QUBES Project

Quantitative Modeling by Biology UnderGraduate Students (QM BUGS)

University of Houston
Feb. 9, 2018

Robert Mayes

- Georgia Southern University

Joseph Dauer

- University of Nebraska

This project was supported in part by a grant from the NSF: **Culturally Relevant Ecology, Learning Progressions, and Environmental Literacy** (DUE-0832173), which we refer to as Pathways. Also by grants from the U.S. Department of Education and Georgia Office of Student Achievement: **Real STEM**. The contents of this presentation do not necessarily represent the policy of the NSF or U. S. Department of Education, and you should not assume endorsement by the Federal Government.

QUBES

Quantitative Undergraduate Biology Education and Synthesis

The **mission** of the QUBES (Quantitative Undergraduate Biology Education and Synthesis) project is to improve learning opportunities for all students enrolled in undergraduate biology courses by reflecting the centrality of quantitative approaches in modern biology.

The **five major QUBES initiatives** include:

– ***QUBES Consortium***: coordinating the efforts and resources of disparate communities invested in promoting quantitative biology education

– ***QUBES Faculty Mentoring Networks***: supporting faculty understanding and implementation of specific quantitative biology concepts and teaching approaches

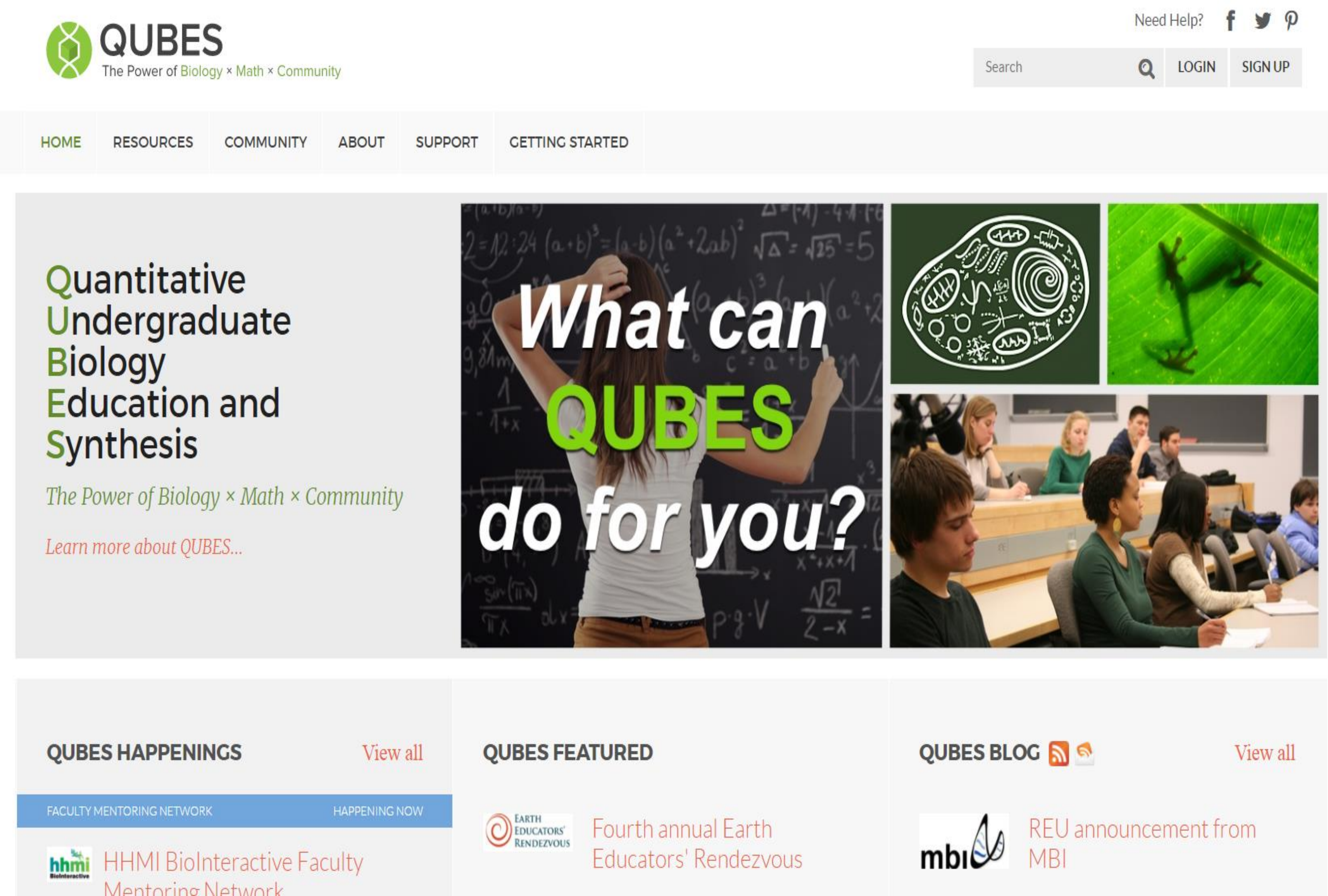
– ***QUBES Hub***: increasing the visibility, utility, and adoption of existing quantitative biology materials and the capacity for peer educator interaction https://qubeshub.org/

– ***QUBES Metrics***: quantifying and tracking faculty contribution to quantitative biology education scholarship

– ***Implementation Research***: studying and disseminating the features of QUBES that increase implementation success

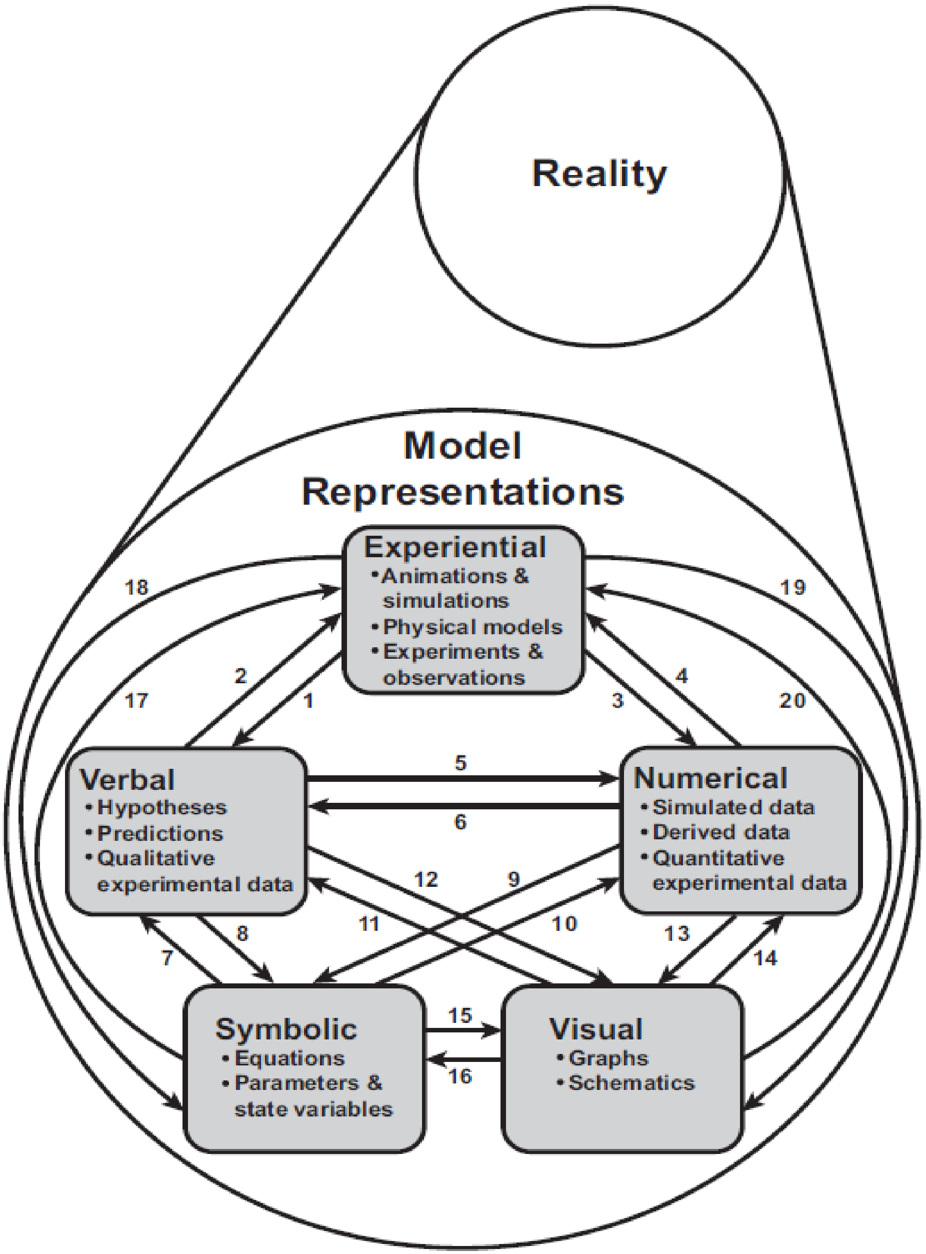
QUBES WORKING GROUP: **Kristen Jenkins, Sam Donovan, Drew LaMar, Carrie Diaz Eaton**, Melissa Aikens, Hannah Callender, Kam Dahlquist, Joe Dauer, Joe Redish, Robert Mayes, Gerg Goins, and John Jungck

QUBES Hub https://qubeshub.org/



QUBES
QM BUGS

- National Institute for Mathematical and Biological Synthesis (NIMBios): Teaching Quantitative Bio – Unpacking the Black Box Working Group
- Dauer and Mayes subgroup to examine impact of QBio on student biology understanding and QR ability
- QR Pilot Assessment (Sp16): White Nose Syndrome assessment focused on quantitative act and quantitative interpretation, attitudes. Pilot with University of Nebraska – Lincoln (n=121)
- Modeling Framework Paper published in PRIMUS (June 2016) moves focus to QM (Eaton, Highlander, Dahlquist, LaMar, Ledder, & Schugart)



Modeling Rule of 5

– Begin with Experiential component (active learning/authentic)
– Multiple model representations
– Teaching Strategy
  – Be explicit
  – Assist reflection
  – Give it context
  – Be interdisciplinary

https://qubeshub.org/groups/nimbios_wg_teachingquantbio/collections/a-interdisciplinary-framework-for-teaching-modeling--primus-paper

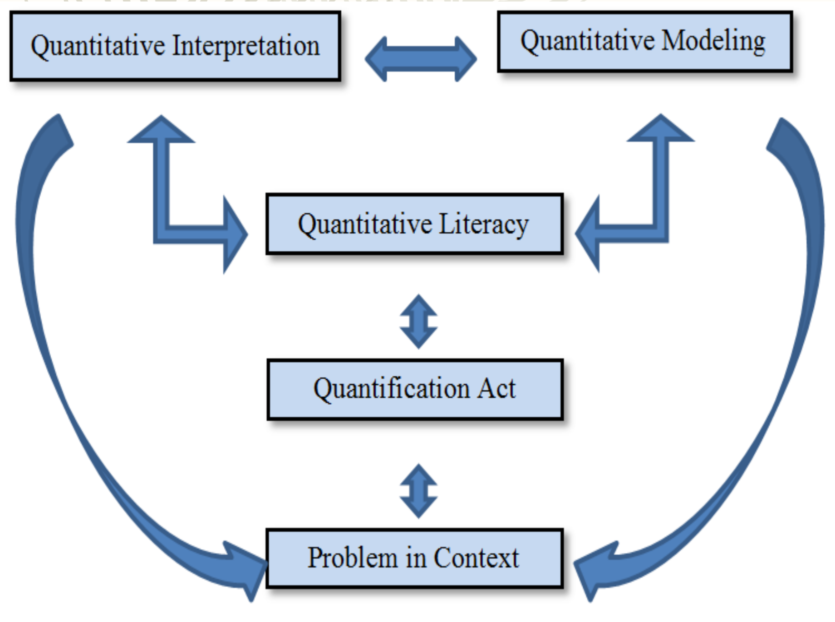
QUBES
QM BUGS

– QA-QL Assessment (Fl6): quantitative act, numeracy, measurement, proportional reasoning, probability and statistics, pilot with small group to assess items. New focus on QM, so not revised.
– QI-QM Assessment (Fl16): White Nose Syndrome (Ver. 2) revision, pilot with small group to test items. Focus on QM – committee review.
– QM Assessment (Fl17): Transpiration assessment. Significant revision with new plant context; tied to multiple modeling frameworks. Pilot with University of Nebraska-Lincoln and Georgia Southern University students (n=171).

