for a linear and exponential growth curve. Explain the variables used in linear and exponential growth models: population size (N) and time (t), and the intrinsic rate of increase (r). Introduce the technique of changing the values of the variables to examine how the growth rate changes. Emphasize how the exponential equation results in an increasing growth rate over time.	~8 min
5. Incorporating carrying capacity *Slides 23-29*	1. Identify predicted carrying capacity on the Connell, 1961 data plot. Define regulating mechanisms and ask students to volunteer likely regulating mechanisms for the barnacle population. 2. Explain the variables used in the logistic growth model: intrinsic rate of increase (r), population size (N), and carrying capacity (K). Emphasize how K influences the growth rate in this model. 3. ***CQ5:*** Students answer and discuss a clicker question about calculating the growth rate of the barnacle population over time using given values for r, K, and N. Provide an example of how to calculate the growth rate for one population size in a logistic growth curve. Emphasize how the equation models what happens to the growth rate as the population approaches carrying capacity (the growth rate increases initially, is the fastest at half the carrying capacity, and decreases as the population approaches carrying capacity). 4. Show students the growth rates for the plot of the Connell, 1961 data. Focus on how the growth rate resembles the trend of logistic growth - increasing then decreasing as the population approaches carrying capacity.	~10 min

Table 3.1: Continued.

Activity	Description	Estimated time
6. Synthesis *Slides 30-34*	1. Summarize the three mathematical models discussed in the activity and how the change in growth rate differs for each. 2. Explain the applications of growth models to economic, medical, and conservation predictions and decision-making. 3. ***TPSQ4:*** Students use data from four different types of organisms (bristlecone pine trees, grey wolves, bacteria, and red foxes) to describe and discuss each population's growth. Students identify if abundance or density is shown, what is happening to the population over time (increasing, decreasing, etc.), and if the growth curve most closely resembles linear, exponential, or logistic growth. Facilitate a whole-class discussion focused on problem-solving techniques. For example, using the y-axis to determine if abundance or density is measured; considering population size and rate of growth separately; and identifying the role of carrying capacity in producing logistic growth. 4. Review the learning outcomes and summary slide of the activity and answer any student questions.	~7 min
Follow-up		
Post-test	Provide students with the post-test following the activity.	~20 min

Table 3.1: Continued.

3.7.1 Pre-class preparation

We recommend that students are familiar with and able to recall the following terms before the lesson: density; abundance; carrying capacity; density dependence; and linear, exponential, and logistic growth (Appendix B). This preparation can be achieved through prior readings, homework assignments, or lectures.

Instructors will need to facilitate conversations among students during this lesson. Additional instructional resources on the content and quantitative skills covered are provided in Appendix B.

3.7.2 Think-Pair-Share and use of clickers

Think-Pair Share (TPS) is a classroom-based active learning strategy in which students think about a problem posed by an instructor individually, work in pairs to solve the problem, and finally share their ideas with the entire class (Kothiyal et al., 2013). This model allows students to individually think about the questions posed, reflect on their own thinking, and obtain immediate feedback from their peers and instructor (Lyman, 1987). During the in-class lesson, students answered several questions using the TPS model. Clickers were also used to facilitate TPS opportunities. Students first answered individually (“think”) followed by discussion with a neighbor and revote (“pair”). After the revote, the instructor asked for students to volunteer their thinking (“share”) and then discussed the correct answer and student thinking. This combination of peer and instructor-led discussion has been shown to result in greater student gains than either peer discussion or instructor explanation alone (Smith et al., 2009). In the instructor slides and student worksheet, each classroom-discussion open-response TPS question opportunity is identified by “TPSQ” and each Clicker Question TPS opportunity is abbreviated “CQ” for Clicker Question (Appendix A, Appendix F). Specific advice on the administration of each of these questions is given in the “Progressing Through the Lesson” section and in the notes section of the lesson slides.

3.7.3 Progressing through the lesson

3.7.3.1 Introduction and assessing prior knowledge (~10 minutes)

The lesson begins with an overview of population dynamics and engaging students’ prior knowledge about barnacles. The instructor first defines population dynamics and informs students that they will be learning some of the methodology used by population ecologists: collecting and analyzing descriptive data and generating and evaluating mathematical models (Appendix A). The instructor then explains that although ecologists in general seek to understand how all organisms in an ecosystem interact, population ecologists approach this goal by focusing on individual populations that they can observe and manipulate with experiments (Appendix A). The instructor can also introduce the seminal role that barnacles played in developing the field and methodology of population ecology and also why barnacles are a good system for studying population growth (Connell, 1961). Since most of the lesson focuses on barnacle population growth, the instructor next gives students the opportunity to engage their prior knowledge about barnacle biology and what affects their population size.

TPSQ1. What affects barnacle population size?

For approximately four minutes, students brainstorm in small groups and write on their worksheet factors they think might affect barnacle population size (Appendix A). This time allows students to review and ask questions about barnacles before seeing data related to barnacle population growth. In our introductory biology course students mentioned: temperature, salinity, human disturbance (crushing), competition, food availability, exposure to the air, wave action, predation, and disease as likely factors affecting barnacle population size. Typical questions that arose about barnacles included, "How long can barnacles live outside of the water? (answer: up to about 6 weeks); "Do barnacles reproduce sexually?" (answer: yes, most species of barnacles are hermaphroditic); and "What preys on barnacles?" (answer: fish, limpets, crabs, sea stars, and marine snails such as whelks).

Following small group discussion, the instructor can solicit answers from students. If desired, the instructor can write these answers on a board and identify biotic versus abiotic factors. A summary slide of factors that students mentioned in the lesson is provided (Appendix A). To transition to the next section of the lecture, the instructor focuses students' attention to the variable of interest on the summary slide – the number of barnacles.

3.7.3.2 Quantifying population size (~5 minutes)

This section of the lesson focuses on how ecologists measure and describe population size. The instructor first introduces density and abundance, explaining that whether density or abundance is used depends on the organism and study design (Appendix A). For example, when observing a population of elephants in the savannah, abundance is likely a more useful measure of population size because you can easily count every individual. If, however, you are observing bacteria in a flask, you would measure density due to the constraints of counting every single individual. Since having a clear understanding of these two measurements is important, the instructor next gives students the opportunity to compare and calculate density and abundance.

CQ1. Which of the following statements describes the two study sites below?

Students observe a diagram and compare the density and abundance of barnacles. Using their clicker, they select from the following answer choices: A) site two has a greater abundance and density than site one; B) site one has a lower abundance but equal density to site two; C) site one has a lower abundance but greater density than site two; or D) the density and abundance are equal for both sites (Appendix A). After responding to the question individually, students discuss in small groups and revote. During this time, the instructor should encourage students to discuss their reasoning and how they calculated density and abundance. In our class, 70% of students answered correctly before peer discussion (answer C) and 93% were correct following peer discussion (Appendix B). These results suggest that students had a good understanding of density and abundance after receiving the definition of both.

After small group discussion, the instructor can ask students to describe how they arrived at their answer. In our class, students described two different ways of determining the correct answer. Some students calculated the density while others used the diagram to visually compare the density and abundance of barnacles in each study site. The clicker question was designed to allow students to conceptually answer the question without calculating the density of the two study sites. After restating different problem-solving techniques, the instructor can provide an explanation of how to calculate density and abundance using mathematical equations (Appendix A).

3.7.3.3 Predicting and plotting population growth (~10 minutes)

Next, students are asked to make a prediction using a graph and plot data of population growth over time. The instructor first introduces the methodology used by Connell, 1961 to study barnacle population growth in the intertidal zone (Appendix A). Emphasis on the following experimental features is important for this lesson: 1) the author measured the density of the population (y-axis); 2) the study was conducted over two months (x-axis); and 3) cages were used to prevent predation during the experiment (Connell, 1961). To provide students with the opportunity to think about the x-and y-axes on the graph, and also how barnacle populations might grow over time, the instructor next asks students to predict barnacle population size over the course of the experiment.

TPSQ2. Draw on your paper what you would expect the growth of this population to look like over the 30-day experiment.

CQ2. Select the growth curve that most resembles your prediction for barnacle population growth.

Students will use the blank graph on their worksheet (with the y- and x-axis provided and labeled) to predict barnacle population size over the course of the study (Appendix A; Appendix F). To easily quantify student predictions, the instructor gives the students a clicker-question (CQ2) asking them to individually vote for the growth curve – A) linear, B) exponential, or C) logistic – that most resembles their prediction (Appendix A). During the individual vote in the lesson, students chose all three growth curves (23% linear, 43% exponential, and 34% logistic). Students then talk with their peers and revote using their clickers. The instructor can encourage students to discuss their reasoning and what they think may influence the type of growth shown in the curve they selected. Following peer discussion in the lesson, 7% selected a linear growth curve, 33% chose exponential, and 60% of students voted for the logistic.

After peer discussion, the instructor can solicit answers from students by having them raise their hands and share their initial prediction and reasoning. In the lesson, student reasoning for each of the growth curves included: linear - "The population will increase steadily over time," exponential - "I don't know what the carrying capacity of the rock is, there is not enough information to know if or when the population will level off," logistic - "Since the study was conducted on a single rock, I figured eventually the barnacles would run out of space, and there would be no more room for additional barnacles to settle, therefore the graph would level off." After discussing students' responses, the instructor provides students with the experimental data to plot and compare to their prediction.

TPSQ3. Use the data provided to plot the barnacle population growth.

CQ3. Select the growth curve that most resembles the curve you generated from the data provided.

Students use data from Connell, 1961 to plot barnacle population size over time on their worksheet (Appendix A; Appendix F). To check that students are plotting the data correctly, the instructor gives the students a clicker question (CQ3) where they select the growth curve – A) linear, B) exponential, or C) logistic – that most resembles their plot of the provided data (S1, slide 15-16). In our class, 99% of students answered correctly during the individual vote and the instructor skipped peer discussion (Appendix C). The instructor next says that while logistic growth is common, other mathematical models (e.g., linear and exponential) can be used to describe growth in populations. Also, since there are periods of linear and exponential growth in the barnacle data, all three of types of growth will be discussed further.

3.7.3.4 Identifying and comparing growth rate (~8 minutes)

This part of the lesson targets the mathematical equations used to describe growth rate. The instructor first defines growth rate and then describes how it differs for the three growth curves (linear, exponential, and logistic), showing, but not yet explaining the three mathematical equations (Appendix A). The instructor can emphasize that one thing ecologists may be interested in determining is how the growth rate changes, or might change, over time. The instructor then uses a clicker question to help students distinguish how growth rate differs in the three growth curves.

CQ4. The growth rate (or change in the population density) is:

Students use a diagram of the three different growth curves (linear, exponential, and logistic) and infer how the growth rate is changing over time in each. Using their clickers (CQ4), students select from the following answer choices: A) increasing over time in all three growth curves; B) increasing over time in the linear and exponential growth curves only; C) constant over time in all three growth curves; or D) constant in the linear growth curve and changes over time in the exponential and logistic growth curves (Appendix A). In our class, 74% of students answered correctly (D) before peer discussion, while 15% selected choice B. After peer discussion, the number of correct responses increased to 86%.

After small group discussion, the instructor solicits answers by having students raise their hands and explain how they arrived at their answer. In the lesson, student reasoning for selecting choice A included: “It looks like the growth rate is increasing in all three graphs, because the population size is getting larger over time.” Reasoning for B included: “The population is increasing over time in the linear and exponential growth curves, however it is leveling off in the logistic.” Reasoning for the correct answer D included: “If you look at the slope of the line, you will see that it is constant in the linear growth curve, however it changes over time in both the exponential and logistic growth curves.”

Next, the instructor demonstrates how to calculate the growth rate at different time-points and population sizes using a linear and exponential growth model (Appendix A). The instructor should first explain the variables used in the linear growth model: population size (N) and time (t), and introduce the technique of changing the values of the variables in the equation to see how the growth rate changes. By selecting two points on the linear growth curve, the instructor shows the students how the growth rate is constant over time. This is also a good time to say that the slope of the line is the growth rate.

The instructor then introduces the variables used in the exponential growth model: population size (N), time (t), and the intrinsic rate of increase (r). The instructor describes the intrinsic rate of increase (r) as a value that ecologists estimate. The instructor exaplains that the simplest way to interpret r in the context of exponential growth is that if r=2/day, for every barnacle present, two additional barnacles will be added per day. The instructor can then use the technique of changing the values of the variables to see how the growth rate will vary. Here it is important that the instructor to emphasize that in exponential growth as the population size increases, the growth rate increases.

3.7.3.5 Determining the influence of carrying capacity (~10 minutes)

This section of the lesson addresses limitations to population growth. Using the Connell, 1961 data, the instructor provides an estimate of the carrying capacity (Appendix A). Here the instructor highlights that the first portion of the graph resembles exponential growth, but that there is a decrease in the growth rate as the barnacle population approaches ~80 barnacles per cm^2, which is an estimate of carrying capacity (Appendix A). The instructor defines regulating mechanisms (those that influence population growth rate) and density-dependent regulation (which occurs when population growth rates are influenced by the density of the population). Here the instructor can ask students to volunteer likely regulating mechanisms for the barnacle population. In our class students mentioned: food availability, predation, disease, and/or space. Given the experimental set-up, where food is plentiful and predation is prevented, the most likely regulating mechanism is space.

After discussing regulating mechanisms, the instructor shows students the logistic growth equation (Appendix A). The instructor asks them to identify the new variable – carrying capacity (K). Here the instructor notes that the first portion of the graph resembles exponential growth and the first portion of the logistic equation is the same as the exponential growth equation (rN). In order to allow students to investigate how the new variable (K) results in a decreasing growth rate, the instructor gives students the opportunity to calculate the growth rate with given values of intrinsic growth rate (r), carrying capacity (K), and varying population sizes (N).

CQ5. If r=2 per day and K=80 barnacles per cm^2, how does increasing the population size (N) affect the population growth rate (dN/dt) in the logistic growth model?