QR Theoretical Framework (Mayes)

NSF Pathways Project

Quantification Act (QA): mathematical process of conceptualizing an object and an attribute of it so that the attribute has a unit measure, and the attribute's measure entails a proportional relationship (linear, bi-linear, or multi-linear) with its unit. **Quantitative literacy (QL):** use of fundamental mathematical concepts in sophisticated ways



Quantitative Interpretation (QI): ability to use models to make predictions and discover trends, which is central to a person being a citizen scientist

Quantitative Modeling (QM): ability to create representations to explain a phenomena

Modeling Theoretical Frameworks

- Three key stages of modeling
  - Model Formulation: QA, QM, Phenomenological and mechanistic models
  - Model Deployment: OI, test, evaluate, apply and validate model
  - Model Reasoning: metacognitive modeling, meta-modeling, and model-based reasoning

Model Formulation

Model Formulation	Analyze[1]		Decompose phenomena into quantifiable variables; explain an anchoring phenomena - introduce driving questions and phenomena for a particular concept (Schwarz)
	Inductive Reasoning[2]		Hypothesize how elements interact conceptually and quantitatively
	Model Construction[3]		Formulation of a quantitative model
	Quantitative Act	Variable Quantification[1]	Mental construct for object within context including both attributes and measure (Thompson); capacity to communicate quantitative account of solution, decision, course of action within context
		Variation[2]	Reason about covariation of 2 or more variables; comparing, contrasting, relating variables in the context of problem
		Quantitative Literacy[2]	Reasons with quantities to explain relationships between variables; proportional reasoning, numerical reasoning; extend to algebraic and higher math reasoning
		Context[3]	Situative view of QR within a community of practice (Shavelson); solves ill-defined problems in socio-political contexts using ad-hoc methods; informal reasoning within science context (Steen & Madison; Sadler & Zeidler)
	Quantitative Modeling	Create Model[3]	Ability to create a model representing a context and apply it within context; use variety of quantitative methods to construct model including least squares, linearization, normal distribution, logarithmic, logistic growth, multivariate, simulation models
		Statistical Analysis[3]	Conduct statistical inference to test hypothesis (Duschl)
		Refine Model[3]	Extend model to new situation; test and refine a model for internal consistency and coherence to evaluate scientific evidence, explanations, and results; (Duschl)
		Model Reasoning[3]	Construct and use models spontaneously to assist own thinking, predict behavior in real-world, generate new questions about phenomena (Schwarz)
	Phenomenological Model[3]		Models only represent the observable properties of the phenomenon, refrain from including the actual underlying mechanism (Louca and Zacharia). Model foregoes any attempt to explain why the variables interact the way they do, and simply attempts to describe the relationship.
	Mechanistic Model[3]		Model assumes complex system can be understood by examining workings of its individual parts and manner in which they are coupled. Mechanistic models typically have a tangible, physical aspect, in that system components are real, solid and visible.

Model Deployment

Model Deployment	Test Model		Investigate the phenomena and the interactions with model
	Model Evaluation		Assess degree of fit and ways to change model
	Model Application[4]		Use the model to predict or explain other phenomena
	Model Validation	Empirical Assessment	Model can explain all of the data and predict future experiments. Assess whether a model can explain all of the data at hand and predict the results of future experiments.
	Model Comparison[5]	Conceptual Assessment	Evaluate how well a model fits with other accepted models and knowledge
	Quantitative Interpretation	Trends[4]	Determine multiple types of trends including linear, power, and exponential trends; recognize and provide quantitative explanations of trends in model representation within context of problem
		Predictions[4]	Makes predictions using covariation and provides a quantitative account which is applied within context of problem
		Translation[5]	Translates between models; challenges quantitative variation between models as estimates or due to measurement error; identifies best model representing a context
		Revision[5]	Revise models theoretically without data, evaluate competing models for possible combination (Schwarz). Models are continually revised to probe new phenomena and account for new data.

Model Reasoning

Modeling Reasoning	Metacognitive Modeling Knowledge		Self-regulated learner explicitly identifies and describes the major steps of modeling process (Papaevripidou and Zacharia)
	Meta-modeling Knowledge	Nature of Models	Epistemic knowledge corresponding to understanding of the nature of models (Schwarz and White; Oh and Oh)
		Purpose and Utility of Model	Appreciation of the purpose and utility of models (Schwarz and White; Oh and Oh)
	Model-based Reasoning	Scientific Model	An idea or set of ideas that explains what causes a particular phenomenon in nature (Modeling for Understanding in Science Education – MUSE)
		Model as Ideas	Models are ideas not physical objects.
		Multiple Representations	Models are communicated through drawings, graphs, equations, three dimensional structures or words. The representations are distinct form the underlying model they purport to explain.
		Acceptability	Don't ask if a model is right, but if it is acceptable. Acceptability is based on model's ability to **explain** all the observations, **predict** the behavior of the system under a given manipulation, and **be consistent** with other knowledge about how the world works and with other models in science.
		Uniqueness	Not always possible or even desirable to exclude all but one model. Different models may account for different aspects of a phenomena.
		Development	An experiment and observations inform the development of a model.
		Application	A model is applied to **explain** reality, make **predictions**, and assessed for how well it explains real-world phenomena.
		Empirical or Theoretical Objects	Models are constituted by a set of objects which may be empirical (genes and alleles in meiotic model) or theoretical objects.
		Processes	Models are constituted of processes in which objects participate (segregation and assortment in meiotic model).
		Guide Future Work	Models influence and constrain the kinds of questions scientists ask about the natural world and the types of evidence they seek.

Quantitative Modeling in Biology for Undergraduate Students (QM BUGS) Diagnostic Assessment

- **Length:** Assessment consists of 30 questions: 19 multiple choice questions (5 options) address quantitative modeling understanding and 11 Lickert questions (1 NA, 2 Strong Disagree to 5 Strongly Agree) address student confidence about modeling in biology.
- **Time to complete:** up to 1 hour
- **Goal:** Assess undergraduate students' quantitative modeling abilities in biology.
- The QM BUGS assessment measures students' proficiency in quantitative modeling (QM - ability to develop a model). The assessment is intended to be given in undergraduate biology courses where quantitative skills are preparing students or actively engaging students in quantitative modeling within biological contexts.
- **Context:** Plant Transpiration

Question	Concept
Q1	Analyze - Anchoring Phenomena
Q2	Construct Model drawing
Q3	Meta-modeling - Purpose and nature of models
Q4	Meta-modeling - Purpose and nature of models
Q5	Inductive Reasoning - Hypothesis development, Variation
Q6	QA Variable Quantification
Q7	QA Variable Quantification measure
Q8	QA Variable Quantification measure
Q9	QM Create Model - phenomenological
Q10	QM Create Model
Q11	QM Create Model
Q12	QM Create Model from theory: mechanistic
Q13	Empirical Test of Model
Q14	Meta-modeling, Nature of Models
Q15	Model comparison
Q16	Model Application QI Trends
Q17	Model Application QI Translation
Q18	Model Application QI Prediction
Q19	QI Revision
Q20	Confidence - QA Variable quantification
Q21	Confidence - QM hypothesis development
Q22a	Confidence - QM hypothesis testing
Q22b	Confidence - QM hypothesis testing
Q22c	Confidence - QM hypothesis testing
Q23a	Confidence - QM creating and reasoning; QI refining
Q23b	Confidence - QM creating and reasoning; QI refining
Q23c	Confidence - QM creating and reasoning; QI refining
Q24	Confidence - QI predictions
Q25	Confidence - QI trends
Q26	Confidence - QI translation

Exemplar 1: Evolution & Ecology (sophomore level)

- Fall 2017: Observed 2 sections of BIOL 3133 using modified RTOP Observation protocol, 3 observations with session selected by faculty as highly quantitative
- Section 1: 42 students, 67% female, 24% African American
- Section 2: 40 students, 80% female, 30% African American
- 80 seat auditorium
- QR at arithmetic and algebraic level, not calculus

Quantitative Biology Topics

presented by instructor over three 90 minute class periods

- Density
- Dispersion (not QR based)
- Demographics: Life tables
- Survivorship curves
- Reproductive rates
- Exponential growth
- Logistic growth
- Evolution: diversity
- Population dynamics

Density (day 1)

- Population ecology defined, population, density, and dispersion.
- QR topic of population density discussed, ask students to define how to find density, though provides basic definition on slide of individuals per unit area or volume: $N = sn/x$.

Density

Although density can be calculated by counting all individuals in a population, in most cases it is impractical or impossible.

- Calculate population density by extrapolating counts from a sub-sampled area
- Estimate population size based on indicator such as nests, burrows, or fecal droppings
- Mark-recapture methods

$$N = \frac{sn}{x}$$

N = Population size

s = number of individuals tagged initially

n = number of individuals caught in 2nd subsample

X = number of marked individuals in 2nd capture

Density Task Instructional Reflection

- What were your questions as a “student” concerning completing the task?
- What instructional strategies would you use to teach the QR aspects of this task?

Density

Scientists studying Hector's dolphins are trying to determine its population density. They identify 180 individuals by photographing their distinctive dorsal fins from boats. After waiting a few weeks, the group photographs a group of Hector's dolphins several hundred miles downward of their migration. They photograph 44 dolphins, 7 of which were previously photographed. What is the estimated population size?

$$\frac{X}{n} = \frac{S}{N} \quad \text{so} \quad N = \frac{Sn}{X}$$

$$N = \frac{180 * 44}{7} = 1{,}131$$

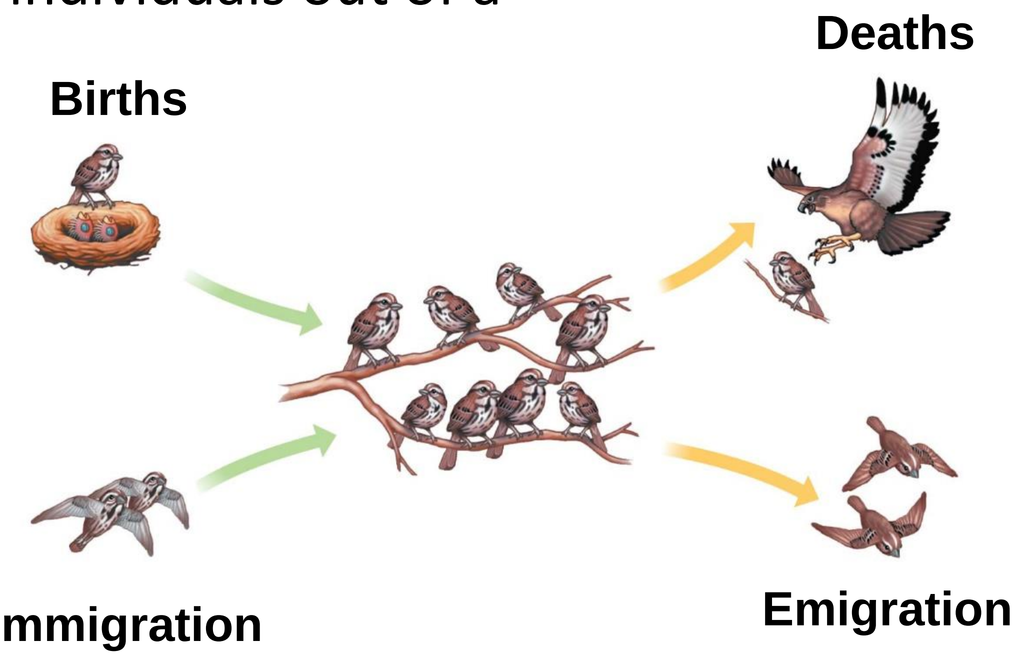
Density

Suppose that wildlife workers capture 328 penguins on an island, mark them, and allow them to mix with the rest of the population. Later, they capture 200 penguins, 64 of which are marked. What is the estimate for the number of penguins on the island?

Density

Density is not a static property, constantly changing based on individuals being added or removed from the population.

- **Immigration:** influx of new individuals from another population
- **Emigration:** Movement of individuals out of a population
- **Birth:** Individuals added to population (all forms of reproduction)
- **Death:** Individuals removed from population.



My observations

- He provides the formula and talks them through it, then provides an example problem of dolphins. Does not have them derive the model, just provides and interprets the example for them.
- Then gives students an example to do at seats on penguins. Students work at seats on the problem individually, no sharing of ideas. After short time he answers the question, not a student.
- Provides great real world examples from his own experience. Density change through immigration, emigration, birth and death. Opportunity for model revision. Does not have students determine or explain the variables.

QM BUGS Assessment Anchoring Phenomena

- QM Bugs Assessment Items are removed since research with assessment is in progress.

Density Anchor: have students run a sampling simulation such as this one
http://www.radford.edu/~jkell/mark_rec103.pdf
Students explore concept and make conjectures. Students discover the formula for capture-release method rather than being given the model.

QM BUGS Assessment Constructing Box Model

QM Bugs Assessment Items are removed since research with assessment is in progress.

Drawing conceptual models based on observations of anchoring phenomena is a good first step in having students build models. Have students construct a box model for population density change. They have to identify reservoirs and flows – immigration, emigration, birth, death – and indicate flow between the reservoirs. Quantify the model more by providing data for a reservoirs and flows between reservoirs.

QM BUGS Assessment Purpose and Nature of Models

QM Bugs Assessment Items are removed since research with assessment is in progress.

Epistemic knowledge corresponding to understanding of the nature of models (Schwarz and White; Oh and Oh). Discuss the nature of the density module with students including the quantitative mathematical representation and related science concepts.

Demographics

- Demography introduced as study of vital statistics of a population and how they change over time, uses life tables which is the QR topic he is setting up.
- Discusses static life table (data collected at all ages at one time), death table, semelparity (1 reproductive event in lifetime) and iteroparity (multiple reproductive events). Discussion of data collection with students, models of data collection.

Demographics

The factors that influence population density and dispersion patterns also can influence other characteristics of a population.

- **Demography:** study of the vital statistics of a population and how they change over time.
- Most often done using life tables

A life table is an age-specific summary of the survival pattern of a population

- Initially developed in 1950s for insurance companies
- **Cohort:** a group of individuals of the same age

Demographics

A cohort life table can be constructed from counts/estimates of all individuals in a population as it progresses through time.

- The first column (x) specifies the age class while the second column (n_x) is the number of individuals at start of each age class.

Stage (x) in months	No. Living at beginning of stage (n_x)
0	44,000
1	9513
2	3529
3	2922
4	2461
5	2300
6	2250
7	2187

Demographics

From this data, we can calculate several life history features

- Proportion surviving to each age class (l_x); divide each n by n_0
- Portion of individuals dying (d_x); $l_x - (l_x+1)$

Stage (x)	No. Living at beginning of stage (n_x)	Portion of original cohort surviving at each stage (l_x)	Portion of original cohort dying (d_x) during each stage.
0	44,000	1	.784
1	9513	.216	.136
2	3529	.080	.014
3	2922	.066	.010
4	2461	.056	.004
5	2300	.052	.001
6	2250	.051	.001
7	2187	.050	-

Demographics

From this data, we can calculate several life history features

- Stage specific mortality rate (q_x); dx/lx

Stage (x)	n_x	l_x	d_x	q_x
0	44,000	1	.784	.784
1	9513	.216	.136	.629
2	3529	.080	.014	.172
3	2922	.066	.010	.158
4	2461	.056	.004	.065
5	2300	.052	.001	.022
6	2250	.051	.001	.028
7	2187	.050	-	-

Next three columns used to determine the population's reproductive output.

- F_x: number of offspring produced at each age
- m_x: Individual fecundity, offspring produced per surviving individual (F_x/n_x)
- $l_x m_x$: number of offspring produced per original individual at each age

Stage (x)	n_x	l_x	d_x	q_x	F_x	m_x	$l_x m_x$
0	44,000	1	.784	.784	0	0	0
1	9513	.216	.136	.629	0	0	0
2	3529	.080	.014	.172	0	0	0
3	2922	.066	.010	.158	0	0	0
4	2461	.056	.004	.065	0	0	0
5	2300	.052	.001	.022	0	0	0
6	2250	.051	.001	.028	0	0	0
7	2187	.050	-	-	45,617	20.86	1.043

By summing up $l_x m_x$ across all ages, you can calculate the **net reproductive rate (R_0)**.

One can think of R_0 as the population's replacement rate. If R_0 = 1.0, than population is just replacing itself. If R_0 > 1.0, population is growing while R_0 < 1.0 means population is declining.

Stage (x)	n_x	l_x	d_x	q_x	F_x	m_x	$l_x m_x$
0	44,000	1	.784	.784	0	0	0
1	9513	.216	.136	.629	0	0	0
2	3529	.080	.014	.172	0	0	0
3	2922	.066	.010	.158	0	0	0
4	2461	.056	.004	.065	0	0	0
5	2300	.052	.001	.022	0	0	0
6	2250	.051	.001	.028	0	0	0
7	2187	.050	-	-	45,617	20.86	1.043

Next important summary variable is **T (generation time)** or the time between the birth of one cohort and the birth of their offspring.

$$T = \frac{\Sigma x l_x m_x}{R_0}$$

Stage (x)	n_x	l_x	d_x	q_x	F_x	m_x	$l_x m_x$	$x l_x m_x$
0	44,000	1	.784	.784	0	0	0	0
1	9513	.216	.136	.629	0	0	0	0
2	3529	.080	.014	.172	0	0	0	0
3	2922	.066	.010	.158	0	0	0	0
4	2461	.056	.004	.065	0	0	0	0
5	2300	.052	.001	.022	0	0	0	0
6	2250	.051	.001	.028	0	0	0	0
7	2187	.050	-	-	45,617	20.86	1.043	7.301

In this case, T equals 7 months.

The last important variable is r, **per capita rate of increase**

$$r = \frac{\ln(R_0)}{T}$$

Stage (x)	n_x	l_x	d_x	q_x	F_x	m_x	$l_x m_x$	$x l_x m_x$
0	44,000	1	.784	.784	0	0	0	0
1	9513	.216	.136	.629	0	0	0	0
2	3529	.080	.014	.172	0	0	0	0
3	2922	.066	.010	.158	0	0	0	0
4	2461	.056	.004	.065	0	0	0	0
5	2300	.052	.001	.022	0	0	0	0
6	2250	.051	.001	.028	0	0	0	0
7	2187	.050	-	-	45,617	20.86	1.043	7.301

Per capita rate of increase = ln (1.043)/7 = .006

Demographics Task Instructional Reflection

- What were your questions as a “student” concerning completing the task?
- What instructional strategies would you use to teach the QR aspects of this task?

Demographics

It is important to note that although R_0 and r seem similar, they are different.

Net reproductive rate

If $R_0 > 1$; population is increasing in size
If $R_0 < 1$; population is decreasing in size
If $R_0 = 1$; population size will remain constant

Per capita rate of increase

If $r > 0$; population is increasing in size
If $r < 0$; population is decreasing in size
If $r = 0$; population size will remain constant

Demographics

Life tables may be static (also called vertical), they provide a "snapshot" of a population at all life stages at same time.

However, they can be dynamic (horizontal). These follow one cohort, say the progeny of a single breeding season, throughout their lives.

- Much harder to do
- Take more time and money

The two types of tables are theoretically identical assuming

(A) the environment is not changing

(B) population is at equilibrium (B=D; I=E)

My observations

- Ask students for example of semelparity with class wide question, a couple respond then he provides examples.
- Provides a life table of data with time (x) vs. population at time (n(x)). Provides model and interprets it. Then adds two more variables: portion of original cohort surviving at each stage (l(x)) and portion of original cohort dying at each age (d(x)). He provides variables and interprets them for the students. These are functions of time in a data table model.
- Stage specific mortality rate $q(x) = d(x)/l(x)$. Again he provides the model and interprets the model for the student. Introduces three more variables: f(x) number of offspring produced at each age, m(x) individual fecundity – offspring produced per surviving individual (f(x)/n(x)). l(x)m(x) number of offspring produced per original individual at each age. Provides interpretation of this last variable with respect to growth of population. Summing up this variable across time is net reproductive rate (R(0)). Does ask students what it means if $R > 0$, $R = 0$, or $R < 0$, but instructor is doing most of the interpretation.
- Generation time T is sum of x time l(x) times m(x) divided by R(0). He provides the formula and interprets it, no questions for students. Per capita rate of increase r is ln(R(0)/T.
- Brings in natural log function. Students likely do not understand why the formulas are what they are – how they came about. They will use them as rules without much understanding of why.
- Provides a life table and has students practice doing the calculation of the variables in the table. Students are discussing the example problem he provided and asking questions on the life table, particularly on how to find the year 0 value for the variables. Ask students to provide the R(0) value and interpret the value in terms of the biology context. Time running out, so shows the solution to the entire table and the values of the variables R(0), T, and r. Tells them the number represents Wolverine populations in Alaska.

QM BUGS Assessment Phenomenological Model

QM Bugs Assessment Items are removed since research with assessment is in progress.

QM Bugs Assessment Items are removed since research with assessment is in progress.

Phenomenological models only represent the observable properties of the phenomenon, refrain from including the actual underlying mechanism (Louca and Zacharia). Model foregoes any attempt to explain why the variables interact the way they do, and simply attempts to describe the relationship. Students discuss in small groups how to find the formulas in the life table, explaining the mathematical relationships related to the science, rather than just being provided the formulas.

Life tables (day 2)

- Instructor provides a population table as a hands-on practice problem. Students work individually on problem.
- Given stage (x), n(x) and m(x) asked to calculate l(x) for a wolverine population.
- Asked to find net reproductive rate (R(0)) and per capita rate of growth r. Are to determine if population is growing or declining.
- No review of the material, students work off of notes with calculators. No student questions, they just work on calculation.

Please take a look at the cohort life table of the Alaskan Wolverine below. What is the net reproductive rate for this population (R_0)? What is the per capita rate of growth (r)? Is the population growing or declining?

Stage (x)	n_x	l_x	m_x	
0	608		0.00	
1	487		0.00	
2	480		0.00	
3	472		0.08	
4	465		0.07	
5	447		0.12	
6	419		0.19	
7	390		0.07	
8	346		0.07	
9	268		0.05	
10	154		0.03	
11	59		0.00	
12	4		0.00	
13	2		0.00	
14	0		0.00	

Life Tables Task Instructional Reflection

- What were your questions as a “student” concerning completing the task?
- What instructional strategies would you use to teach the QR aspects of this task?

Stage (x)	n_x	l_x	M_x	l_xM_x	Xlx mx
0	608	-	0.00	0.000	0
1	487	0.80	0.00	0.000	0
2	480	0.79	0.00	0.000	0
3	472	0.78	0.08	0.062	.186
4	465	0.76	0.07	0.053	.212
5	447	0.74	0.12	0.089	.445
6	419	0.69	0.19	0.131	.786
7	390	0.64	0.07	0.045	.315
8	346	0.57	0.07	0.040	.32
9	268	0.44	0.05	0.022	.198
10	154	0.25	0.03	0.008	.08
11	59	0.10	0.00	0.000	
12	4	0.01	0.00	0.000	
13	2	0.00	0.00	0.000	2.542
14	0	0.00	0.00	0.000	5.65

Please take a look at the cohort life table of the Alaskan Wolverine below. What is the net reproductive rate for this population (R_0)? What is the per capita rate of growth (r)? Is the population growing or declining? Draw a survivorship curve for this population and explain what type of survivorship it exhibits.

My observations

- No student questions, they just work on calculation. A couple of students ask instructor for individual help, he circulates through the room. Also have several pairs of students talking about the problem after about 10 minutes. After 15 minutes instructor begins asking class wide questions.
- Ask students to **QA** on n(x) but quickly interprets for them that it indicates multiple life breeding. Ask them how they calculate l(x), student responses correctly, then he interprets several values of l(x) for them. Tells them how to calculate next value, ask students what variable R(0) is telling them about population growth or decay, several respond correctly it is declining. Leads students through calculation of r on the white board. Discusses generation time calculation, asks students to respond, only two respond they got that far. He displays the calculation on the population table.
- Asks students to interpret generation time of 5.65. So students are provided opportunity to **QI**. Several student questions about the appropriate calculation procedures and interpretation of the results. Relates the generation time to human populations, Gen X for example. More student generated questions about interpreting the model, instructor provides good variety of examples including salmon. Calculates the per capita rate of growth r = -0.141 and interprets the variable for students. More student generated questions about the meaning of r.

QM BUGS Assessment
QA Variable Quantification Object

6. Select all of the following relationships that are true for transpiration? (QA Variable Quantification - a, b, c, d and e)
   a. **Temperature** increase triggers plant to open stomata which increases transpiration rate
   b. **Relative humidity** of air surrounding plant drops making it harder for water from plant to evaporate
   c. **Wind and air movement** move saturated air away from leave resulting in decreased transpiration
   d. **Light** makes photosynthesis possible, plant opens stomata to take in CO_2 which decreases transpiration
   e. **Soil moisture** availability is low so plant transpires more water

Quantitative act includes variable quantification as an object with attributes and measure, covariation of variables, and context. Students are provided context and identify variables, including measure and attributes, rather than being given the life table. Let then determine which objects are important for the problem.

QM BUGS Assessment
QA Variable Quantification Measure

QM Bugs Assessment Items are removed since research with assessment is in progress.

Quantitative act includes variable quantification as an object with attributes and measure, covariation of variables, and context. Students determine the measures associated with variables, use dimensional analysis to assist in understanding relationships between variables.

Survivorship Curves

- Survivorship curve as plot of n(x) vs. x on log scale. Provides table model then graph model of age vs. number of survivors, males and females graphed separately.

Survivorship Curves

A **survivorship curve** is a graphical way of representing the data presented in a life table.

- Essentially the graph is a plot of n_x vs x (on log scale)

Table 53.1 Life Table for Belding's Ground Squirrels (*Spermophilus beldingi*) at Tioga Pass, in the Sierra Nevada of California*

Age (years)	FEMALES					MALES				
	Number Alive at Start of Year	Proportion Alive at Start of Year	Number of Deaths During Year	Death Rate†	Average Additional Life Expectancy (years)	Number Alive at Start of Year	Proportion Alive at Start of Year	Number of Deaths During Year	Death Rate†	Average Additional Life Expectancy (years)
0–1	337	1.000	207	0.61	1.33	349	1.000	227	0.65	1.07
1–2	252‡	0.386	125	0.50	1.56	248‡	0.350	140	0.56	1.12
2–3	127	0.197	60	0.47	1.60	108	0.152	74	0.69	0.93
3–4	67	0.106	32	0.48	1.59	34	0.048	23	0.68	0.89
4–5	35	0.054	16	0.46	1.59	11	0.015	9	0.82	0.68
5–6	19	0.029	10	0.53	1.50	2	0.003	2	1.00	0.50
6–7	9	0.014	4	0.44	1.61	0				
7–8	5	0.008	1	0.20	1.50					
8–9	4	0.006	3	0.75	0.75					
9–10	1	0.002	1	1.00	0.50					

Source: P. W. Sherman and M. L. Morton, Demography of Belding's ground squirrel, *Ecology* 65:1617–1628 (1984).

*Females and males have different mortality schedules, so they are tallied separately.