In order to allow students to investigate how the new variable (K) results in a decreasing growth rate, students calculate the growth rate for different population sizes (N) (given values for the intrinsic growth rate (r) and carrying capacity (K)) to determine what happens as the population approaches carrying capacity (Appendix A; Appendix F). Students work on these calculations in their small groups and select from the following (CQ5): A) as N approaches K, the growth rate increases; B) as N approaches K, the growth rate slows; or C) as N approaches K, the growth rate stays constant. If students are having difficulty, the instructor can provide an example calculation using a population size (N) of 40 (Appendix A). In our class, students struggled to use the logistic equation to calculate growth rate on their own, so the instructor allowed students to work together in pairs to answer the question (Appendix A). After the instructor-led example and group problem-solving, 76% of students correctly answered choice B. Students could have arrived at the correct answer to this question through reasoning or calculation.

After small group discussion, the instructor emphasizes how the equation models what happens to the growth rate as the population approaches carrying capacity (the growth rate increases initially, is fastest at half the carrying capacity, and decreases as the population continues to approach carrying capacity). Next, the instructor shows students the growth rates calculated for the plot of the Connell, 1961 data (Supporting File S1: Describing and modeling populations over time- Lecture Slides, slide 29). Here the instructor focuses on how the growth rate increases then decreases as the population approaches carrying capacity.

3.7.3.6 Synthesis (~7 minutes)

To conclude, students are given the opportunity to synthesize the concepts covered throughout the lesson. The instructor summarizes how the growth rate differs in linear, exponential, and logistic growth curves (Appendix A). Then, the instructor provides a few examples of how the growth model can be applied, including economic, medical, and conservation predictions and decision-making (Appendix A). Students are presented with growth curves showing the population size over time for four different types of organisms (Appendix A).

TPSQ4. Describe the following populations over time:

In small groups, students discuss the population growth curves for bristlecone pine trees, grey wolves, bacteria, and red foxes. For each growth curve, they: 1) identify if density or abundance is shown; 2) describe what is happening to the population growth rate (increasing, decreasing, etc.); and 3) identify if the graph most closely resembles linear, exponential, logistic growth, or other growth. The goal is to allow students the time to synthesize all of the information gained throughout the lesson and to apply quantitative reasoning to different types of organisms.

After small group discussion, the instructor solicits answers from the class to determine how they answered each of the questions, focusing on the problem-solving techniques used. For example, the instructor can highlight looking at the y-axis to determine if abundance or density is measured, the importance of considering population size and rate of growth separately, and the role of carrying capacity in producing the logistic growth curve.

The instructor concludes the lesson by reviewing the learning outcomes and by answering any student questions (Appendix A).

3.8 Teaching discussion

We used formative, real-time, and summative assessment to reflect on the effectiveness of this lesson. Here we discuss student responses to pre/post multiple-choice questions, exam questions, and a student attitudinal survey. Student responses to in-class questions are provided in the Progressing Through the Activity Section.

3.8.1 Student performance and conceptual difficulties

3.8.1.1 Pre/post multiple-choice questions

Introductory biology students answered ten pre/post multiple-choice questions (abbreviated PPTQ). The questions can be further grouped into four main categories that correspond with the parts of the lesson: 1) quantifying population size, 2) predicting population growth, 3) identifying and comparing growth rate, and 4) determining the influence of carrying capacity (Table 3.2). We report the percent correct for each question for those students who completed all components of the activity (n=433).

	Quantifying Population Size	**Predicting Population Growth**	**Identifying and Comparing Growth Rate**	**Determining the Influence of Carrying Capacity**
Targeted Student Thinking	Calculate density and abundance for different populations.	Use data to generate a population growth curve.	Use slope to predict where the growth rate is fastest in linear, exponential, and logistic growth curves.	Select the areas on a growth curve where carrying capacity and density dependence are most likely shown.
Pre/Post-Test Questions	PPTQ1 PPTQ2	PPTQ3	PPTQ4 PPTQ5 PPTQ6 PPTQ7 PPTQ8	PPTQ9 PPTQ10
Clicker Questions	CQ1	CQ2 CQ3	CQ4 CQ5	-
Exam Questions	-	-	EQ1 EQ2 EQ3	EQ4

Table 3.2: Summary of assessment questions used in the lesson. Formative, real-time, and summative assessment questions used to examine student understanding of population growth organized by the four main learning targets. Questions are abbreviated PPQT (pre/post-test), CQ (clicker), and EQ (exam).

Across all three classes, the overall average pre-test score was 69% and the average post-test score was 78%. To calculate the normalized gain for overall scores on the pre/post-test, we used the following formula (Hake, 1998): (% of students who scored correct on the post-test - % of students who scored correct on the pre-test) / (100% - % of students who scored correct on the pre-test). The normalized gain for the pre/post-test was <g>= 0.32. We also calculated normalized change (Marx and Cummings, 2007) for overall scores for each individual student and averaged the scores. For normalized change, individual student positive changes from pre-to post were calculated using the normalized gain formula (Hake, 1998); negative changes are calculated: (% of students who scored correct on the post-test - % of students who scored correct on the pre-test) / (% of students who scored correct on the pre-test); and students who scored 0% or 100% on both the pre and post were removed. The normalized change for the pre/post-test was <c>=0.33.

We also calculated normalized gain scores (Hake, 1998) at the individual question level and found a range from <g>=0.14 to <g>=0.94 (Figure 3.2). Student performance on individual questions is discussed below.

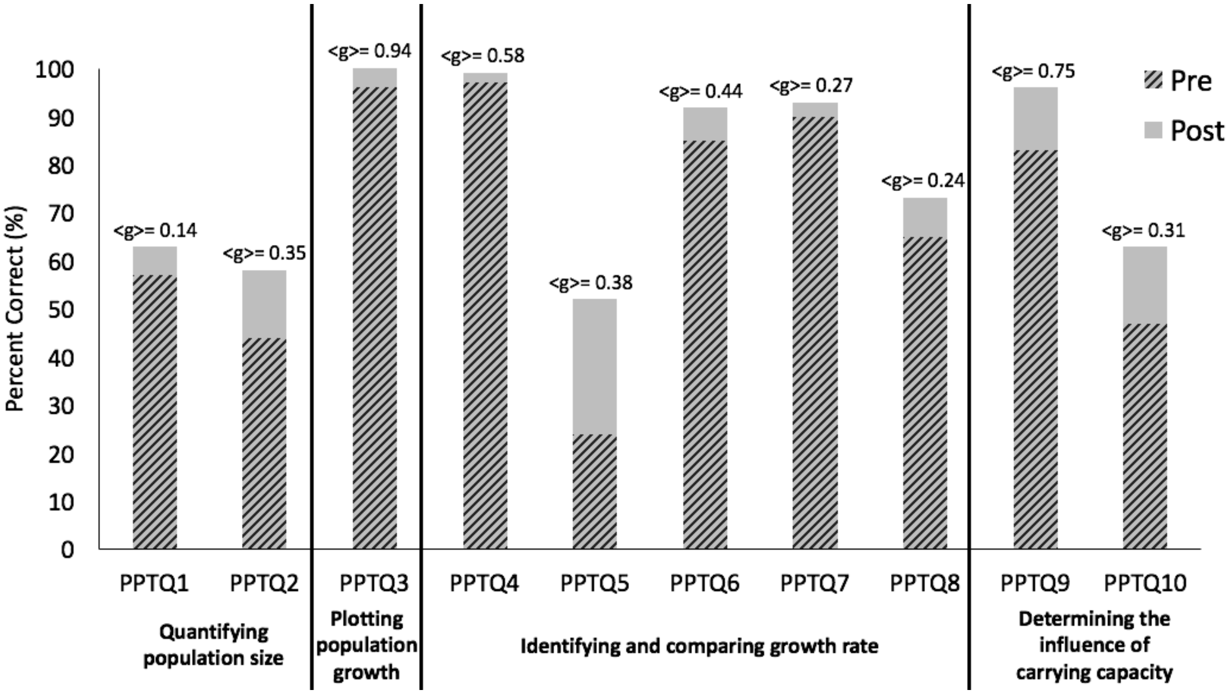


Figure 3.2: Pre/post assessment question responses. Student percent correct before and after instruction on pre/post-test questions (abbreviated PPTQ). Normalized gain <g> is provided for each question.

1. Quantifying population size

Two pre/post-test questions (PPTQ1 and PPTQ2) were designed to investigate students' ability to calculate density and abundance of a population (Table 3.2, Appendix D). Experts would generally approach these questions by calculating density [density (D)= number of individuals (n) / unit volume (v)], and counting the number of individuals for abundance. After instruction, students showed improvement on both PPTQ1 and PPTQ2 (Figure 3.2).

All wrong answer choices for PPTQ1and PPTQ2 targeted incorrect calculations and included incorrect units (Appendix D). For PPTQ1, the density of the sunflowers is the same in two different quadrats even though they take up different areas (answer C), but students who missed this question on the post-test were roughly evenly divided between incorrect answer choice A (quadrat 1 has greater density, 19%) and answer choice B (quadrat 2 has greater density, 17%). For PPTQ2, the most common incorrect answer on the post-test was D (24%), where the density was incorrectly written as 5 individuals and abundance was written as 20 individuals per square meter. These incorrect answers suggest that some students were still confused about what density measures and the correct units, and how density differs from abundance.

2. Plotting population growth

One question on the pre/post-test (PPTQ3) asked students to plot data and select which of three given growth curves (linear, exponential, and logistic) their plot most resembles (Table 3.2, Appendix D). Before and after instruction the percentage of students answering PPTQ3 correctly was high (Figure 3.2). This result suggests that students were able to successfully generate a plot when provided data and a graph with the x-and-y axes labeled.

3. Identifying and comparing growth rate

Two pre/post-test questions (PPTQ4 and PPTQ5) asked students to determine how growth rate changes over time in exponential and logistic growth curves (Table 3.2, Appendix

D). Experts would generally approach these questions using the slope of the line to estimate growth rate. On the post-test, students were far more likely to predict the growth rate for an exponential growth model (PPTQ4, 99% correct) compared to a logistic growth model (PPTQ5, 52% correct) (Figure 3.2). The most common incorrect answer for PPTQ5 is that growth rate increases over time in a logistic model (incorrect answer A) where students likely equated a larger populations size with a faster growth rate. This conceptual difficulty was previously reported for college students who were asked to compare speed at two different points along a graph; more than half of the students answered incorrectly (McDermott et al., 1983; Mokros and Tinker, 1987).

For pre/post-test questions PPTQ6, PPTQ7, and PPTQ8 students compared growth rates within and between linear and exponential growth curves (Appendix D). On the post-test, students performed well on a question that asked them to compare the growth rate between two points on a linear growth curve (PPTQ6, 92% correct) and on a question that asked them to compare two points on an exponential growth curve (PPTQ7, 93% correct). However, it was a more challenging for students to compare a point on a linear growth curve with a point on an exponential growth curve (PPTQ8, 73% correct). The most common incorrect answer is that that the growth rates were equal (answer C), which suggests that students are not consistently using the slope of the line to estimate growth rate.

4. Determining the influence of carrying capacity

Two pre/post-test questions investigated students' ability to integrate the concept of carrying capacity in logistic growth curves (PPTQ9 and PPTQ10). For PPTQ9, students were asked whether carrying capacity impacts logistic growth curves (answer A, correct), exponential growth curves (answer B), both growth curves (answer C), or neither growth curve (answer D). The majority of students on the post-test (96%) answered this question correctly (answer A). However, in PPTQ10, where students were asked whether density-dependent growth impacts logistic growth curves (answer A, correct), exponential growth curves (answer B), both growth curves (answer C), or neither growth curve (answer D), only 63% of the students answered correctly. This result suggests that while students generally understand carrying capacity, they are more uncertain of the role of density-dependence.

3.8.1.2 Exam questions

Students were given four exam questions (abbreviated EQ) about population growth (Appendix E). Students scored greater than 70% on all four exam questions. Students used the logistic model to calculate growth rate (EQ1), determine when growth rate would be fastest (EQ2, EQ3), and estimate carrying capacity (EQ4).

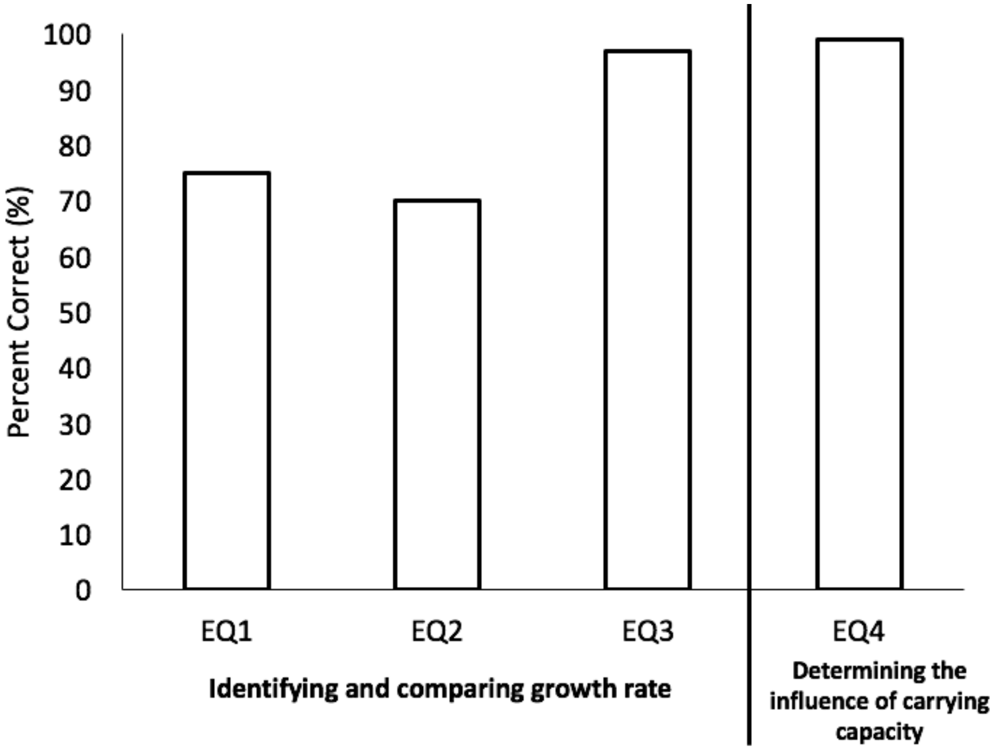


Figure 3.3: Student percent correct for exam questions (abbreviated EQ).