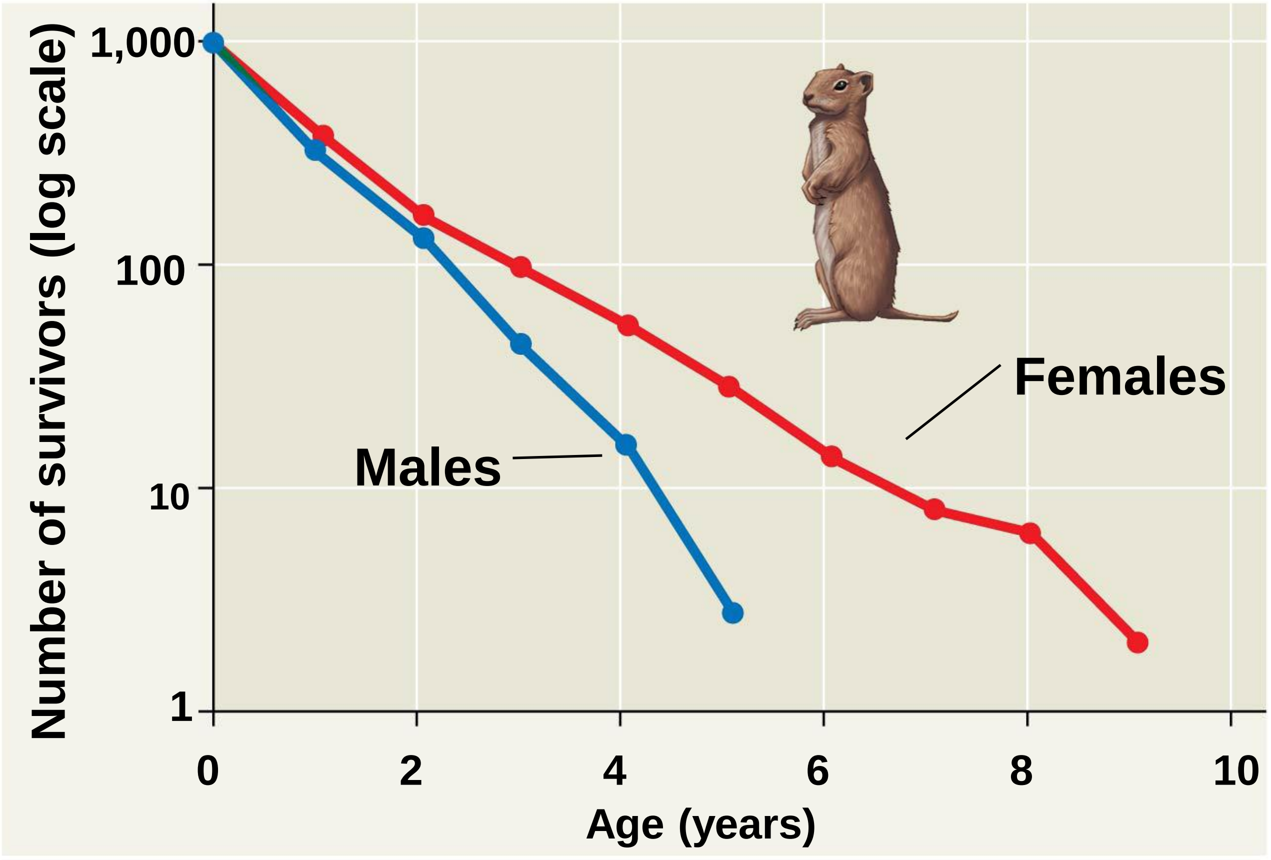
†The death rate is the proportion of individuals dying during the specific time interval.

‡Includes 122 females and 126 males first captured as 1-year-olds and therefore not included in the count of squirrels age 0–1.

Survivorship Curves

A **survivorship curve** is a graphical way of representing the data presented in a life table.

- usually survivorship curve extrapolated to begin with cohort of convenient size (1000 individuals)



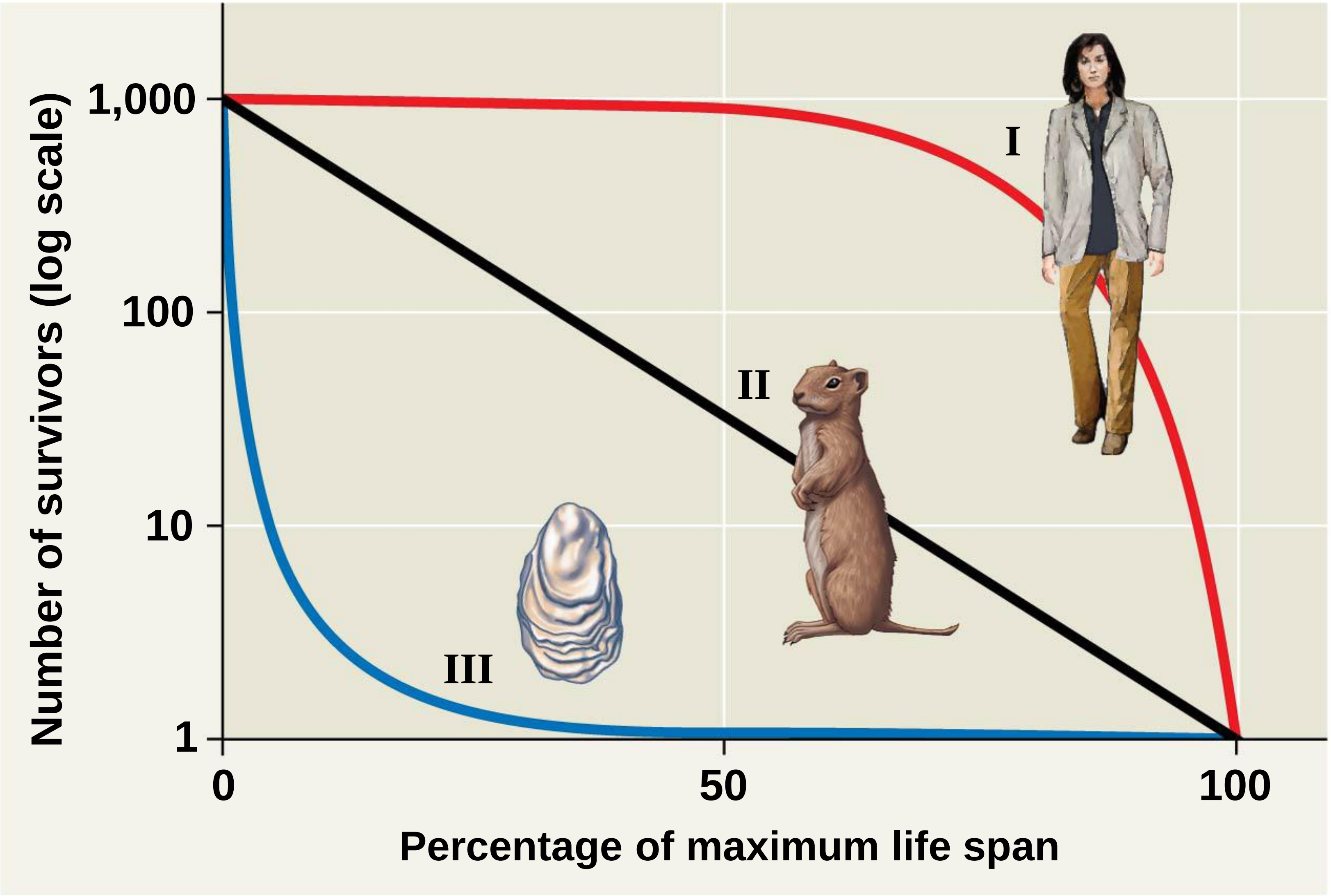
Survivorship Task Instructional Reflection

- What were your questions as a “student” concerning completing the task?
- What instructional strategies would you use to teach the QR aspects of this task?

Survivorship Curves

Survivorship curves can be classified into three general types (idealized)

- Type I: Low death rates during early and middle life and an increase in death rates among older age groups
- Type II: A constant death rate over the organism's life span
- Type III: High death rates for the young and a lower death rate for survivors



Number of survivors (log scale)
1,000
100
10
1
0
50
100
Percentage of maximum life span
I
II
III

My observations

- Asks students to interpret the two graphs, several respond with conjectures. Model comparison, linear trend both discussed so QI. Instructor continues with more indepth interpretation of the graphs and the table models.
- Type I, II and III death rates discussed, compares to different species: humans are type 1 with low infant death rates and higher older death rates as compared to insects which are type III and have high infant mortality rate and lower older death rates. Student asks conceptual/application question about death rate types, faculty responds. Shows graphical model of death rate types I, II and III on same graph, but does not provide student opportunity to generate a graph, good opportunity for QM missed.
- Graphs are linear (type II like prairie dog), but nonlinear models for type I and III. Uses white board to provide more examples of death types, including birds who decline quickly after hatching but then get more linear, also zigzag graph of species who molt.

QM BUGS Assessment QI Model Comparison

QM Bugs Assessment Items are removed since research with assessment is in progress.

QM BUGS Assessment
QI Model Comparison

- Students compare the table to the graph. What variables were plotted and why? Why were other variables not used (QA)?
- Why was a log graph used? What is a log graph anyway?
- Why provide both a table and graph model? Which model is better for what purpose?

QM BUGS Assessment
QI Trends

QM Bugs Assessment Items are removed since research with assessment is in progress.

QI includes using models to explore trends, and make predictions. Have students discuss in pairs the trends they observe in the survivorship table and graph. Is the graph better for seeing trends? Have students extend trends to discussion of Type I, II, and III, let them sketch out the trends for these types rather than providing the graph.

Reproductive Rates

- Per capita rate of increase formula is provided and explained, drops immigrants and emigrants and focus on only births and deaths: delta N/delta t = B – D.
- Asks students to think about B = bN and D = mN where annual rates b and m are considered. Includes quantitative concepts of rate.

Reproductive Rates

Demographers studying sexually reproducing species generally ignore males.

- Usually sustainability is function of females ability to give rise to more females

Reproductive table, or fertility schedule, is an age-specific summary of the reproductive rates in a population.

- Calculated by measuring the reproductive output of a cohort from birth until death

Table 53.2 Reproductive Table for Belding's Ground Squirrels at Tioga Pass

Age (years)	Proportion of Females Weaning a Litter	Mean Size of Litters (Males + Females)	Mean Number of Females in a Litter	Average Number of Female Offspring*
0–1	0.00	0.00	0.00	0.00
1–2	0.65	3.30	1.65	1.07
2–3	0.92	4.05	2.03	1.87
3–4	0.90	4.90	2.45	2.21
4–5	0.95	5.45	2.73	2.59
5–6	1.00	4.15	2.08	2.08
6–7	1.00	3.40	1.70	1.70
7–8	1.00	3.85	1.93	1.93
8–9	1.00	3.85	1.93	1.93
9–10	1.00	3.15	1.58	1.58

Source: P. W. Sherman and M. L. Morton, Demography of Belding's ground squirrel, *Ecology* 65:1617–1628 (1984).

*The average number of female offspring is the proportion weaning a litter multiplied by the mean number of females in a litter.

Per Capita Rate of Increase

Change in population size	$=$	Births	$+$	Immigrants entering population	–	Deaths	–	Emigrants leaving population

If immigration and emigration are ignored, a population's growth rate (per capita increase) equals births minus deaths.

$$\frac{\Delta N}{\Delta t} = B - D$$

More appropriately, births and deaths can be expressed as the average number of births and deaths per individual over a specified time frame.

$B = bN$ = where b annual per capita birth rate

$D = mN$ = where m annual per capita death rate

Reproductive Rate Task Instructional Reflection

- What were your questions as a “student” concerning completing the task?
- What instructional strategies would you use to teach the QR aspects of this task?

Per Capita Rate of Increase

More appropriately, births and deaths can be expressed as the average number of births and deaths per individual over a specified time frame.

$B = bN$ = where b is annual per capita birth rate

$D = mN$ = *where m* is annual per capita death rate

For example, there are 34 births per year in a population of 1,000 individuals. Annual per capita birth rate is 34/1000 or .034. If population only had 500 individuals, how many births would you expect in a give year

$B = bN$ = (0.034)(500) = 17 births per year

Based on per capita birth and death rates, the population growth equation can be revised…

$$\frac{\Delta N}{\Delta t} = bN - mN$$

Population ecologists are most interested in the difference between per capita birth and death rates (determines the rate of increase or decrease throughout a population). This difference is denoted r (per capita rate of increase).

$$\frac{\Delta N}{\Delta t} = rN$$

Zero population growth (ZPG) occurs when r = 0. Births and deaths balance each other out exactly. Equation only for a discrete, fixed time interval with no E or I.

My observations

- Uses population of Georgia as an example that relates to students place. 10.3 million population with annual birth rate of 0.03 and death rate of 0.008. Works out example on the white board for students. Gives increase of 0.301 million in population.
- Confirms with generic question “Does that make sense?” which instructor uses a few times in the class. No students respond with other than a mumble.
- Introduces zero population growth when r = 0 and birth and deaths are balanced. Provides equation model and ask students to interpret the rate r and what it means, one student responds r is not limited.

QM BUGS Assessment Mechanistic Model Creation

QM Bugs Assessment Items are removed since research with assessment is in progress.

Mechanistic model assumes complex system can be understood by examining workings of its individual parts and manner in which they are coupled. Mechanistic models typically have a tangible, physical aspect, in that system components are real, solid and visible. Let students create population growth model based on known theories?

QM BUGS Assessment
QI Prediction

QM Bugs Assessment Items are removed since research with assessment is in progress.

QI includes using models to make predictions. Students use the population growth equation to predict a future population growth value. Students predict when population growth is 0 and explain why this is significant.

Exponential Growth

- Instructor presents exponential growth curve with number of generations vs. population size, elephants as example.

Exponential Growth

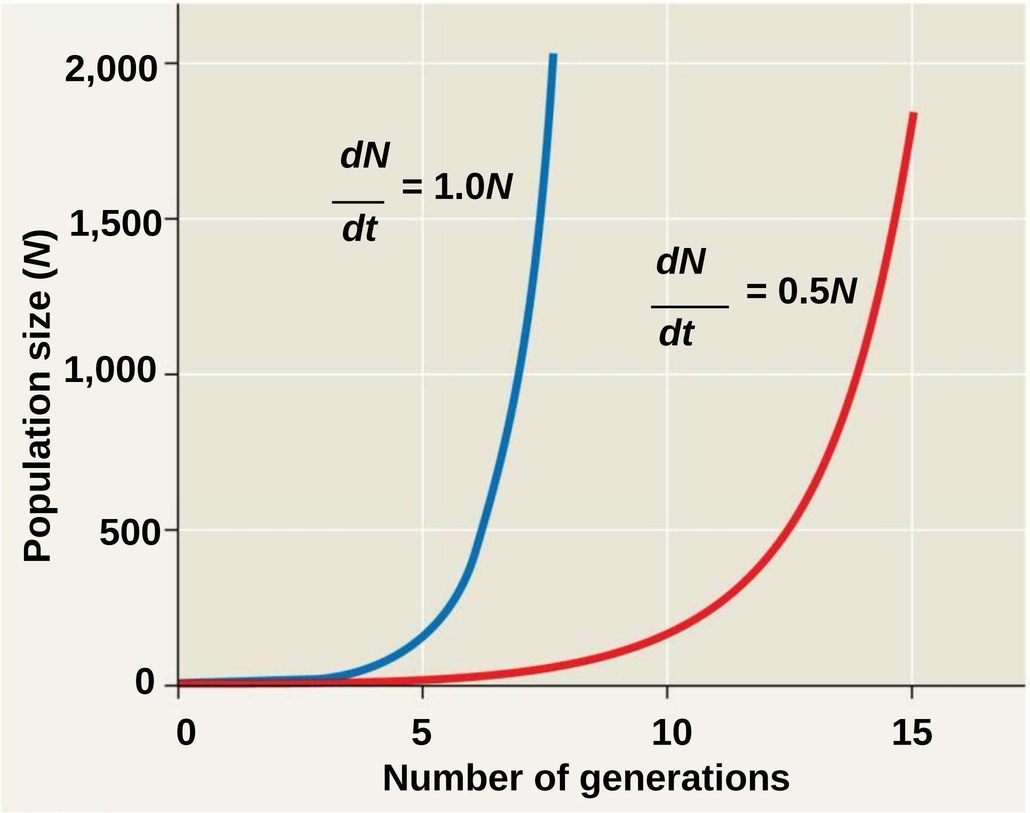
When all members of a population have access to unlimited resources and are free to reproduce at their physiological capacity, that population will experience **exponential population growth**.

- This is maximum per capita rate of increase

The size of a population that is growing exponentially increases at a constant rate.

- species introduced to new environment

- rebounding species from catastrophic numbers loss



Exponential Growth Task Instructional Reflection

- What were your questions as a “student” concerning completing the task?
- What instructional strategies would you use to teach the QR aspects of this task?

Exponential Growth

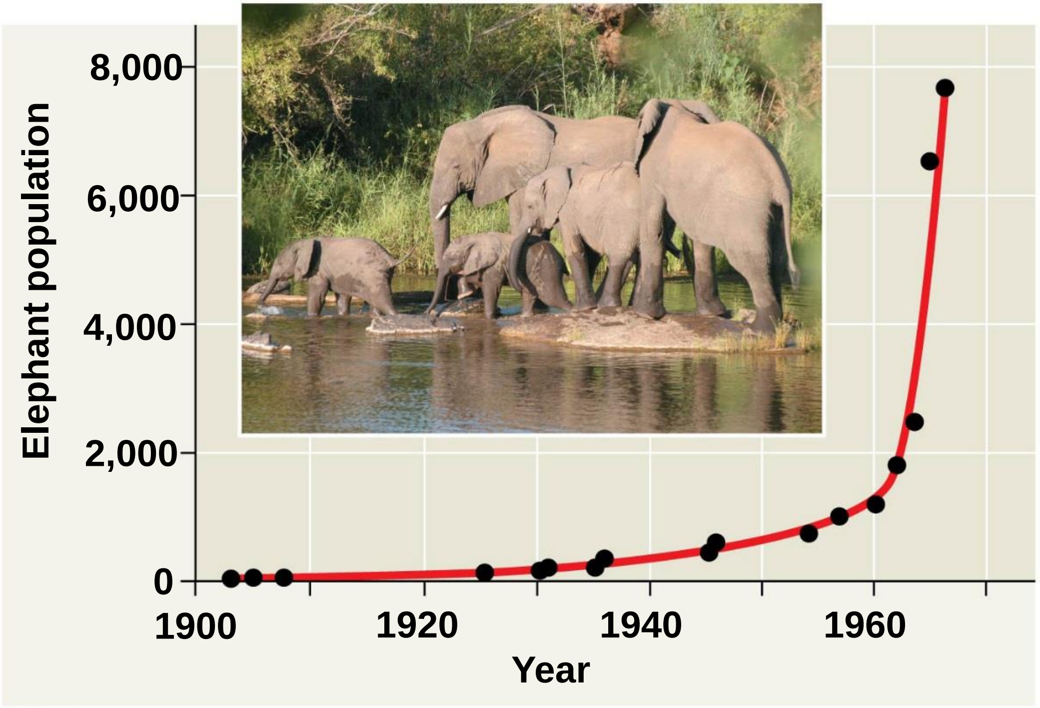
When all members of a population have access to unlimited resources and are free to reproduce at their physiological capacity, that population will experience **exponential population growth**.

- This is maximum per capita rate of increase

The size of a population that is growing exponentially increases at a constant rate.

- species introduced to new environment

- rebounding species from catastrophic numbers loss



Exponential Growth

Based on continuous exponential population growth, you can predict the population at given time (t) using the following equation.

$$N_t = N_0 e^{rt}$$

Where N_t is the population size at time t, N_0 is the original population size, r is the per capita rate of increase, and t is time.

Exponential Growth

If the human population was 5.4 billion in 1993 and the world human per capita rate of growth is 0.014, what was the projected population size in 2000.

$$N_t = N_0 e^{rt}$$

$$N_t = 5.4e^{(0.014)(7)}$$

$$N_t = 5.4e^{(0.098)}$$

$$N_t = 5.4\ (1.103)$$

$$N_t = 5.96\ \text{billion}$$

Exponential Growth

Research on a population of June beetles determines that the population size is 3,000. Over the course of a month, 400 births and 150 deaths are recorded in the population. Estimate r and calculate what the population size is predicted to be in 6 months.

$$N_t = N_0 e^{rt}$$

My observations

- Provides a growth curve graph and interprets for the students. States that exponential growth has a constant rate of increase. Provides equation for exponential growth: N(t)=N(0)e^(rt). He interprets.
- Calls e Napier's constant, tells students they do not need to know this number at this time.
- Provides two different model representations – graph and equation, but does not do much to translate between them, missed QI translation opportunity.
- On white board shows using natural log to bring down the power, states that students often make an error in using a calculator to do natural log. Does not explain inverse function relationship between exponential and logarithm.
- Provides an exponential growth example through human population, using model to find growth in 5 years form 1993. Provides students example to work through on June beetles. Provides story problem format and at white board leads students through the problem, including calculation of rate from birth and death rates.
- Instructor asks class wide questions, but is answering most of the questions. Isolated student responses to instructor questions. Has students do the calculation on calculator or phone once he has setup the formula. Several students expressed problem with working with number e on their calculator. No indication the students understand what the number is or why it is being used as the base for an exponential growth model.
- Sets stage for concept of logistic growth, since exponential growth is not sustainable.

QM BUGS Assessment

QM Create Model

QM Bugs Assessment Items are removed since research with assessment is in progress.

QM includes creating and refining models, then reasoning with those models: construct and use models spontaneously to assist own thinking, predict behavior in real-world, generate new questions about phenomena (Schwarz)

QM BUGS Assessment

QM Create Model

QM Bugs Assessment Items are removed since research with assessment is in progress.

QM includes creating and refining models, then reasoning with those models: construct and use models spontaneously to assist own thinking, predict behavior in real-world, generate new questions about phenomena (Schwarz)

QM BUGS Assessment Empirical Test of Model

QM Bugs Assessment Items are removed since research with assessment is in progress.

Model validation through empirical assessment: Model can explain all of the data and predict future experiments. Assess whether a model can explain all of the data at hand and predict the results of future experiments. Provides students data table of exponential growth rather than providing equation up front. Have them compute rate of change to see there is a constant rate of change using discrete formula, then move to continuous formula. Verify data fits model and discuss error in data fit. Explore conversion to base e and discuss why this is done.

Logistic Growth (day 3)

– Logistic model is introduced, concept of carrying capacity K. Resource limitation as profound impact on population growth rate, birth declines, disease/predation increases.

Logistical Model

Resources rarely remain abundant enough for exponential growth

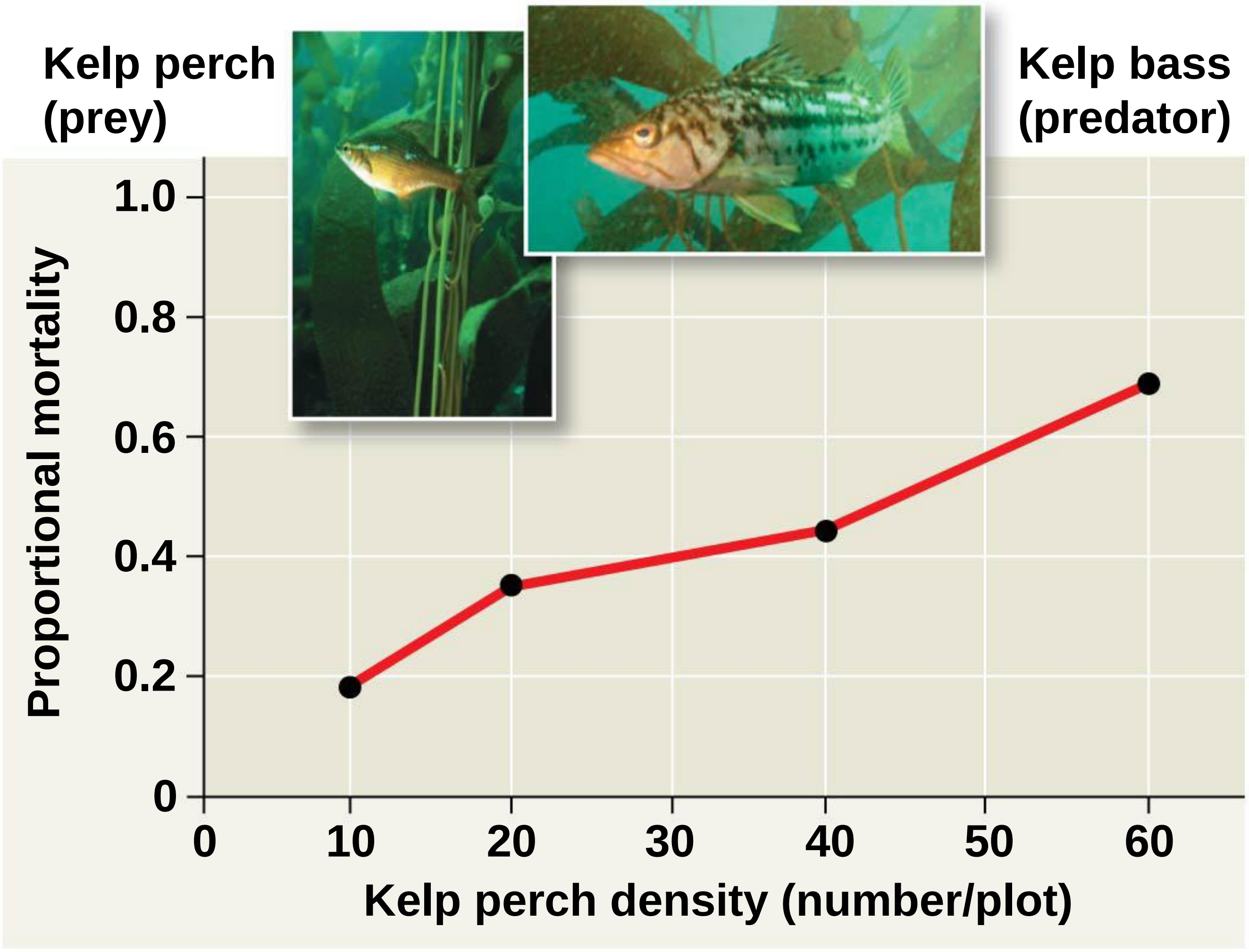
Ultimately, there is a limit to the number of individuals that can sustainably occupy any given habitat.

- Carrying capacity (*K*)
- Varies over space and time with abundance of limiting resources

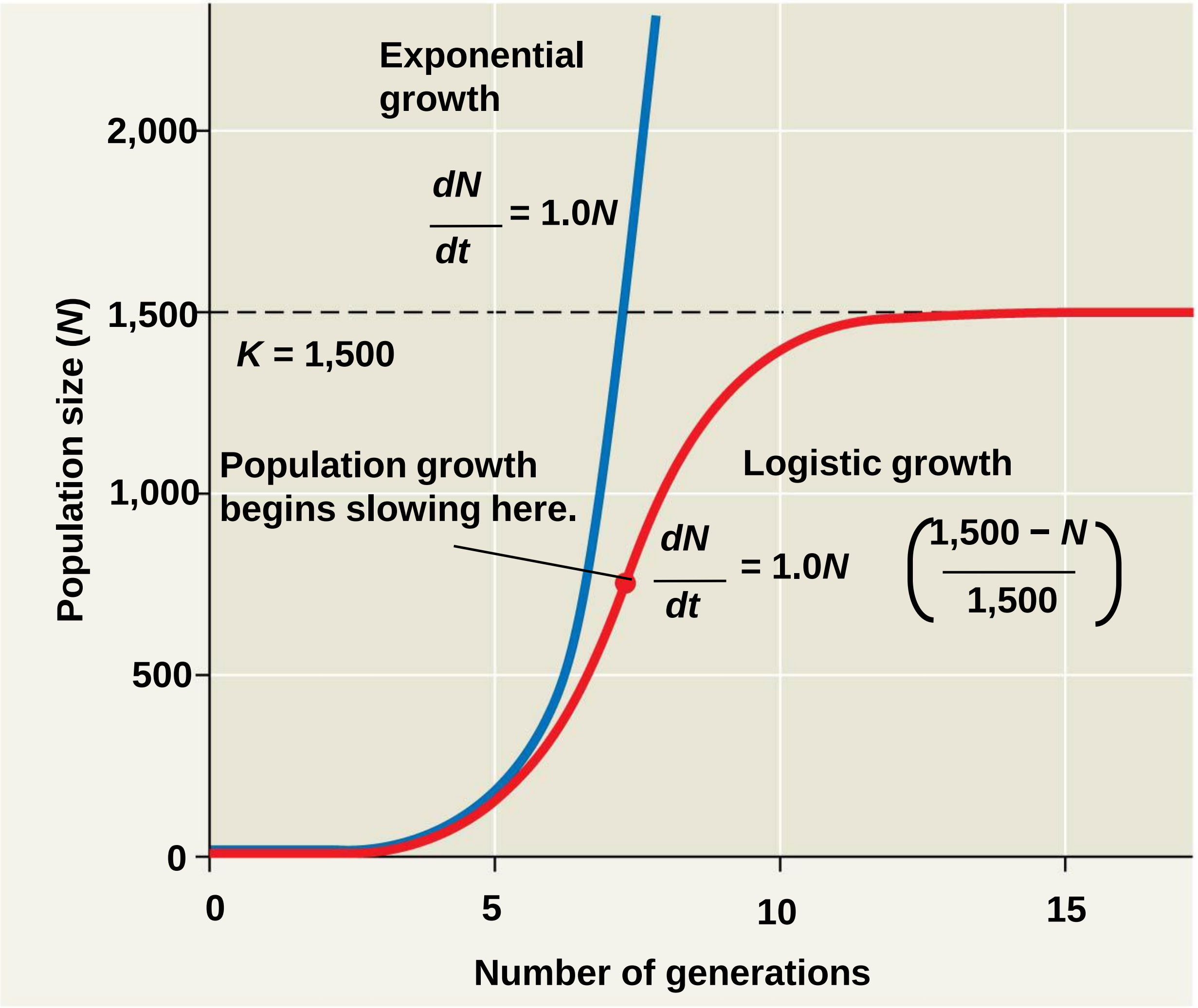
Resource limitation can have profound effects on population growth rate

- Resources insufficient for reproduction (*b* will decline)
- Energy to maintain themselves declines or disease/predation increase (*m* will increase)

Many factors that regulate population growth are density dependent



Logistical Model



Notice population per capita growth rate highest when population at half carrying capacity

Logistic Growth Task Instructional Reflection

- What were your questions as a “student” concerning completing the task?
- What instructional strategies would you use to teach the QR aspects of this task?