3.8.1.3 Student perceptions

Students were given a short survey on their perception of the lesson's usefulness immediately following the post-test (Appendix G). Overall, students stated that participating in this lesson increased their understanding of how ecologists measure and model population size (88% agree/ strongly agree). When asked to explain, students provided reasons such as: "I learned about the different models of population growth and how to calculate growth rate for each," "It gave me a clear understanding of how ecologists measure and model population size by giving me real life examples and visuals to help me understand," and "This lesson helped increase my understanding of how ecologists measure population size because it was hands on, fun, and engaging to do the calculations as an entire class."

The majority of students found the clicker questions, peer discussion, whole group discussion, and the in-class worksheet to be useful/ very useful (Table 3.3). When asked to describe what parts of the population growth lesson were particularly useful to their learning, representative student comments included: “I found the peer discussion to be helpful because it helps me see different viewpoints that I would not have otherwise thought of,” “I really liked having the worksheet in the lesson because it made us more engaged with the problems in the lesson,” and “the clicker questions, class discussions, and worksheet all combined to help me better learn the material.” Together, these results suggest that students enjoyed the lesson and perceived it as useful to their learning.

Lesson Components	**Not useful at all**	**Somewhat useful**	**Useful**	**Very Useful**
Clickers	2%	23%	52%	23%
Peer Discussion	7%	41%	38%	14%
Whole Group Discussion	5%	37%	46%	12%
In-Class Worksheet	3%	25%	45%	27%

Table 3.3: Student responses to attitudinal survey. Students responses to survey questions asking how useful each of the lesson components were to their learning (n=433).

3.9 Additional suggestions to enhance student learning while using this lesson

Based on the student performance on the clicker, pre/post-test, and exam questions, we make the following recommendations to further improve student learning:

1. Density and abundance

Some students had difficulty calculating density, distinguishing between density and abundance, and identifying the correct units for density and abundance (Figure 3.2, PPTQ1 and

PPTQ2). We recommend explicitly discussing the units of density and abundance as a valuable tool for students and providing more practice problems distinguishing between the two.

2. Calculations

A subset of students struggled in the lesson to understand and use equations to calculate growth rate for the three different growth curves. For example, it was our intention was to use the suggested calculations that are part of CQ5 (Appendix A) as an exercise to allow students to explore how changing the variables results in changes to the population model. Many students were unable to input values for the variables and their attention focused on this skill rather than conceptually understanding the equation. Students also requested more practice using the equations on a post-attitudinal survey (Appendix G). There are a few online resources (e.g., Jeanne, 2003) that students could complete as a homework assignment to increase familiarity with the variables.

3. Estimating growth rate.

The pre/post-test revealed that students were more comfortable thinking about growth rates in exponential models than in logistic models. We also found that students could more easily make comparisons between points on the same growth curve then between points on different growth curves (Figure 3.2, PPTQ 6-8). We therefore recommend emphasizing slope and additional opportunities for students to practice and complete problems where they estimate or calculate the slope in the context of population growth models.

4. Integrating density-dependent growth

Many students could not identify and explain how density influences the population models (Figure 3.2, PPTQ10). We think students would benefit from more time focused on density-dependence to help them connect the concepts of density-dependence, carrying capacity, and logistic growth.

3.10 Conclusions

This clicker-based lesson engages students in quantitative reasoning skills essential for population ecology – calculating and interpreting density and abundance; generating graphs from existing data; calculating growth rates from linear, exponential, and logistic growth curves; and making inferences about population growth over time using mathematical models. A diversity of inclusive teaching practices are used throughout the lesson, including clicker questions with the think-pair-share model, worksheets, and instructor led discussions. Assessment results reveal student learning and identify persistent areas of conceptual difficulty.

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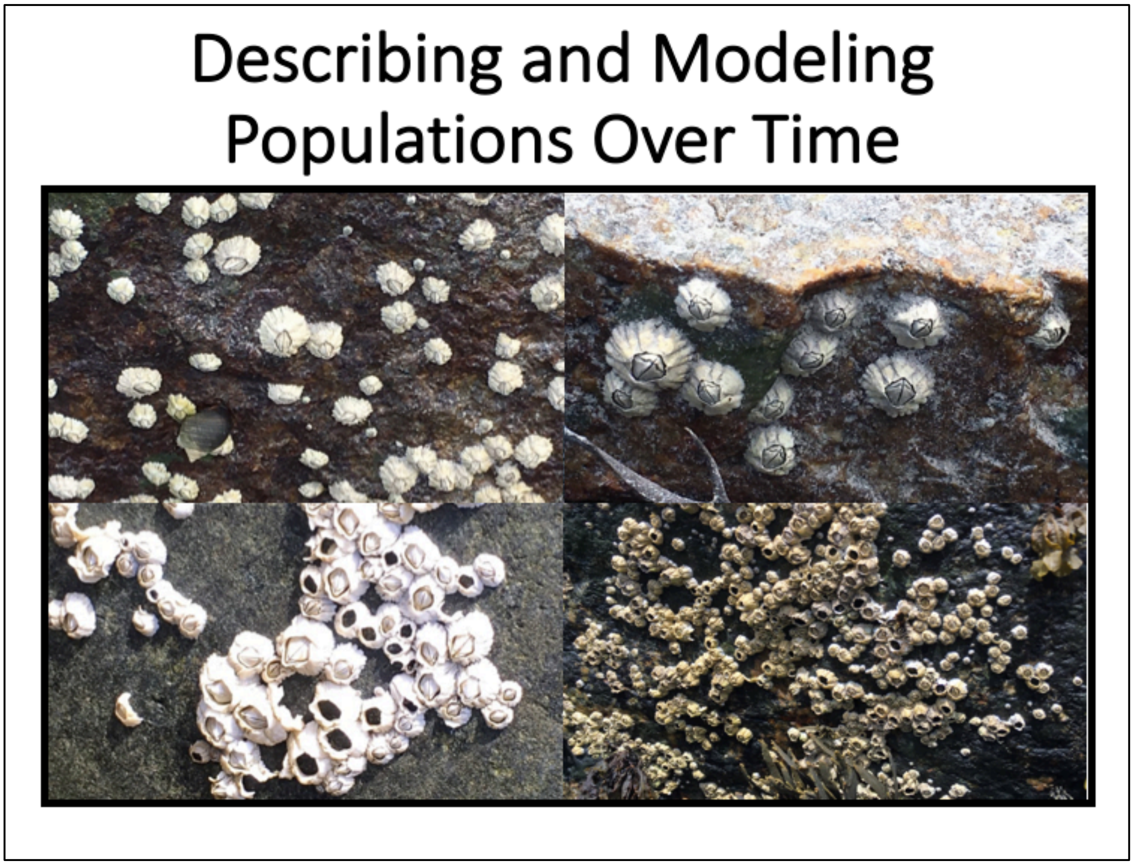
APPENDIX A

LESSON PRESENTATION SLIDES

Final lesson slides used in the BIO 100 Introductory Biology course at the University of Maine.



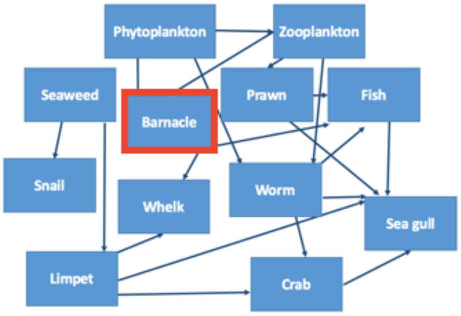
Describing and Modeling Populations Over Time

Population dynamics - studies the size and age compositions of populations and the environmental processes affecting them.

Collect and analyze descriptive data
Density
Abundance
Birth rates
Death rates

Generate and evaluate mathematical models
Growth rates
Carrying capacity
Density dependence
Density independence

Studying barnacles provided important understanding to the developing field of ecology

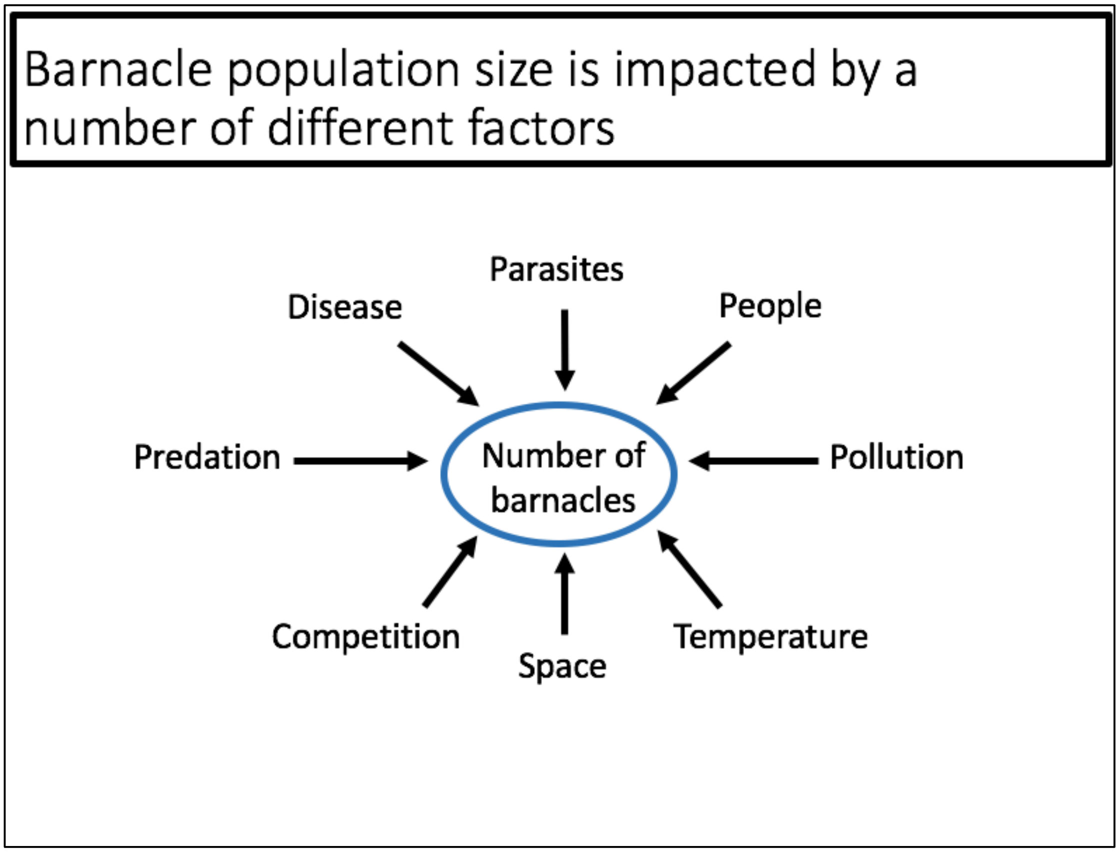


Why barnacles?

Stationary marine animals that live in the intertidal zone

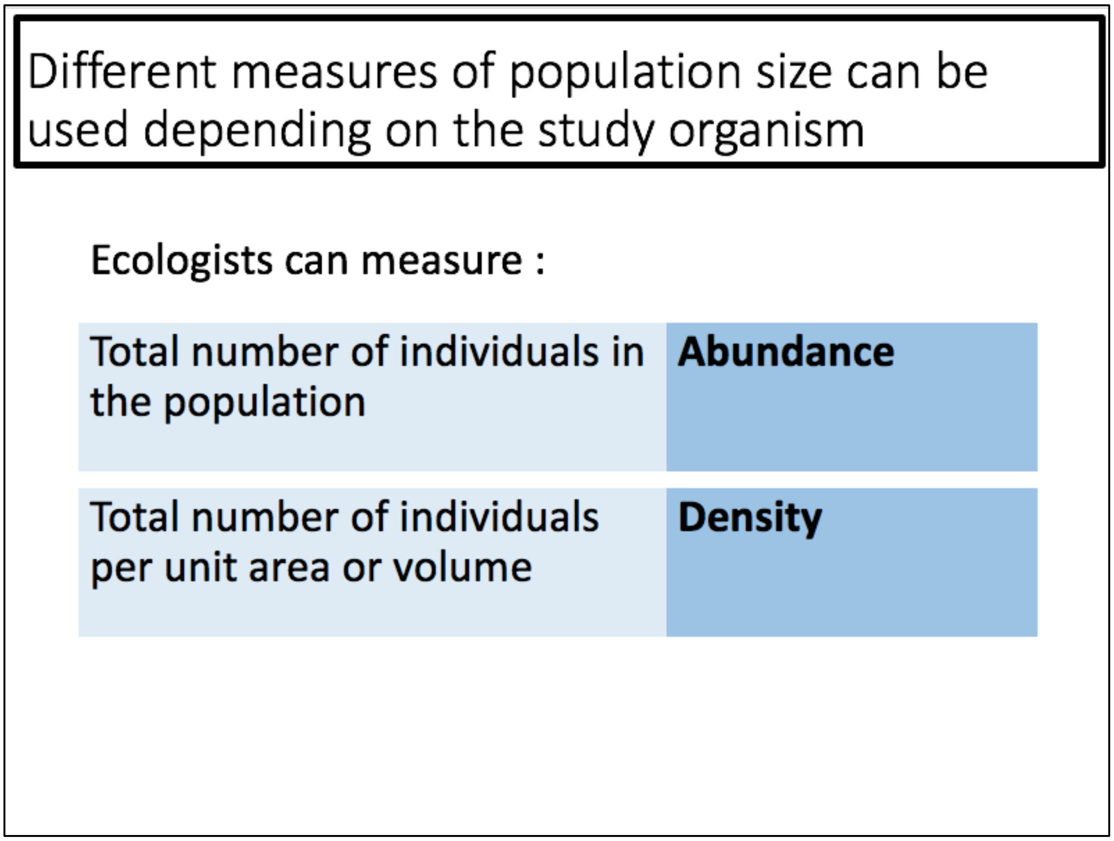
- Begin their life as larva floating in the water
- Settle and live cemented on hard surfaces (e.g., rocks)
- Feed on plentiful plankton in the water

Stationary = easy to count and observe over time



Barnacle population size is impacted by a number of different factors

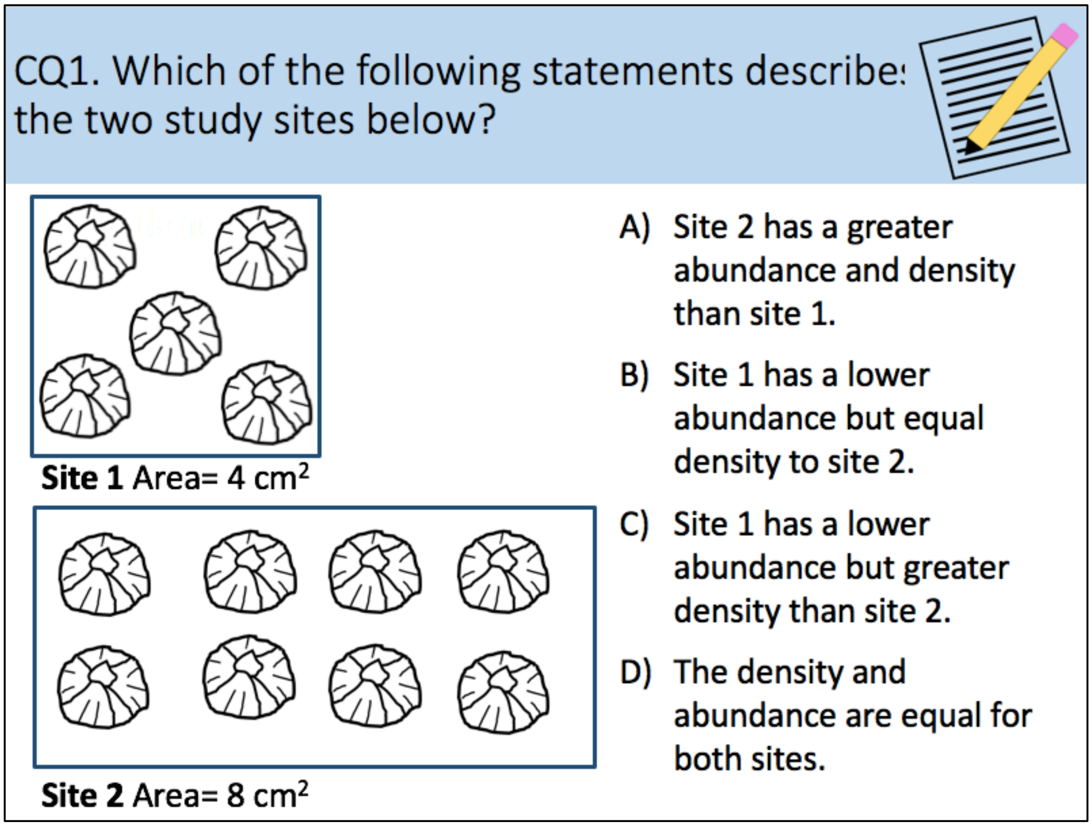
Parasites
Disease
People
Predation
Number of barnacles
Pollution
Competition
Space
Temperature



Different measures of population size can be used depending on the study organism

Ecologists can measure :

Total number of individuals in the population	**Abundance**
Total number of individuals per unit area or volume	**Density**



CQ1. Which of the following statements describe
the two study sites below?

Site 1 Area= 4 cm^2

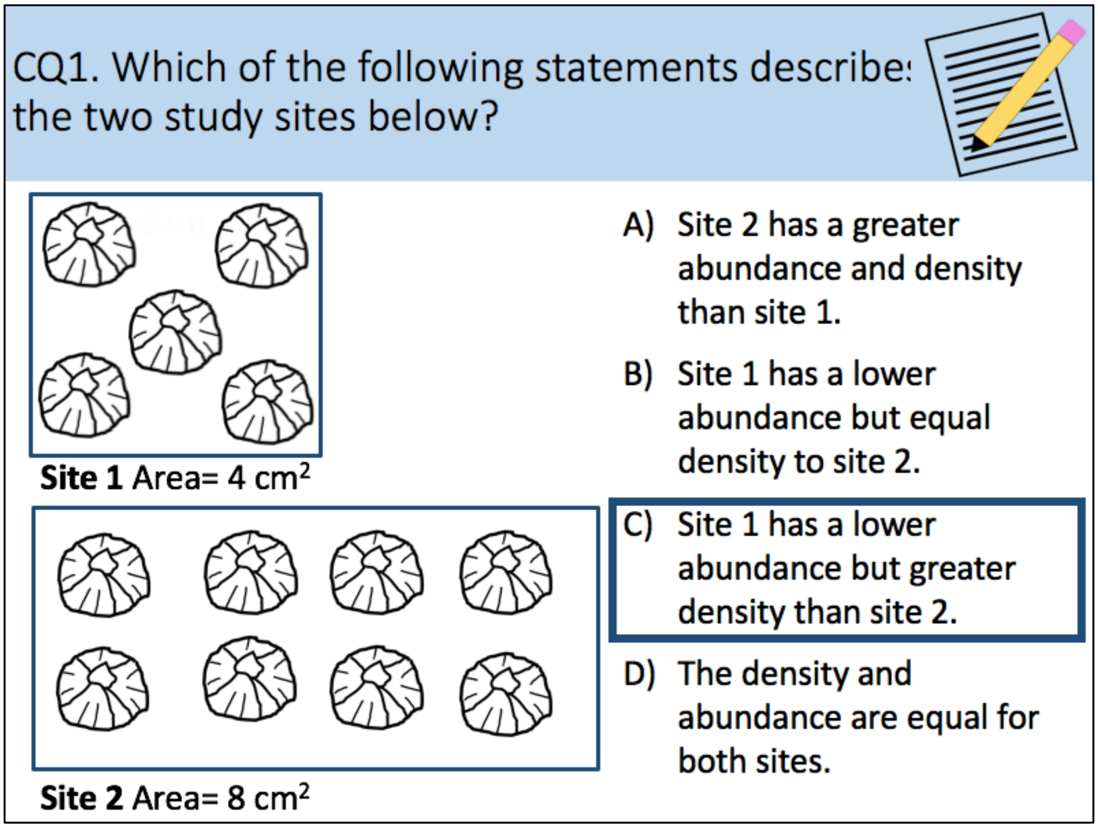
Site 2 Area= 8 cm^2

A) Site 2 has a greater abundance and density than site 1.

B) Site 1 has a lower abundance but equal density to site 2.

C) Site 1 has a lower abundance but greater density than site 2.

D) The density and abundance are equal for both sites.



CQ1. Which of the following statements describe
the two study sites below?

Site 1 Area= 4 cm^2

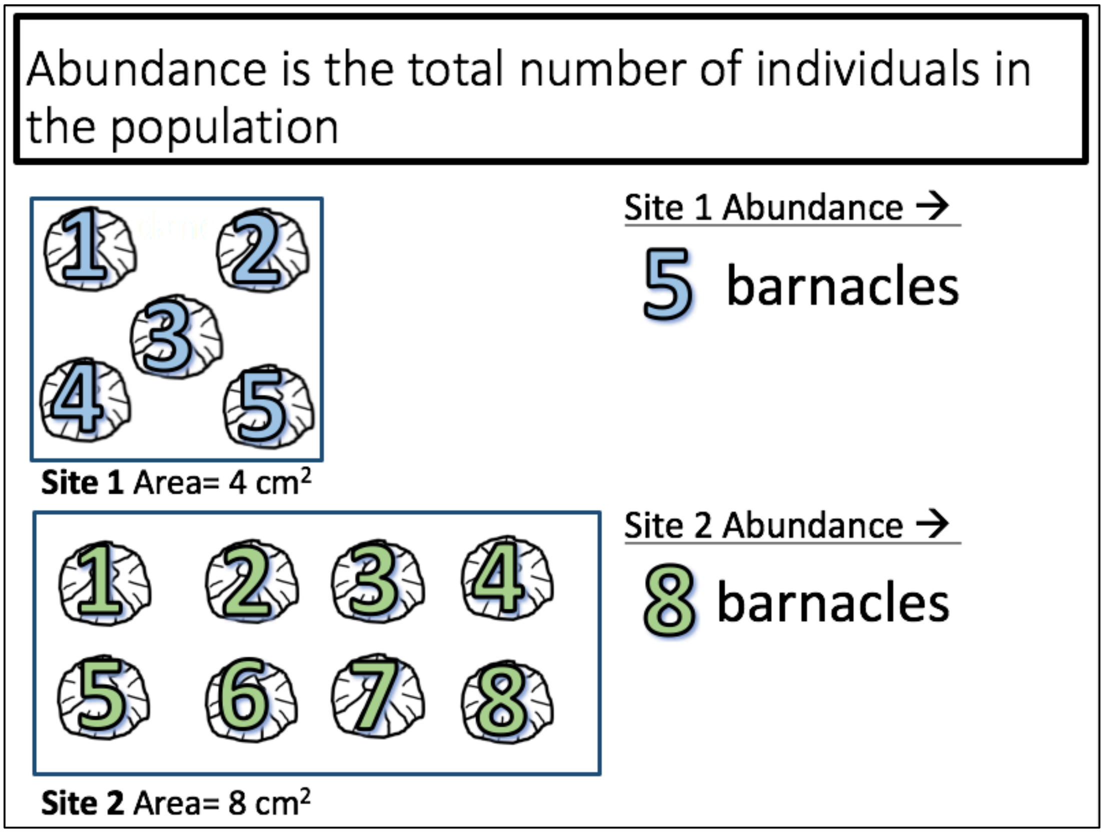
Site 2 Area= 8 cm^2

A) Site 2 has a greater abundance and density than site 1.

B) Site 1 has a lower abundance but equal density to site 2.

C) Site 1 has a lower abundance but greater density than site 2.

D) The density and abundance are equal for both sites.



Abundance is the total number of individuals in the population

Site 1 Abundance →

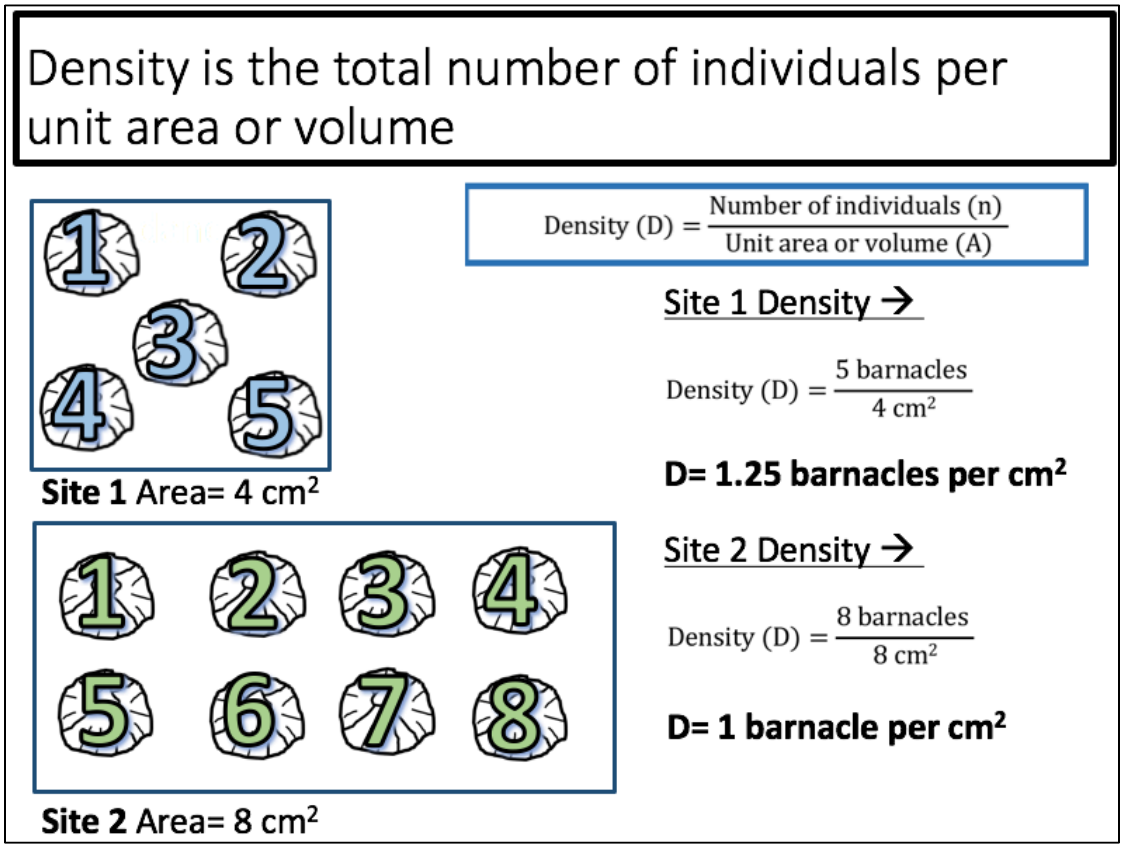
5 barnacles

Site 1 Area= 4 cm^2

Site 2 Abundance →

8 barnacles

Site 2 Area= 8 cm^2



Density is the total number of individuals per unit area or volume

$$\text{Density (D)} = \frac{\text{Number of individuals (n)}}{\text{Unit area or volume (A)}}$$

Site 1 Area= 4 cm^2

Site 1 Density →

$$\text{Density (D)} = \frac{\text{5 barnacles}}{4\ \text{cm}^2}$$

D= 1.25 barnacles per cm^2

Site 2 Area= 8 cm^2

Site 2 Density →

$$\text{Density (D)} = \frac{\text{8 barnacles}}{8\ \text{cm}^2}$$

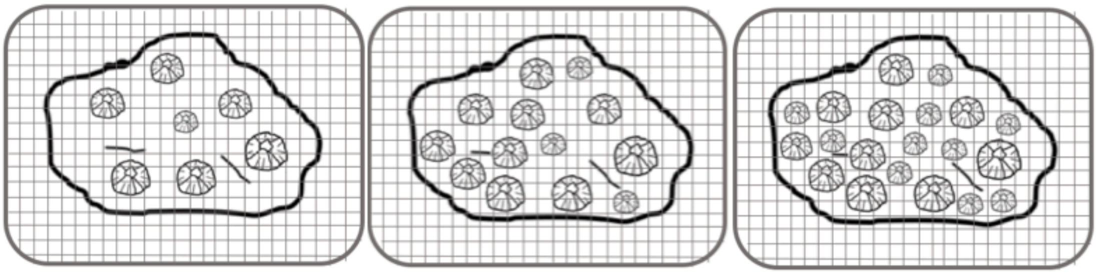
D= 1 barnacle per cm^2

In this study, density was used to measure barnacle population size over time

Empty rocks were placed in the intertidal zone.