Logistical Model

The **logistic population growth** model expresses this mathematically.

$$\frac{\Delta N}{\Delta t} = r_{inst} N \frac{(K - N)}{K}$$

When N is small, $(K - N)/K$ is close to 1, and the population's growth rate is close to maximum.

When N is large, $(K - N)/K$ is close to 0, and the population's growth rate is going to be small.

When $N = K$, the population stops growing.

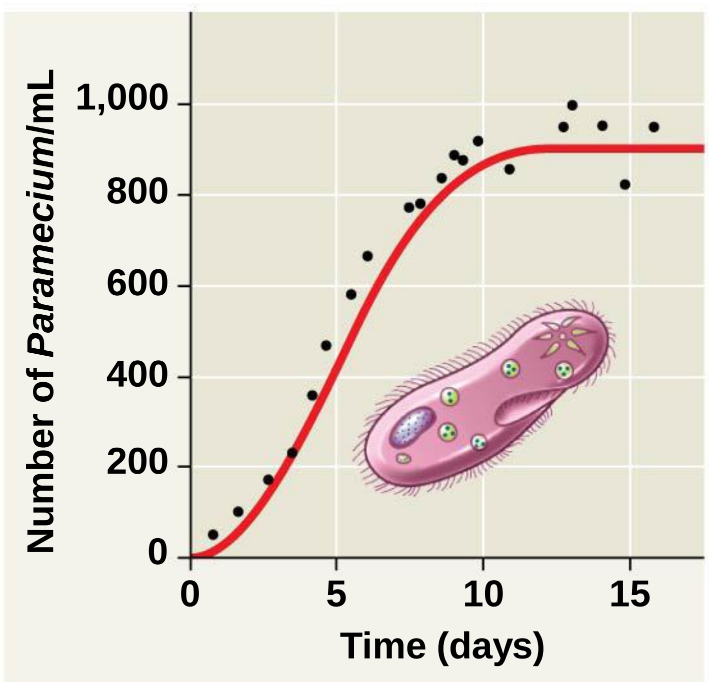
<u>Major assumption</u>: regardless of population density, each individual added to a population has same negative effect on population growth rate.

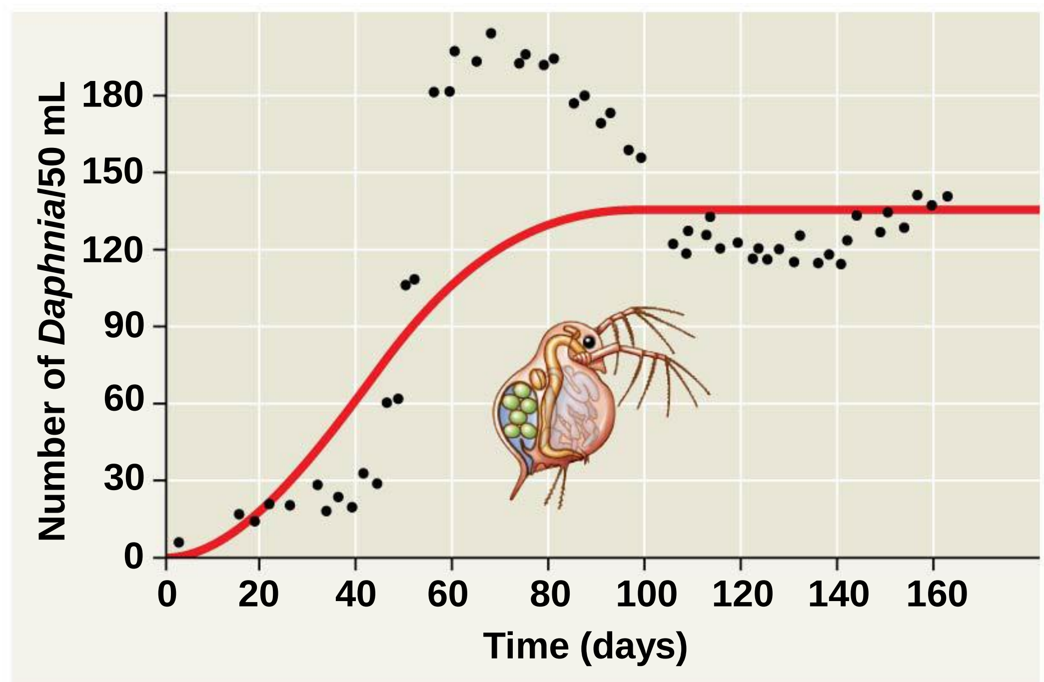
Example

The Georgia Department of Fish and Wildlife sets guidelines for hunting and fishing in the state, and it reported an estimate of 900,000 deer prior to the hunting season of 2004. It has been estimated that "a deer population that has plenty to eat and is not hunted by humans or other predators will double every three years." This corresponds to a per capita increase of $r = \ln(2)/3 = 0.2311$. Suppose the carrying capacity is 1,072,764 deer. Predict the population in 2007.

Logistical Model and Reality

Growth of several species in laboratory (beetles, crustaceans, *Paramecium*, etc…) fit logistical model well. However, some species' populations appear to grow well beyond their carrying capacity.





Logistical Model and Reality

Growth of several species in laboratory (beetles, crustaceans, *Paramecium*, etc…) fit logistical model well. However, some species' populations appear to grow well beyond their carrying capacity.

- Model assumes populations adjust instantaneously to growth and increasing lack of a limiting resource
- In many cases though, there is a delay. Continued reproduction despite the burden of a limited resource(s) cause a population to overshoot its carrying capacity for a short time.




My observations

- Shares a graph model of Kelp perch density by proportional mortality – increase in mortality as perch density increases. He provides and interprets the model for students, no questions.
- Displays logistical growth graph model compared to exponential growth rate for generic number of generations vs. population size. He interprets the graph for students. Provides equation model for logistic growth delta N/delta t = r(instantaneous) x N x (K-N)/K. Student asks question about r(inst). He does QA on variables for them, discussion N is small as ratio in formula is close to 1, means population rate of increase is close to maximum growth, when N is large ratio near 0 so population rate of increase is small. Students interrupt with two questions on meaning of this. When N=K population stops growing. Provides all the QA and QI.
- Returns to graph model to answer students question on trends in growth. Provides an example from Georgia Department of Fish and Wildlife on deer. Provides r, carrying capacity, and deer population, asks to predict population in 3 years. Student asks QA question about variables in problem, instructor explains. Using same logistic model he asks class wide questions on what values to substitute for given variables, several students respond. Sets up equation and solves it for them as some students follow along on calculator. Student asks question about time units being in 3 year interval, he explains. One student asks question about adding increase to base population to get the answer. Ask questions if change for every 3 years would stay the same, they are not sure, he explains that since getting closer to K then there will be less growth. Student asks questions about ½ K as point when population begins to decline.
- Provides example of logistic growth of paramecium contrasted with Daphnial (water fleas) who go beyond carrying capacity but then crashes back to equilibrium K. Student provides insight that this is due to large birth rates without being asked. Discusses oscillation effect of over shooting K. Student asks if it eventually levels out to K, he responds yes. Several students ask questions about exceeding carrying capacity and resulting crash. Instructor states that exceeding carrying capacity is due to high birth rates – strong exponential growth.
- Compares human growth rate to logistic growth, our rate of growth is slowing. Student states technology is increasing carrying capacity, he agrees but argues there are limitations. Asks students what would cause collapse, they offer several: disease, war, food shortage.

QM BUGS Assessment
Empirical Test of Model

QM Bugs Assessment Items are removed since research with assessment is in progress.

QM includes fitting a mathematical model to data. Provide student with logistic trend data set. In small groups explore what mathematical function displays this trend – linear, polynomial, exponential, radical, rational? Have them sketch a curve of best fit, then if needed introduce the logistic function. Fit logistic curve and discuss data trends vs. curve.

QM BUGS Assessment QM Model Revision

QM Bugs Assessment Items are removed since research with assessment is in progress.

QM includes model revision. Once students understand unconstrained exponential growth, have them revise the model to fit real world data – result is logistic curve. Have them compare the exponential growth to logistic growth to see they are similar initially.

Evolution: diversity

- Moves to discussion of evolution and life history diversity – traits that affect an organism's schedule of reproduction and survival: age of reproduction, how often organism reproduces, number of offspring produced per reproductive episode.
- Semelparity vs. iteroparity as various life histories.

Evolution and Life History Diversity

Life history: The traits that affect an organism's schedule of reproduction and survival. (3 main variables)

- The age at which reproduction begins
- How often the organism reproduces
- How many offspring are produce per reproductive episode

Various life histories; often dependent on semelparity vs iteroparity

Evolution and Life History Diversity

Life history: The traits that affect an organism's schedule of reproduction and survival. (3 main variables)

- The age at which reproduction begins
- How often the organism reproduces
- How many offspring are produce per reproductive episode

Various life histories; often dependent on semelparity vs iteroparity

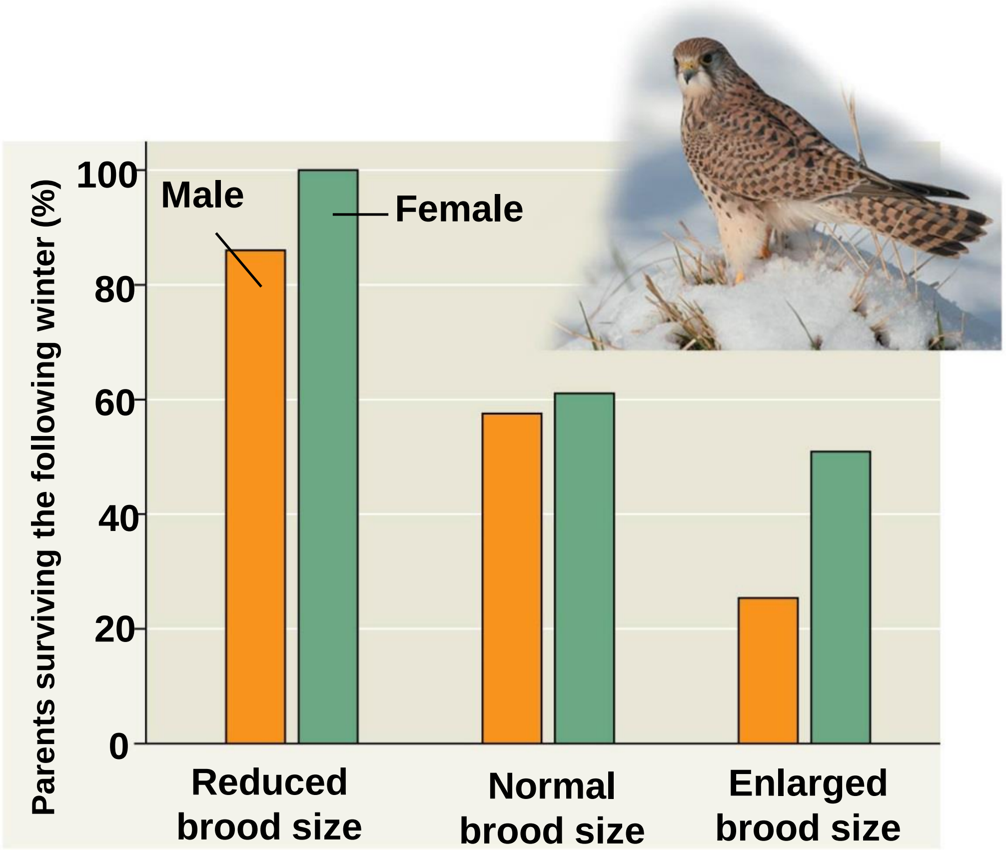
Generally, highly variable or unpredictable environments likely favor semelparity, while dependable environments may favor iteroparity

“Trade-offs” and Life Histories

No organism could produce as many offspring as a semelparous species and provision them as well as an iteroparous species.

- Not enough energy, organisms have finite resources
- There must be some trade-offs between survival and reproduction

Another study in Scotland found that red deer that reproduced in a given summer were more likely to die the next winter than were females that did not reproduce.