Cages were placed on the rocks to prevent predation.

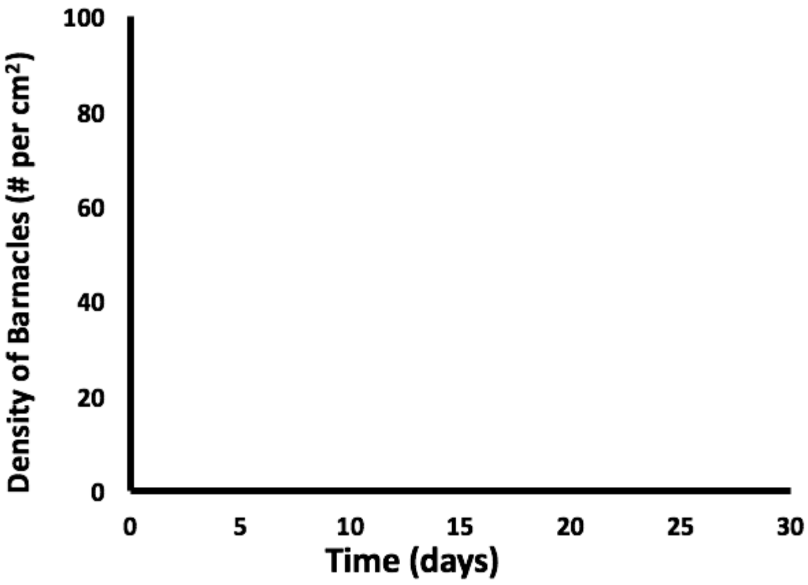
The population of settling barnacles on these rocks was observed daily for the month of April.



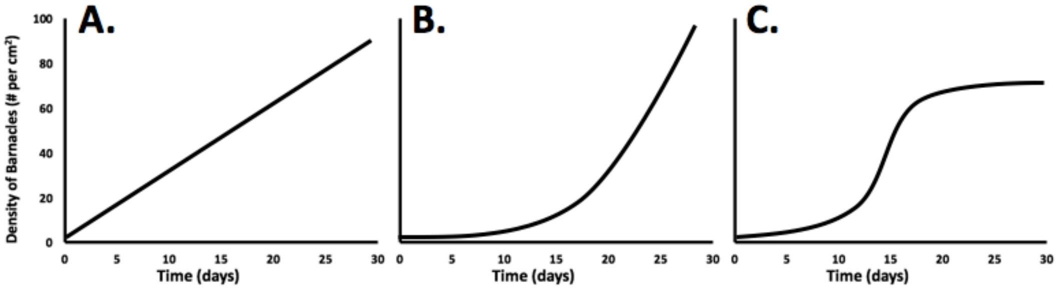
Beginning of April → **End of April**

Connell, J. 1961. Effects of competition, predation by *Thais lapillus*, and other factors on natural populations of the barnacle *Semibalanus balanoides*. Ecological Society of America, 31: 61-104.

TPSQ2. Draw on your paper what you would expect the growth of this population to look like over the 30 day experiment.

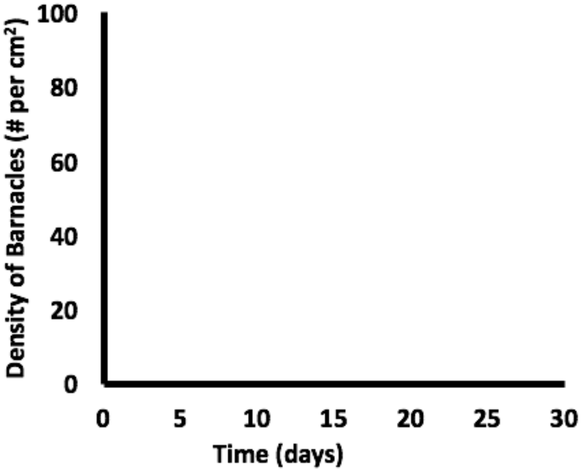


CQ2. Select the growth curve that most resembles your prediction for barnacle population growth.

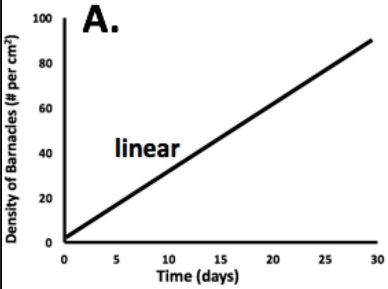


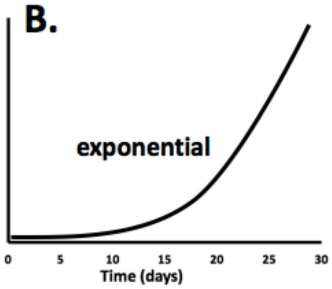
TPSQ3. Use the data provided to plot the barnacle population growth.

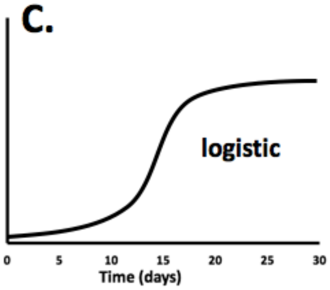
Time	Density of Barnacles (# per cm²)
1	2
5	12
10	70
15	76
20	79
25	78
30	78



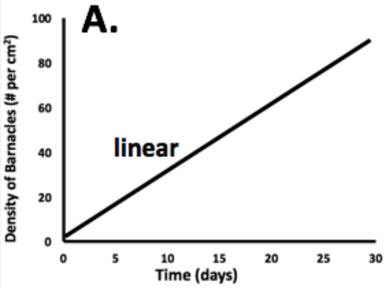
CQ3. Select the growth curve that most resembles the plot you generated from the data provided.

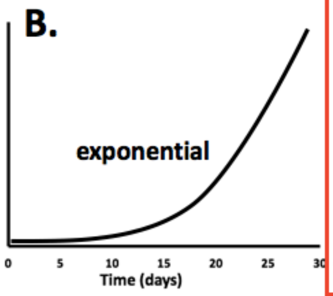


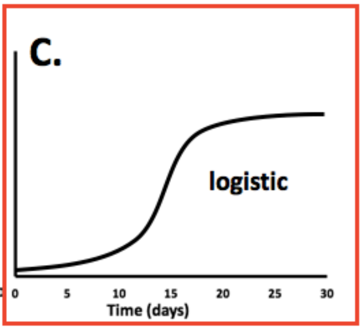




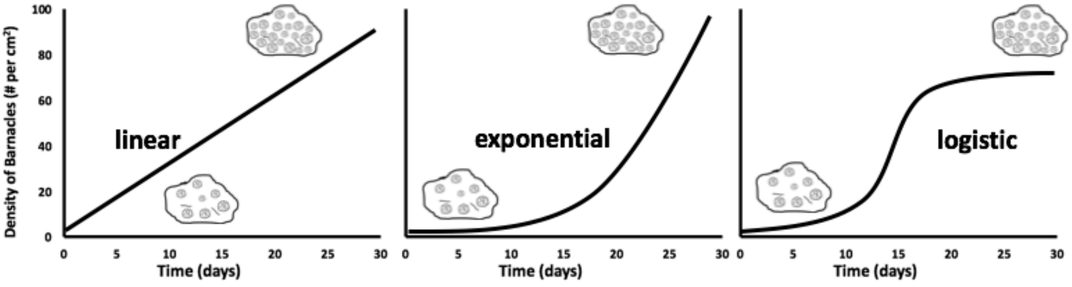
CQ3. Select the growth curve that most resembles the plot you generated from the data provided.







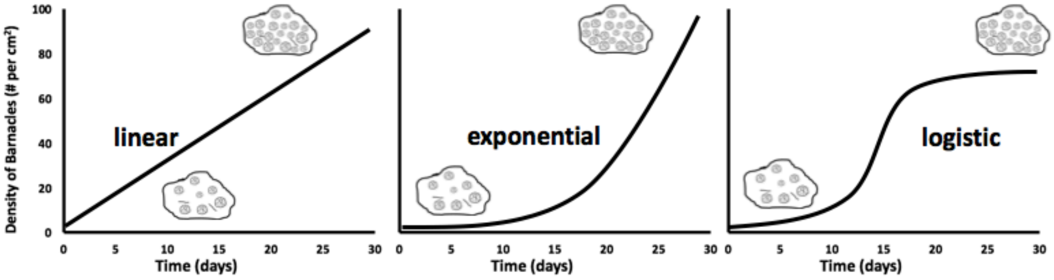
Growth models can simplify the complexity of ecology



$$\frac{dN}{dt} = \frac{N_2 - N_1}{t_2 - t_1} \qquad \frac{dN}{dt} = rN \qquad \frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

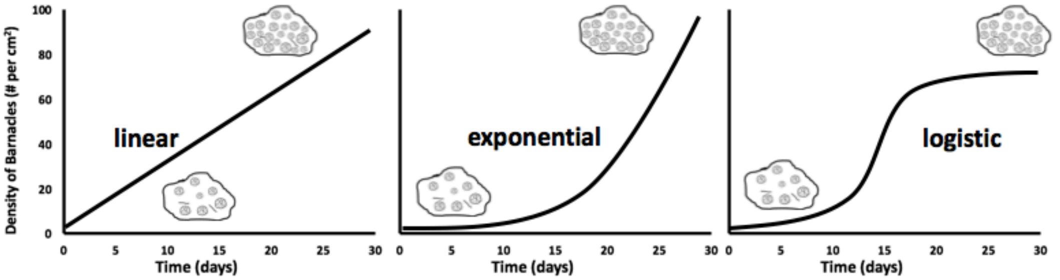
dN/dt = **population growth rate** = **rate** of change in the number of individuals in the population or density of the population

CQ4. The population growth rate (or change in population density) is:



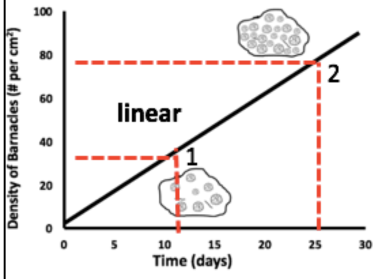
A) increasing over time in all three growth curves.
B) increasing over time in the linear and exponential growth curves only.
C) constant over time in all three growth curves.
D) constant in the linear growth curve and changes over time in the exponential and logistic growth curves.

CQ4. The population growth rate (or change in population density) is:



A) increasing over time in all three growth curves.
B) increasing over time in the linear and exponential growth curves only.
C) constant over time in all three growth curves.
D) constant in the linear growth curve and changes over time in the exponential and logistic growth curves.

In linear growth, the population growth rate is constant over time



A constant number of individuals are being added over time.

Population growth rate constant

(Same at every point in time)

Linear Model:

$$\text{Population growth rate} = \frac{dN}{dt} = \frac{N_2 - N_1}{t_2 - t_1}$$

N= population size measured by density (# per cm^2)

t= time (days)

N_1= 30 barnacles per cm^2 t_1=10 days

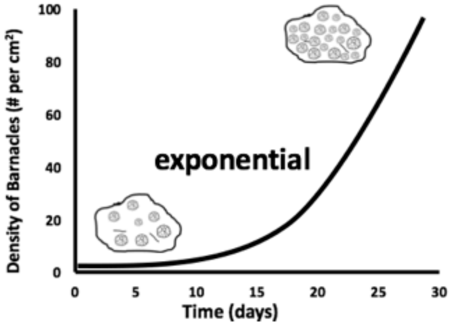
N_2= 78 barnacles per cm^2 t_2=25 days

(dN/dt)= (78-30) / (25-10)

(dN/dt)= (48/15)

(dN/dt)= +3.2 barnacles per cm^2/ day

In exponential growth, the population growth rate is increasing continuously



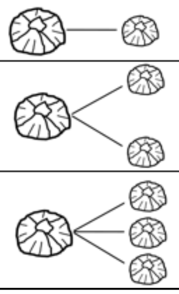
An increasing number of individuals are being added over time.

Population growth rate increasing continuously

Exponential Model:

Population growth rate $= \frac{dN}{dt} = rN$

N= population size (# per cm^2)
t= time (days)
r = rate of intrinsic population increase
r = birth rate – death rate
(in barnacles r = settlement rate – death rate)

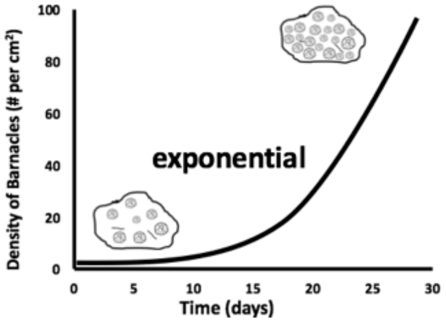


r= 1 per day per individual

r= 2 per day per individual

r= 3 per day per individual

In exponential growth, the population growth rate is increasing continuously



An increasing number of individuals are being added over time.

Population growth rate increasing continuously

Exponential Model:

Population growth rate $= \frac{dN}{dt} = rN$

If r = 2 per day:

When N= 1 barnacles per cm^2 →

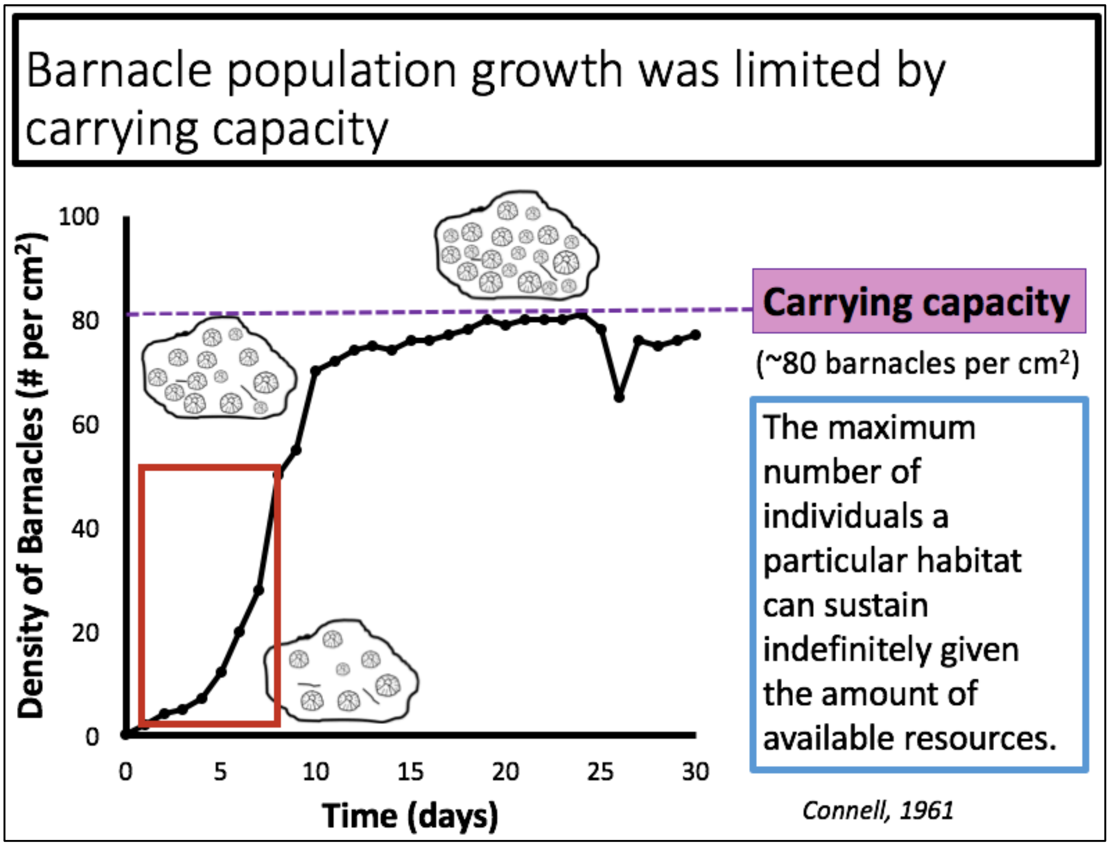
(dN/dt)= **+2 barnacles per cm^2/ day**

When N= 10 barnacles per cm^2 →

(dN/dt)= **+20 barnacles per cm^2/ day**

When N= 100 barnacles per cm^2 →

(dN/dt)= **+200 barnacles per cm^2/ day**



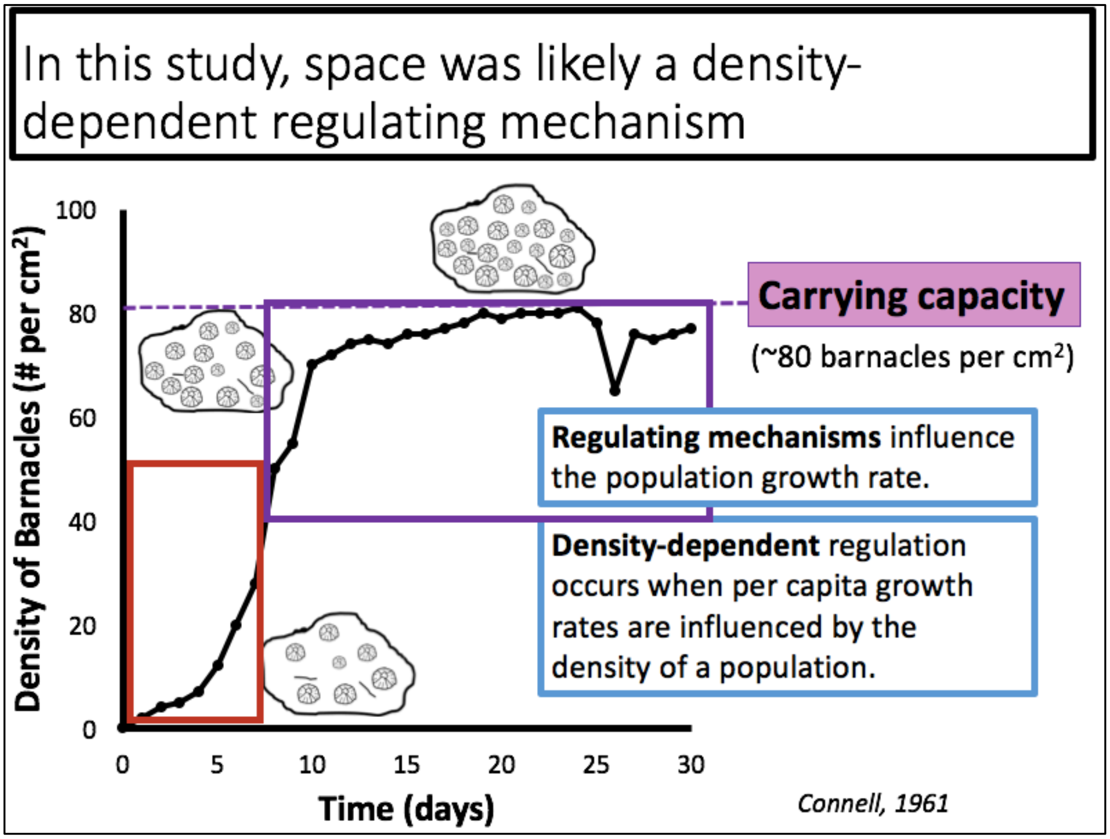
Barnacle population growth was limited by carrying capacity

Carrying capacity

(~80 barnacles per cm^2)

The maximum number of individuals a particular habitat can sustain indefinitely given the amount of available resources.

Connell, 1961



In this study, space was likely a density-dependent regulating mechanism

Carrying capacity

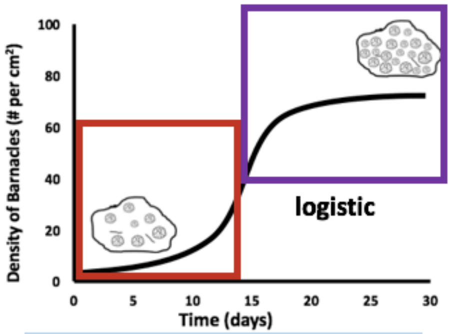
(~80 barnacles per cm^2)

Regulating mechanisms influence the population growth rate.

Density-dependent regulation occurs when per capita growth rates are influenced by the density of a population.

Connell, 1961

In logistic growth, the population growth rate increases then decreases over time



An increasing number of individuals are added initially, then a decreasing number of individuals added over time.

Population growth rate increasing, then decreasing

Logistic Model:

$$\text{Population growth rate} = \frac{dN}{dt} = \boxed{rN}\boxed{\left(1-\frac{N}{K}\right)}$$

r = settlement rate – death rate

N= population size

K= carrying capacity

K=The maximum number of individuals a particular habitat can sustain indefinitely given the amount of available resources.

K=~80 barnacles per cm^2

CQ5. If r=2 per day per individual and K= 80 barnacles per cm^2, how does increasing the population size (N) affect the population growth rate (dN/dt) in the logistic model?

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

dN/dt = growth rate
r= rate of intrinsic population increase
N= population size
K= carrying capacity

Hint: Calculate the population growth rate for the following population sizes and focus on what occurs as N gets close to K.

N approaches K

Population Size (N) (barnacles per cm^2)	**dN/dt (barnacles per cm^2 / day)**
1	
20	
40	
60	
70	
80	

A) As N approaches K, the population growth rate increases.
B) As N approaches K, the population growth rate slows.
C) As N approaches K, the population growth rate stays constant.

CQ5. If r=2 per day per individual and K= 80 barnacles per cm^2, how does increasing the population size (N) affect the population growth rate (dN/dt) in the logistic model?

Logistic Model:

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

Example calculation

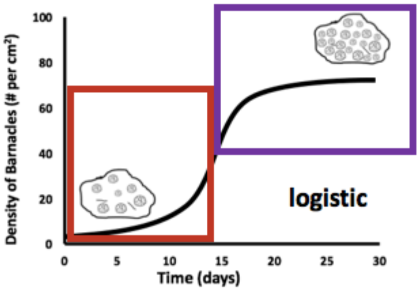
N= 40 barnacles per cm^2

$$\frac{dN}{dt} = (2 \text{ per day}) * (40 \text{ barnacles per cm}^2)\left(1 - \frac{40 \text{ barnacles per cm}^2}{80 \text{ barnacles per cm}^2}\right)$$

$$\frac{dN}{dt} = (80) * (0.5) = +\mathbf{40\ barnacles\ per\ cm^2\ /day}$$

CQ5. If r=2 per day per individual and K= 80 barnacles per cm^2, how does increasing the population size (N) affect the population growth rate (dN/dt) in the logistic model?

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



Population Size (N) (barnacles per cm^2)	dN/dt (barnacles per cm^2 / day)
1	+ 1.98
20	+ 30
40	+ 40
60	+ 30
70	+ 17.5
80	+ 0

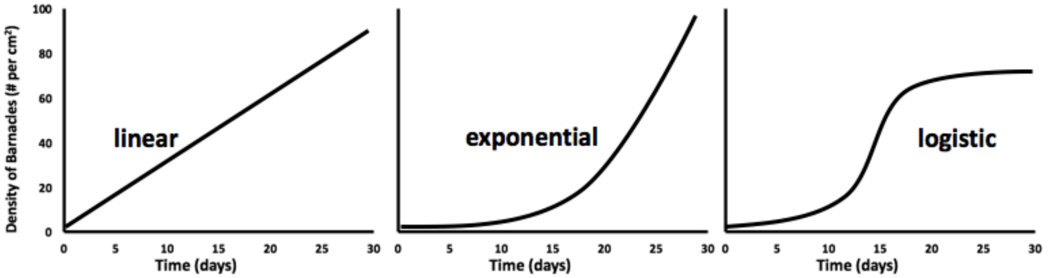
A) As N approaches K, the population growth rate increases.

B) As N approaches K, the population growth rate slows.

C) As N approaches K, the population growth rate stays constant.

Different mathematical models describe how population growth rate changes over time

$$\frac{dN}{dt} = \frac{N_2 - N_1}{t_2 - t_1} \qquad \frac{dN}{dt} = rN \qquad \frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$



A constant number of individuals are being added over time.	An increasing number of individuals are being added over time.	An increasing number of individuals are added initially, then a decreasing number of individuals added over time.
Population growth rate constant	**Population growth rate increasing**	**Population growth rate increasing, then decreasing**

Population models can be used to simplify the complexity of many different organisms

Bristlecone pine

Place picture of Bristlecone pine tree

Gray wolf

Place picture of a gray wolf

Bacteria in a flask

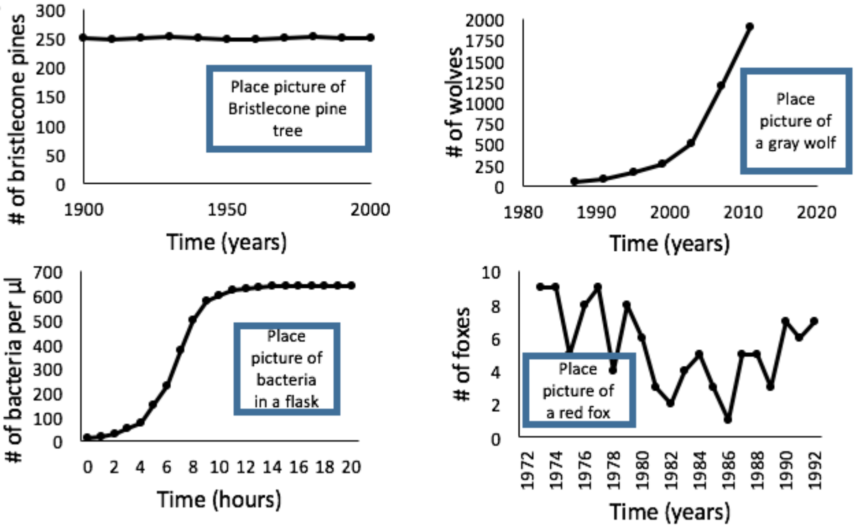
Place picture of bacteria in a flask

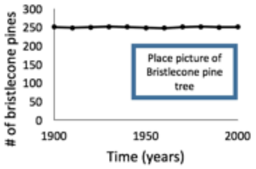
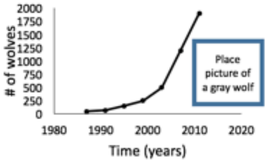
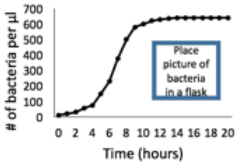
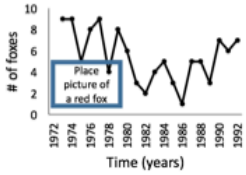
Red fox