"Trade-offs" and Life Histories

K-selection: Density-dependent selection, selection for traits that are sensitive to population densities.

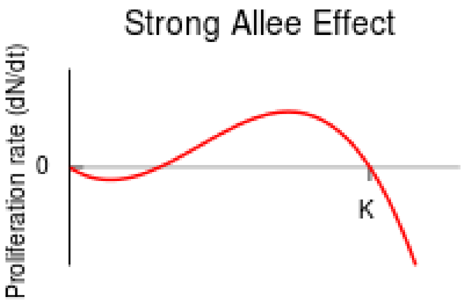
- Operates in populations living at a density near the limit imposed by resources (K)

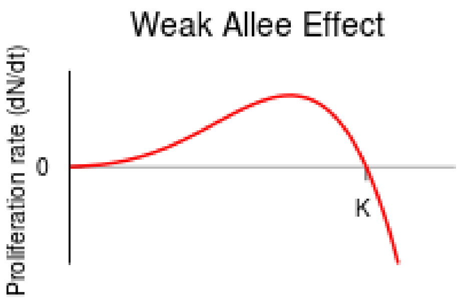
r-selection: Density-independent selection, selects for life history traits that maximize reproduction.

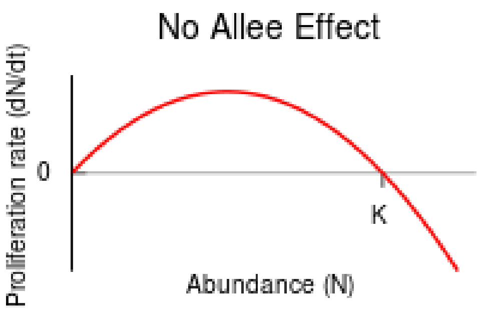
- Occurs in environments in which population densities are well below carrying capacity or face little competition.

Logistical Model and Reality

Allee Effect: Individuals may have a more difficult time surviving or reproducing if the population size is small







Ecological mechanisms include mate limitation, cooperative defense, cooperative feeding, and environmental conditioning.

Evolution Diversity Task Instructional Reflection

- What were your questions as a “student” concerning completing the task?
- What instructional strategies would you use to teach the QR aspects of this task?

Many factors that regulate population growth are density dependent

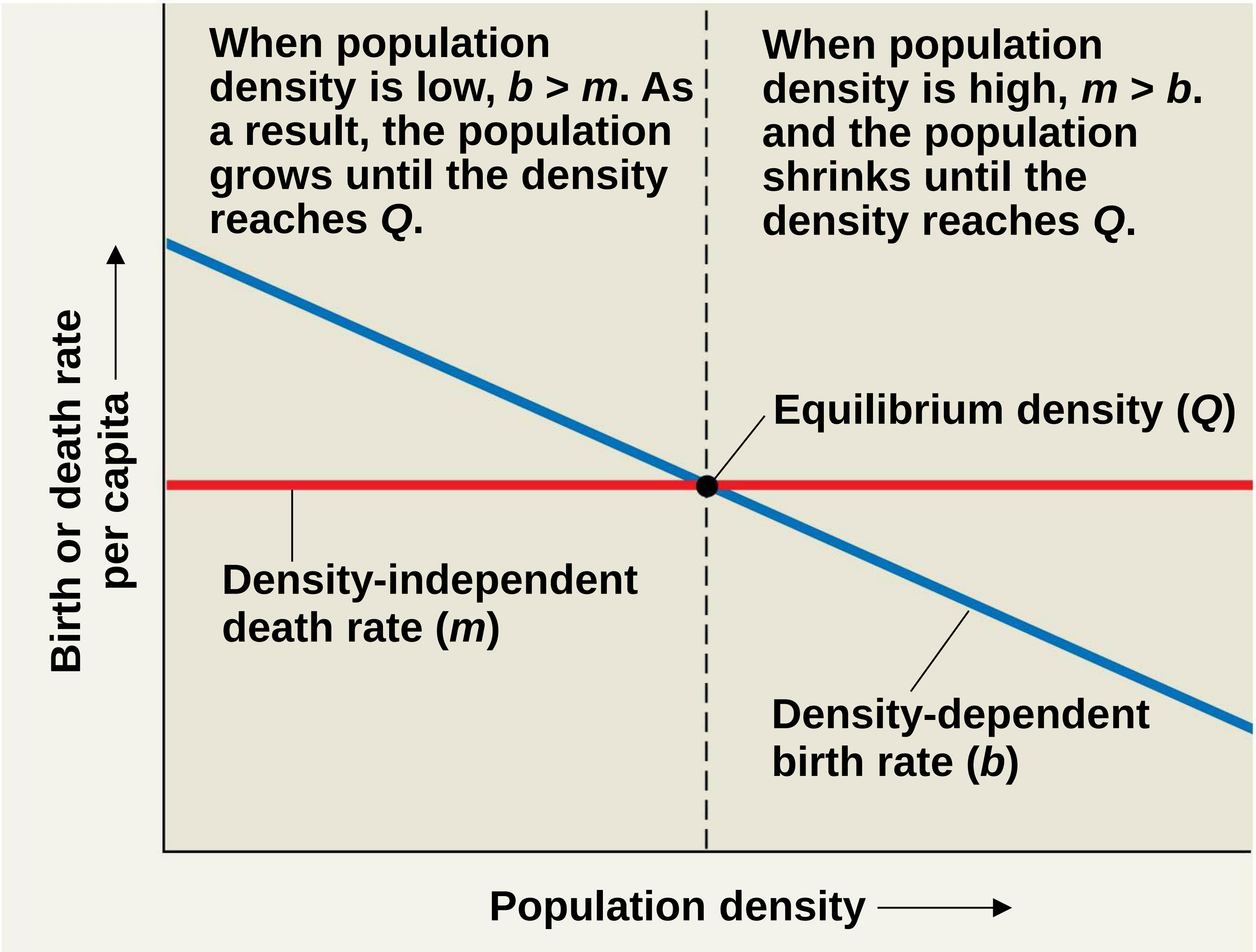
Density-independent populations, birth rate and death rate do not change with population density.

- Some physical factor which kills similar portions of the population regardless of its density.

Density-dependent populations, birth rates fall and/or death rates increase with population density.

- Limiting resource, behavioral changes, biotic control

Sometimes a mixture of both.


When population density is low, b > m. As a result, the population grows until the density reaches Q.
When population density is high, m > b. and the population shrinks until the density reaches Q.
Equilibrium density (Q)
Density-independent death rate (m)
Density-dependent birth rate (b)
Birth or death rate per capita
Population density

My observations

- Provides examples of species with different life histories – salmon, century plant, sea turtle. Highly unpredictable environment favor semelparity, dependable environments favor iteroparity. Little discussion at this point, instructor presenting information.
- Provides histogram model of parents surviving following winter vs. reduced/normal/enlarged brood size. Again he interprets, does not ask for QI from students.
- Trade-off between survival and reproduction. K-selection density-dependent selection, population lives near density capacity K (humans). R-selection density-independent selection, maximum reproduction. Student ask question about which is more efficient in resource use.
- Allee effect – individuals may have more difficult time surviving or reproducing if population is small. Shows three graph models for strong allee effect (polymonial cubic), weak allee effect (logistic with collapse) and no alee effect (parabolic). Ask students why they think the trends represented are happening, little response, instructor provides explanation.
- Density-independent populations birth rate and death rate do not change with population density. Density-dependent populations birth rates and death rates increase with population density. Provides visual model of population density vs. birth or death rate per capita. He interprets, then asks students question on where birth and death rates are higher in the model. A few students reply. Student asks question about model, so he goes through QI of model asking them where birth – death rates are positive or negative.

QM BUGS Assessment Meta-modeling Purpose and Nature of Models

QM Bugs Assessment Items are removed since research with assessment is in progress.

Models consist of objects, processes and theories. Have small groups of students discuss the objects, processes and theories underlying the alee effect graphical models

QM BUGS Assessment Inductive Reasoning – Hypothesis Development

QM Bugs Assessment Items are removed since research with assessment is in progress.

Small groups of students develop hypothesis about the relationship between population density and birth/death rate per capita. Support hypothesis with science theory.

Population Dynamics

- Population dynamics example of Isle Royale – moose and wolf populations.

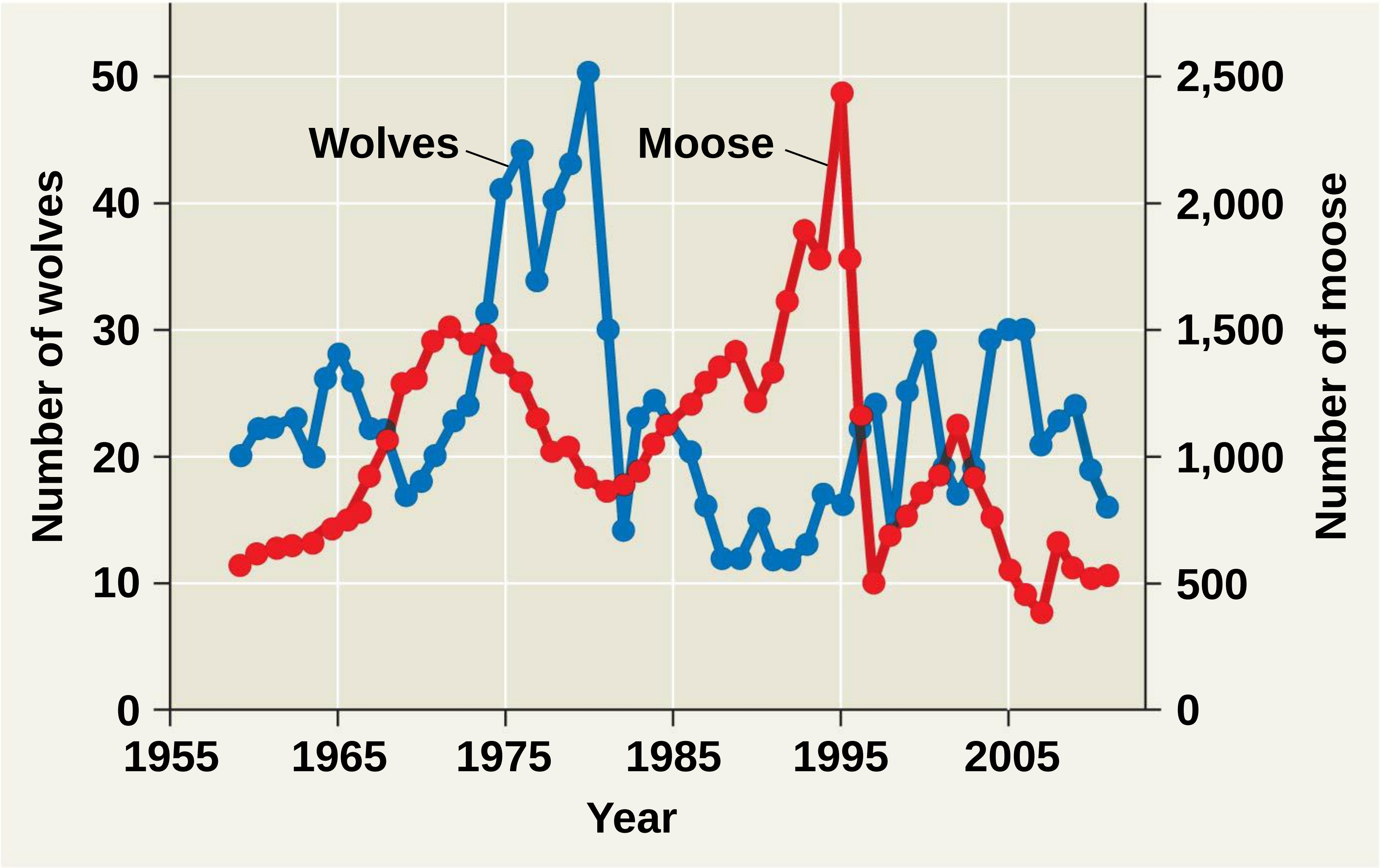
Population Dynamics

The study of **population dynamics** focuses on the complex interactions between biotic and abiotic factors that cause variation in population size

Long-term population studies have challenged the hypothesis that populations of large mammals are relatively stable over time

Both weather and predator population can affect population size over time

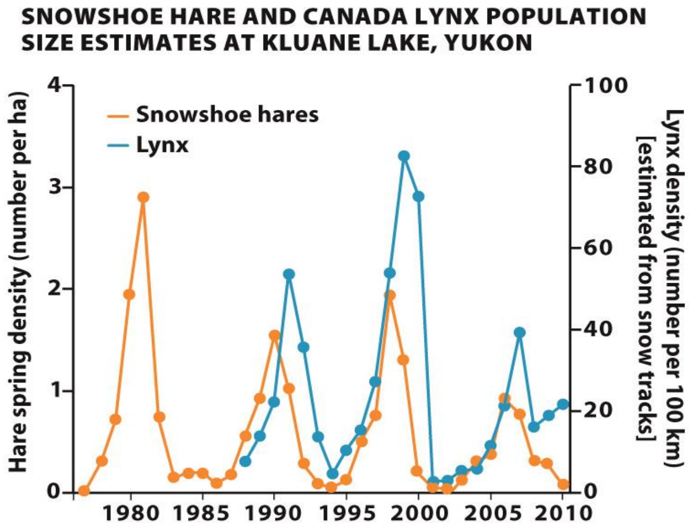
- Example: the moose population on Isle Royale collapsed during a harsh winter, and when wolf numbers peaked



Wolves
Moose
Number of wolves
Number of moose
Year
50
40
30
20
10
0
2,500
2,000
1,500
1,000
500
0
1955
1965
1975
1985
1995
2005