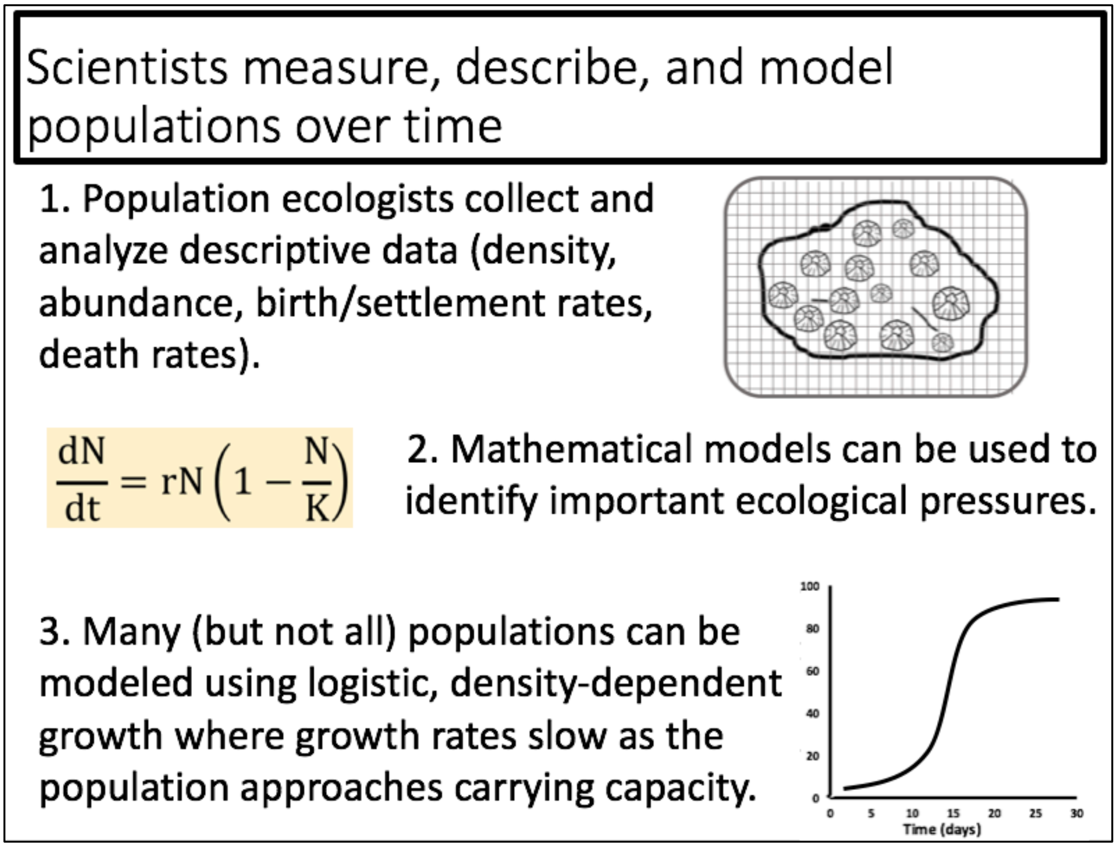
Place picture of a red fox

TPSQ4: Describe the following populations over time using the following guidelines:

1. Identify if density or abundance is shown.
2. Describe what is happening to the population (increasing, decreasing, etc.).
3. Identify if the graph most closely resembles linear, exponential, logistic growth, or other.



	1. Abundance 2. The population size is not changing over time. 3. Linear $\frac{dN}{dt} = \frac{N_2 - N_1}{t_2 - t_1}$
	1. Abundance 2. Population size is increasing at an increasing rate. 3. Exponential $\frac{dN}{dt} = rN$
	1. Density 2. Population size is increasing fast at first then slowing. 3. Logistic $\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$
	1. Abundance 2. The population size is fluctuating over time at varying rates. 3. Other



Scientists measure, describe, and model populations over time

1. Population ecologists collect and analyze descriptive data (density, abundance, birth/settlement rates, death rates).

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

2. Mathematical models can be used to identify important ecological pressures.

3. Many (but not all) populations can be modeled using logistic, density-dependent growth where growth rates slow as the population approaches carrying capacity.

APPENDIX B

RECOMMENDED INSTRUCTOR POPULATION ECOLOGY RESOURCES

Resource	**Description**
Connell JH. (1961). Effects of competition, predation by *Thias lapullus*, and other factors on natural populations of the barnacle *Balanus balanoides.* Ecol. Monog. 31:61-104.	The lesson is based on the experimental design and data collected as part of this seminal ecological study.
Cotgreave P, Forseth I. 2002. Introductory ecology. Blackwell Science. Chapter 6: 94-107.	Textbook used to guide development of the lesson.
Urry LA, Cain ML, Wasserman SA, Minorsky PV, Jackson RB, Reece JB. 2014. *Biology in focus*. Pearson. Chapter 40, 818-844.	Students in our class were asked to read Chapter 40: Population Ecology and the Distribution of Organisms before this lesson.
Population ecology. 2014. Retrieved from Nature website: http://www.nature.com/scitable/knowledge/population-ecology-13228167	An overview of population ecology with references to the scientific literature.
Hale BM, McCarthy, ML. 2005. An introduction to population ecology, JOMA, 1. Retrieved October 21, 2008 from http://www.maa.org/press/periodicals/loci/joma/an-introduction-to-population-ecology	A six-part instructor guide with student exercises.
Population growth: density effects [Lecture transcript]. 2016. Retrieved from Open Yale Courses website: http://oyc.yale.edu/ecology-and-evolutionary-biology/eeb-122/lecture-26	A 43-minute lecture on population growth and the effects of density.

Table B.1: Recommended instructor population ecology resources.

APPENDIX C

CLICKER QUESTIONS USED IN THE ACTIVITY AND DISTRIBUTION OF STUDENT ANSWERS

Clicker questions are presented below with the correct answer highlighted in blue and underlined (except for CQ2 where there is no correct answer). The distribution of student responses is indicated in parentheses. If students voted individually, talked to their neighbor, and voted again, the distribution of both votes is included (individual vote; following peer discussion).

CQ1: Which of the following statements describes the two study sites below?

A. Site 2 has a greater abundance and density than site 1 (16%; 4%)
B. Site 1 has a lower abundance but equal density to site 2 (10%; 2%)
C. Site 1 has a lower abundance but greater density than site 2 (70%; 93%)
D. The density and abundance are equal for both sites (4%; 1%)

CQ2: Select the growth curve that most resembles your prediction for barnacle population growth?

A. linear (23%; 7%)
B. exponential (43%; 33%)
C. logistic (34%; 60%)

CQ3: Select the growth curve that most resembles the plot you generated from the data provided.

A. linear (0%)
B. exponential (1%)
C. logistic (99%)

CQ4: The population growth rate (or change in population density) is:

A. increasing over time in all three growth curves (10%; 5%)
B. increasing over time in the linear and exponential growth curves only (15%; 9%)
C. constant over time in all three growth curves (1%; 0%)
D. constant in the linear growth curve and changes over time in the exponential and logistic growth curves (74%; 86%)

CQ5: If r=2 per day and K= 80 barnacles per cm^2, how does increasing the population size (N) affect the rate of population growth (dN/dt) in the logistic growth curve?

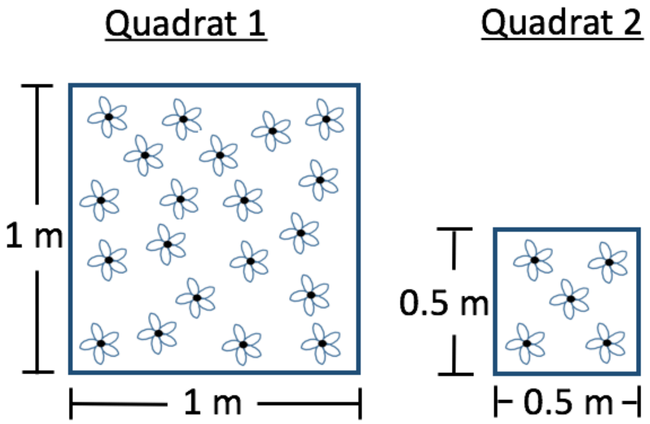
A. As N approaches K, the population growth rate increases (12%)
B. As N approaches K, the population growth rate slows (76%)
C. As N approaches K, the population growth rate stays constant (12%)

APPENDIX D

PRE/POST-TEST QUESTIONS AND DISTRIBUTION OF STUDENT ANSWERS BEFORE AND AFTER INSTRUCTION

Distribution of student responses to the pre/post-test are presented below with the correct answer highlighted in blue and underlined. Percentages are presented for the pre- and post-test (pre; post).

Ecologists used two quadrats (1m x 1m and 0.5m x 0.5m) to measure the density and abundance of sunflowers. Use this diagram to answer questions 1-2.



PPTQ1. Which of the following statements regarding the density of sunflowers in quadrats 1 and 2 do you most agree with?
A) The density in quadrat 1 is greater than in quadrat 2 (29%; 19%)
B) The density in quadrat 2 is greater than in quadrat 1 (10%; 17%)
C) The density in quadrats 1 and 2 are equal (57%; 63%)
D) The density cannot be calculated given the provided information (4%; 1%)

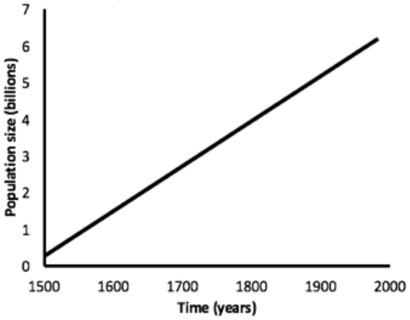
PPTQ2.Which of the following is true regarding the density and abundance of sunflowers in quadrat 2?
A) Density= 20 individuals; Abundance= 5 individuals per square meter (11%; 11%)
B) Density= 20 individuals per square meter; Abundance= 5 individuals (44%; 58%)
C) Density= 20 individuals per square meter; Abundance= 5 individuals per square meter (13%; 7%)
D) Density= 5 individuals; Abundance= 20 individuals per square meter (32%; 24%)

The table below summarizes the population size of humans world-wide from the year 1500 to 2000. Use this information to answer questions 3-4.

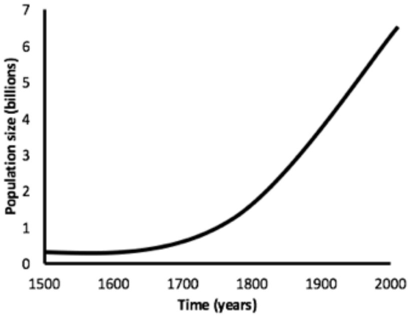
Year	**Population Size (billions)**
1500	**0.3**
1600	**0.3**
1700	**0.4**
1800	**1.9**
2000	**6.1**

PPTQ3. Which of the following growth curve is most like the data shown above?

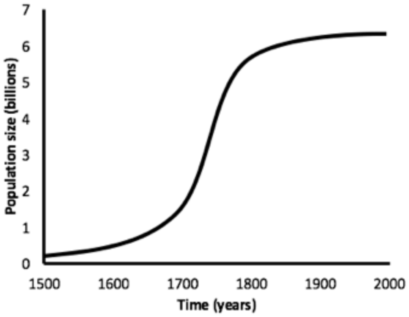
Graph #1



Graph #2



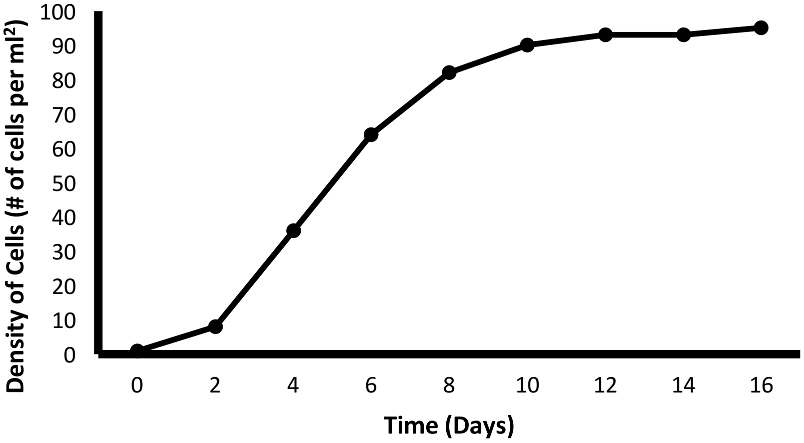
Graph #3



A) Graph # 1 (0%; 0%)
B) Graph # 2 (96%; 100%)
C) Graph # 3 (4%; 0%)

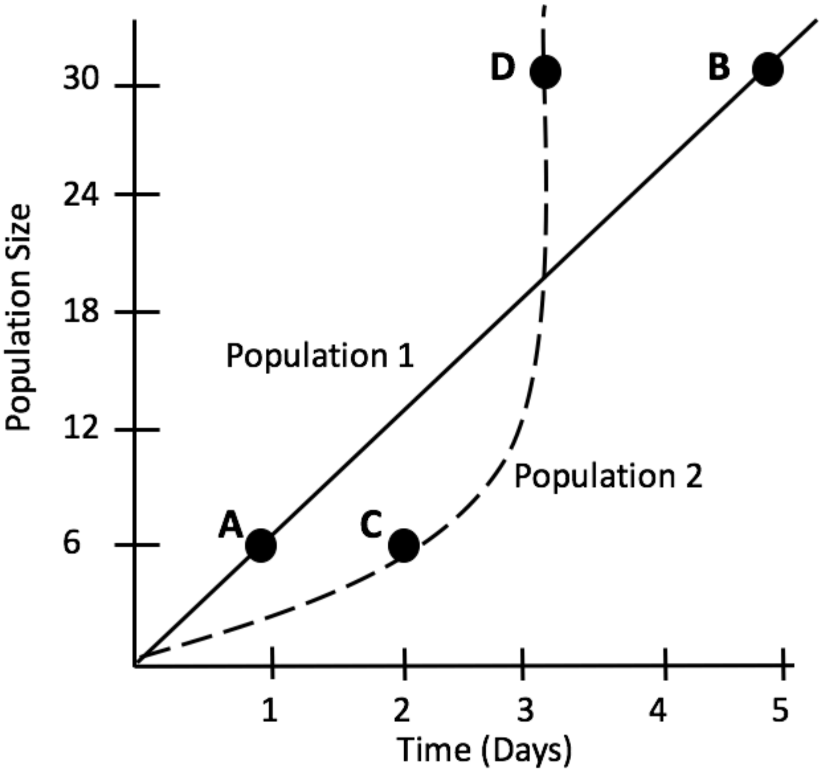
PPTQ4. In the growth curve you have selected, the growth rate is:
A) Increasing over time (97%; 99%)
B) Decreasing over time (0%; 0%)
C) Remaining constant over time (2%; 1%)
D) Increasing initially then decreasing over time (1%; 0%)

The density of paramecium growing in a flask is measured over time. Use this growth curve to answer question 5.



PPTQ5. In the growth curve above, the growth rate is:
A) Increasing over time (66%; 38%)
B) Decreasing over time (2%; 1%)
C) Remaining constant over time (9%; 9%)
D) Increasing initially then decreasing over time (24%; 52%)

Use the information provided in the growth curve to answer questions 6-8.

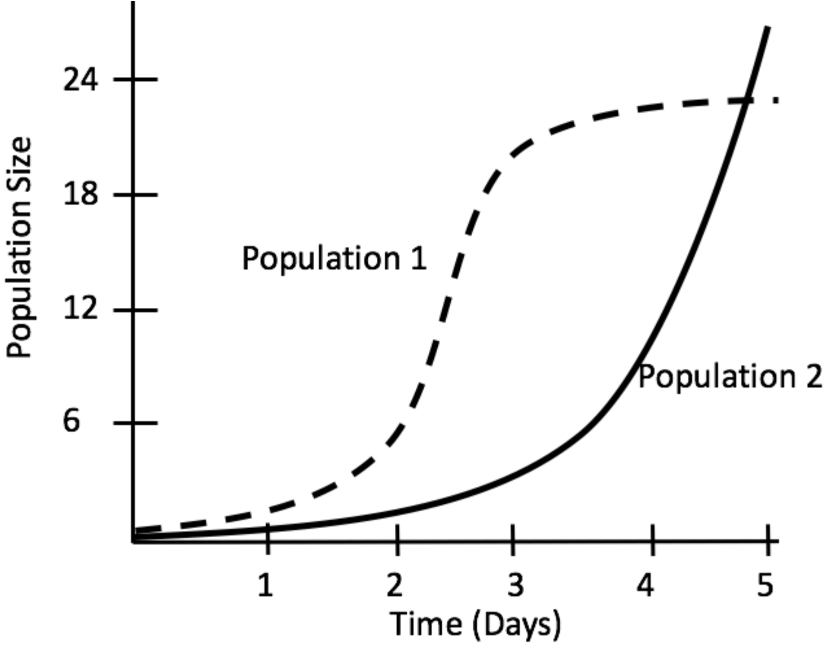


PPTQ6. For A and B which of the following is likely true?
A) The growth rate is greater at B than A (9%; 5%)
B) The growth rate is greater at A than B (3%; 2%)
C) The growth rate is equal at A and B (85%; 92%)
D) The growth rate cannot be determined between A and B (3%; 1%)

PPTQ7. For C and D which of the following is likely true?
A) The growth rate is greater at C than D (7%; 6%)
B) The growth rate is greater at D than C (90%; 93%)
C) The growth rate is equal at C and D (3%; 1%)
D) The growth rate cannot be determined between C and D (0%; 0%)

PPTQ8. For points A and C which of the following is likely true?
A) The growth rate is greater at A than C (65%; 73%)
B) The growth rate is greater at C than A (9%; 7%)
C) The growth rate is equal at A and C (17%; 3%)
D) The growth rate cannot be determined between A and C (9%; 7%)

Use the growth curve below to answer questions 9-10.



PPTQ 9. A change in the growth rate affected by carrying capacity (the maximum number of individuals a particular habitat can sustain indefinitely given the amount of available resources) is modeled in which of the following?

A) Population 1 only (83%; 96%)
B) Population 2 only (6%; 2%)
C) Both Population 1 and Population 2 (8%; 2%)
D) Neither Population 1 nor Population 2 (3%; 0%)

PPTQ 10. Which of the following populations are exhibiting density-dependent growth?

A) Population 1 only (47%; 63%)
B) Population 2 only (32%; 19%)
C) Both Population 1 and Population 2 (18%; 16%)
D) Neither Population 1 nor Population 2 (3%; 2%)

APPENDIX E

EXAM QUESTIONS AND DISTRIBUTION OF STUDENT ANSWERS

Distribution of student responses to the exam questions are presented below with the correct answer highlighted in blue and underlined.

EQ1. For a population of salmon where r=0.5 and K=500, at which of the following salmon population sizes will the growth rate be zero individuals per day?

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

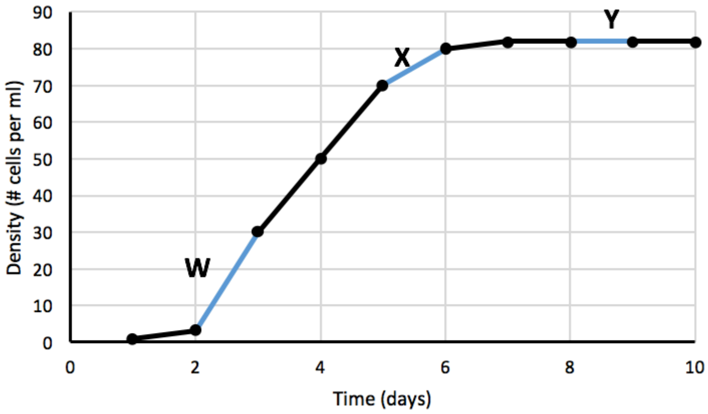
A) 1 individual (12%)
B) 100 individuals (5%)
C) 250 individuals (8%)
D) 500 individuals (75%)

EQ2. For the same population of salmon described above, at what population size will the growth rate be the fastest?

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

A) 1 individual (10%)
B) 250 individuals (70%)
C) 500 individuals (8%)
D) 750 individuals (12%)

The density of paramecium growing in a flask is measured over time. Use this growth curve to answer questions 3-4.



EQ3. At which segment on the graph is the population likely exhibiting the fastest growth rate?
A) Segment W (97%)
B) Segment X (3%)
C) Segment Y (0%)

EQ4. Which segment on the curve best shows the carrying capacity of the environment of the population shown?
A) Segment W (0%)
B) Segment X (1%)
C) Segment Y (99

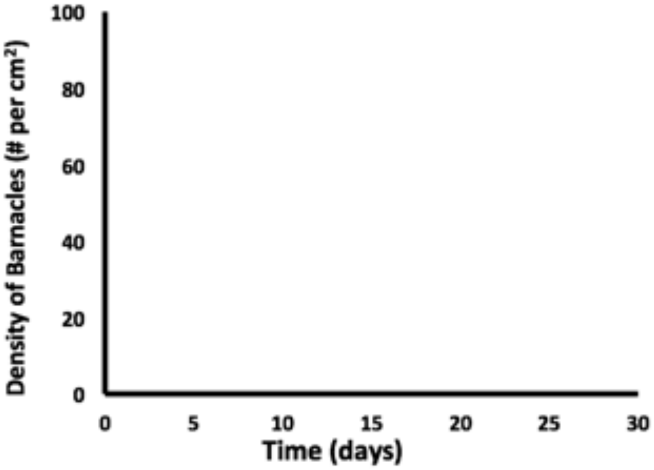
APPENDIX F

STUDENT WORKSHEET TO BE USED ALONG WITH THE ACTIVITY

CQ1. Use this space to calculate the density and abundance for the two study sites of barnacles.

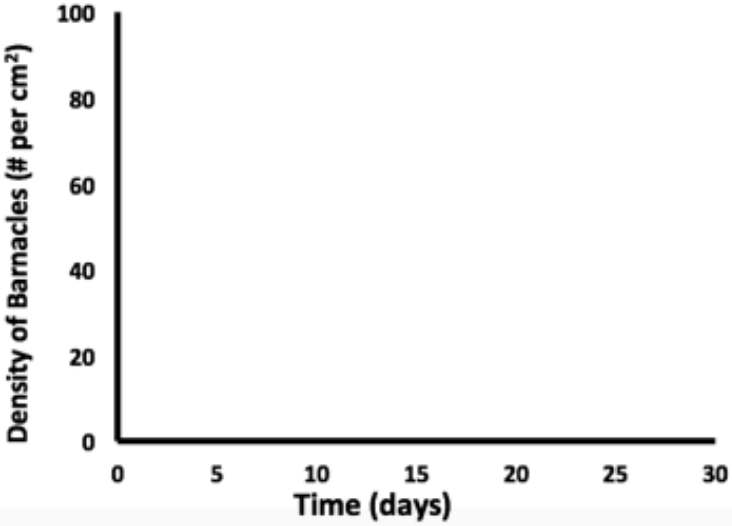
	Abundance	Density
Study site 1		
Study site 2		

TPSQ2. Draw what you would expect the growth of the population of barnacles to look like over the 30-day experiment. (On day 25, the barnacle population reached ~78 barnacles per cm^2).



TPSQ3. Plot the data from the actual experiment of barnacle population growth over time.

Time	Density of Barnacles (# per cm^2)
1	
5	
10	
15	
20	
25	
30	



CQ5. If r=2 per day per individual and K= 80 barnacles per cm^2, how does increasing the population size (N) affect the population growth rate (dN/dt) in the logistic model?

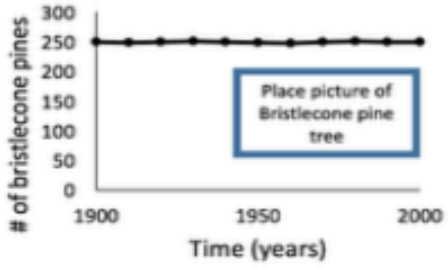
Population Size (N) (barnacles per cm^2)	dN/dt
1	
20	
40	
60	
70	
80	

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

In your own words, summarize how increasing the population size (N) affects the population growth rate (dN/dt):

TPSQ4. Use the spaces provided to describe the following populations.

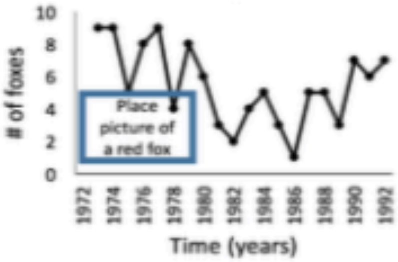
1. Identify if density or abundance is shown.
2. Describe what is happening to the population (increasing, decreasing, etc.).
3. Identify if the growth curve most closely resembles linear, exponential, logistic, or other.



1.

2.

3.



1.

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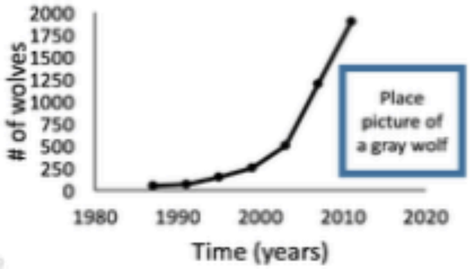

1.

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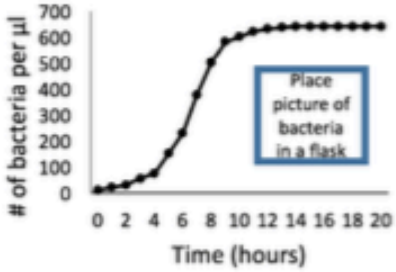

1.

2.

3.

APPENDIX G

ATTITUDINAL QUESTIONS ASKED OF STUDENTS AND DISTRIBUTION OF STUDENT RESPONSES

1.Participating in this activity increased my understanding of how ecologists measure and model population size:
A) Strongly disagree
B) Disagree
C) Agree
D) Strongly agree

2. How useful for your learning were the following components used in the population growth activity:
Clicker questions:
A) Not at all useful
B) Somewhat useful
C) Useful
D) Very Useful

Peer discussion
A) Not at all useful
B) Somewhat useful
C) Useful
D) Very Useful

Whole group discussion
A) Not at all useful
B) Somewhat useful
C) Useful
D) Very Useful

Provided worksheet
A) Not at all useful
B) Somewhat useful
C) Useful
D) Very Useful

3. Briefly describe what parts of the population growth in-class activity were useful for your learning.

4. Please provide constructive feedback to improve the population growth in-class activity.

5. Do you have any unanswered questions or areas of confusion after completing the in-class activity on modeling population growth? If so, please list them here.

BIOGRAPHY OF THE AUTHOR

Elizabeth Ann Trenckmann was born February 8th, 1993, in Pueblo, Colorado. She was raised in La Veta, Colorado. Elizabeth graduated from La Veta High school in 2011 and attended Maine Maritime Academy (MMA). At MMA, Elizabeth was a student in the Marine Biology Program. She pursued an undergraduate honors thesis, investigating the effects of changing salinity on the respiration rate of hermit crabs in the intertidal zone, under the supervision of Dr. Alan Verde. Elizabeth earned her Bachelor of Science degree in Marine Biology and a minor in Business and Logistics in May, 2015.

Elizabeth started graduate school at the University of Maine to get her Master of Science in Teaching degree. While at the University, she has been a teaching assistant for the School of Biology and Ecology. Elizabeth was the lead author for "An active-learning lesson that targets student understanding of population ecology," which was submitted for publication in the online journal article *CourseSource,* in 2017. Elizabeth is a candidate for the degree in the Master of Science in Teaching from the University of Maine in May, 2017.