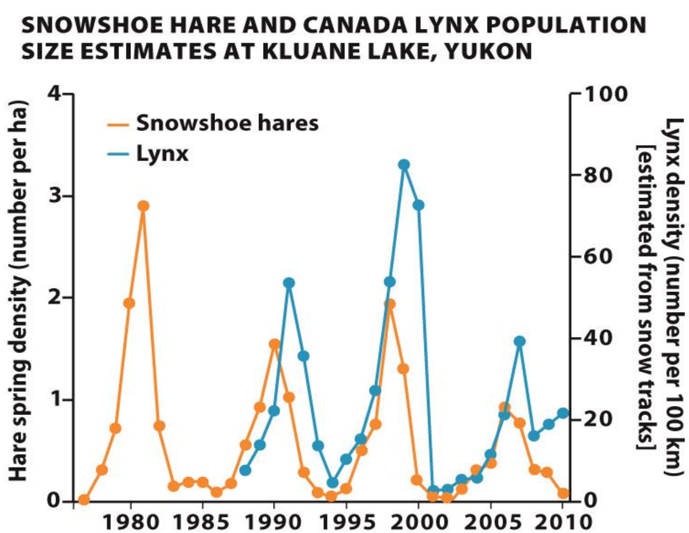
Population Cycles

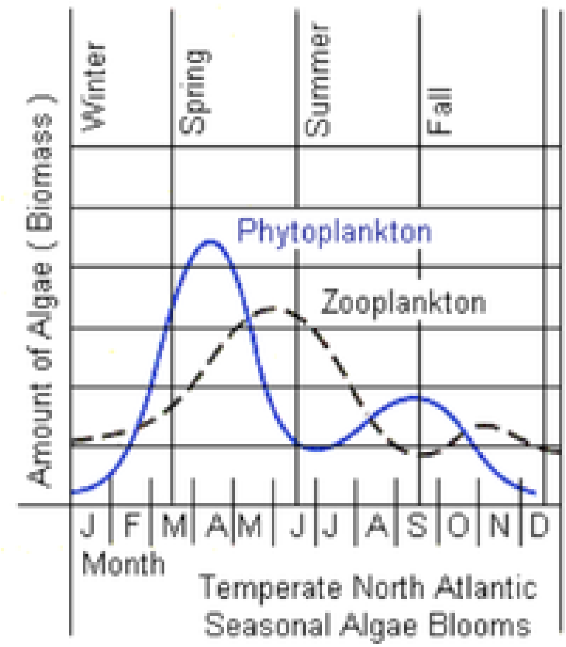
Predator and prey populations also respond to each other. Predator populations increase as their prey population increases, but this naturally leads to more predation which begins to decrease prey population. This, in turn, limits food availability and the predator population begins to decline. (**Boom-and-Bust Cycles**)



Population Cycles

Predator and prey populations also respond to each other. Predator populations increase as their prey population increases, but this naturally leads to more predation which begins to decrease prey population. This, in turn, limits food availability and the predator population begins to decline. (**Boom-and-Bust Cycles**)





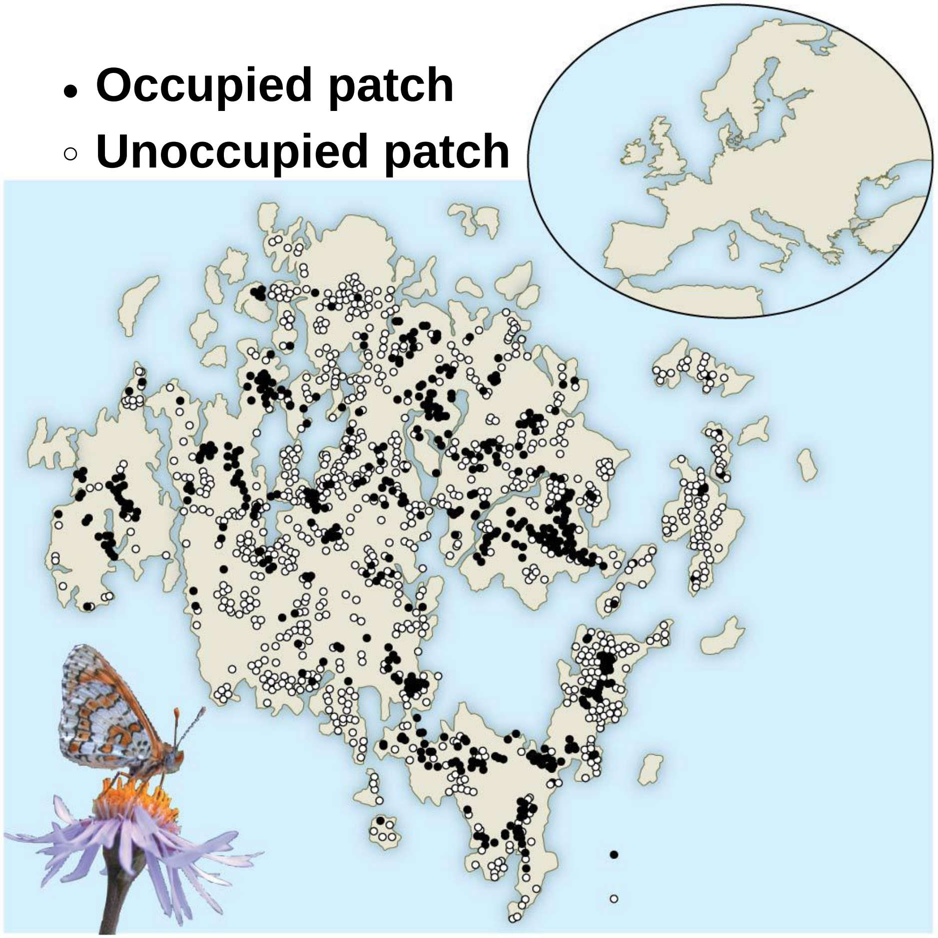
Population Dynamics Task Instructional Reflection

- What were your questions as a "student" concerning completing the task?
- What instructional strategies would you use to teach the QR aspects of this task?

Immigration, Emigration, and Metapopulations

Metapopulations are groups of populations linked by immigration and emigration.

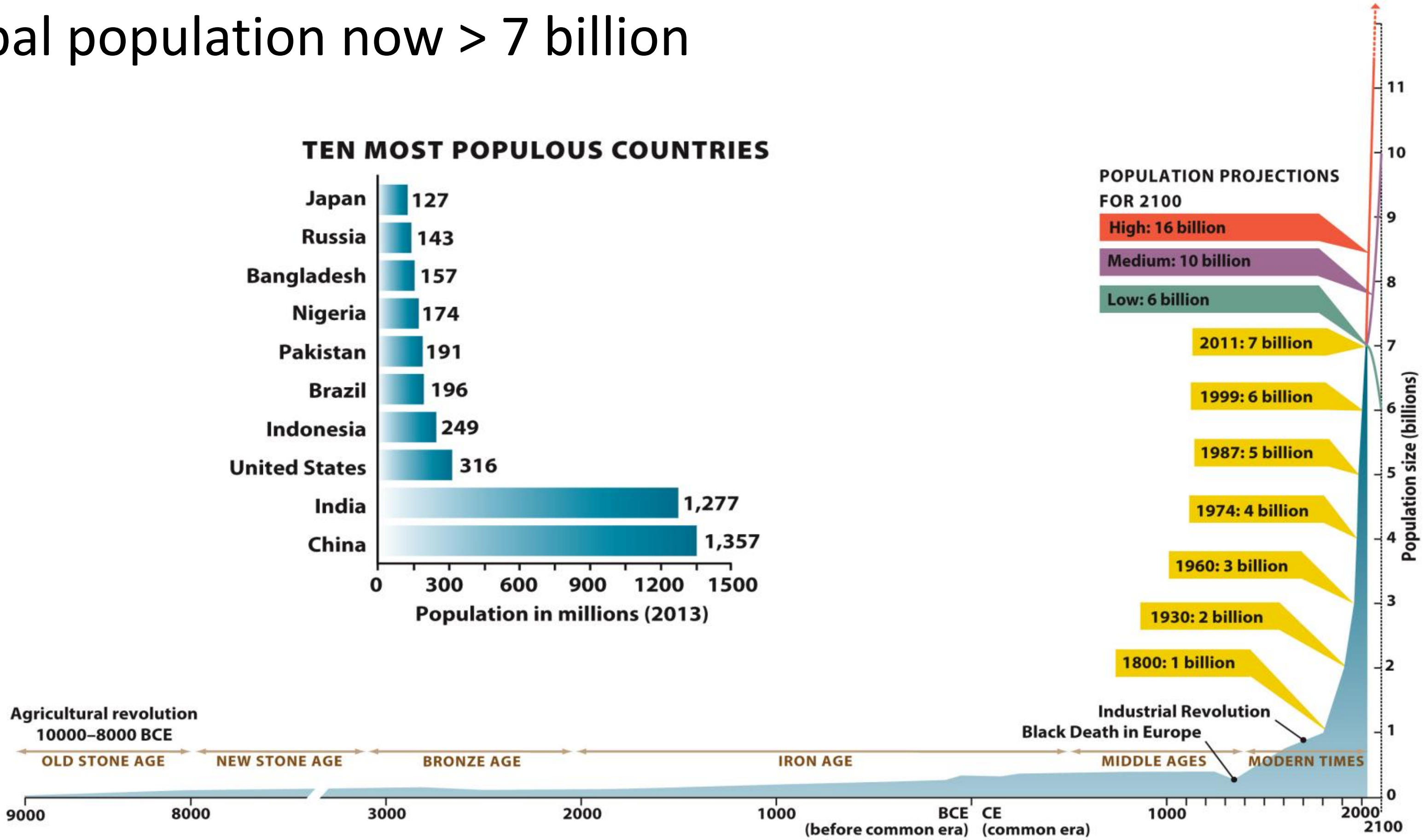
- Usually local populations are patches of suitable habitat surrounded by unsuitable habitat
- Local population becomes extinct, can be recolonized by another patch



The Global Human Population

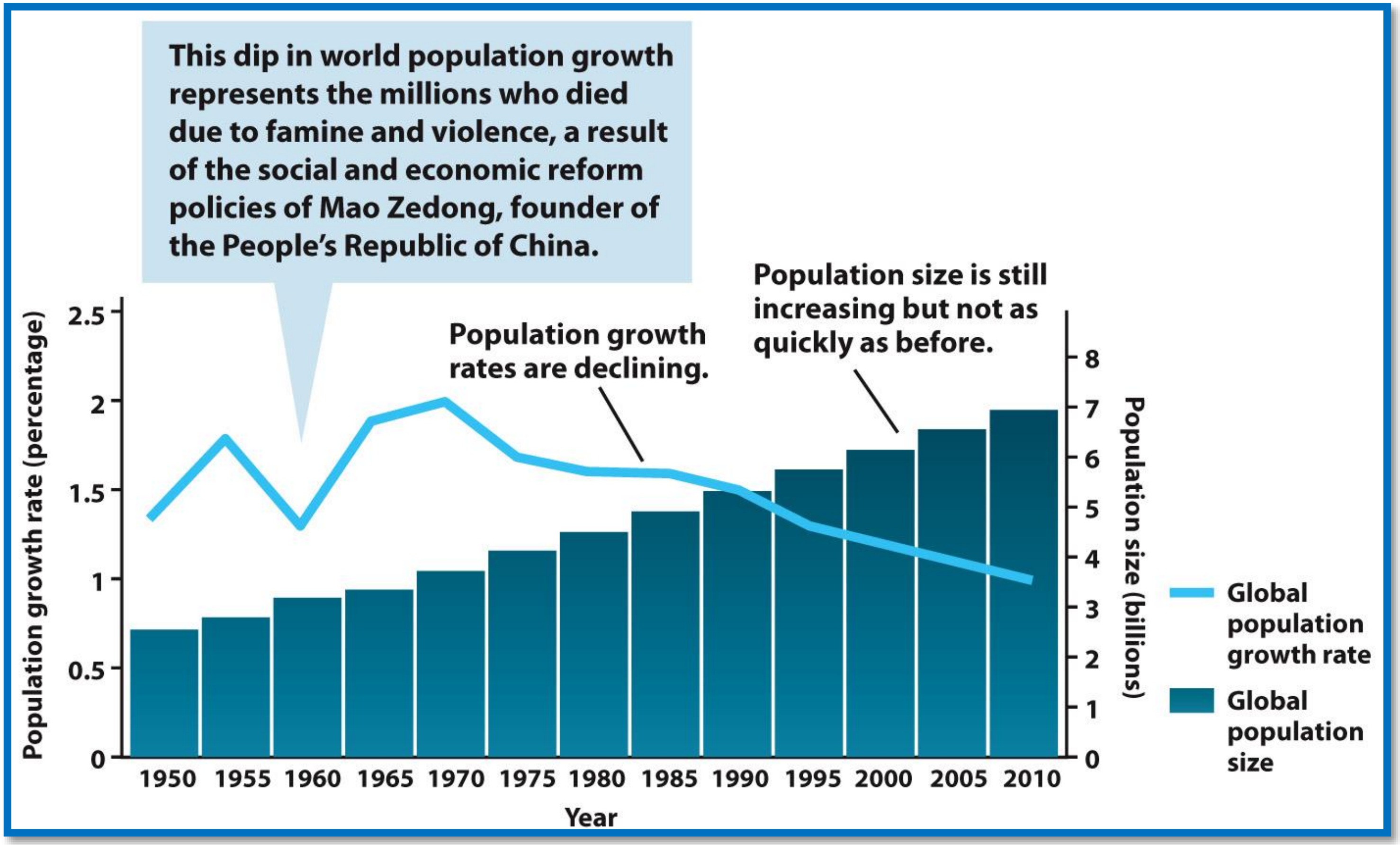
No population can grow indefinitely, and humans are no exception

- Slow growth until about 1650, then exponential growth
- Global population now > 7 billion



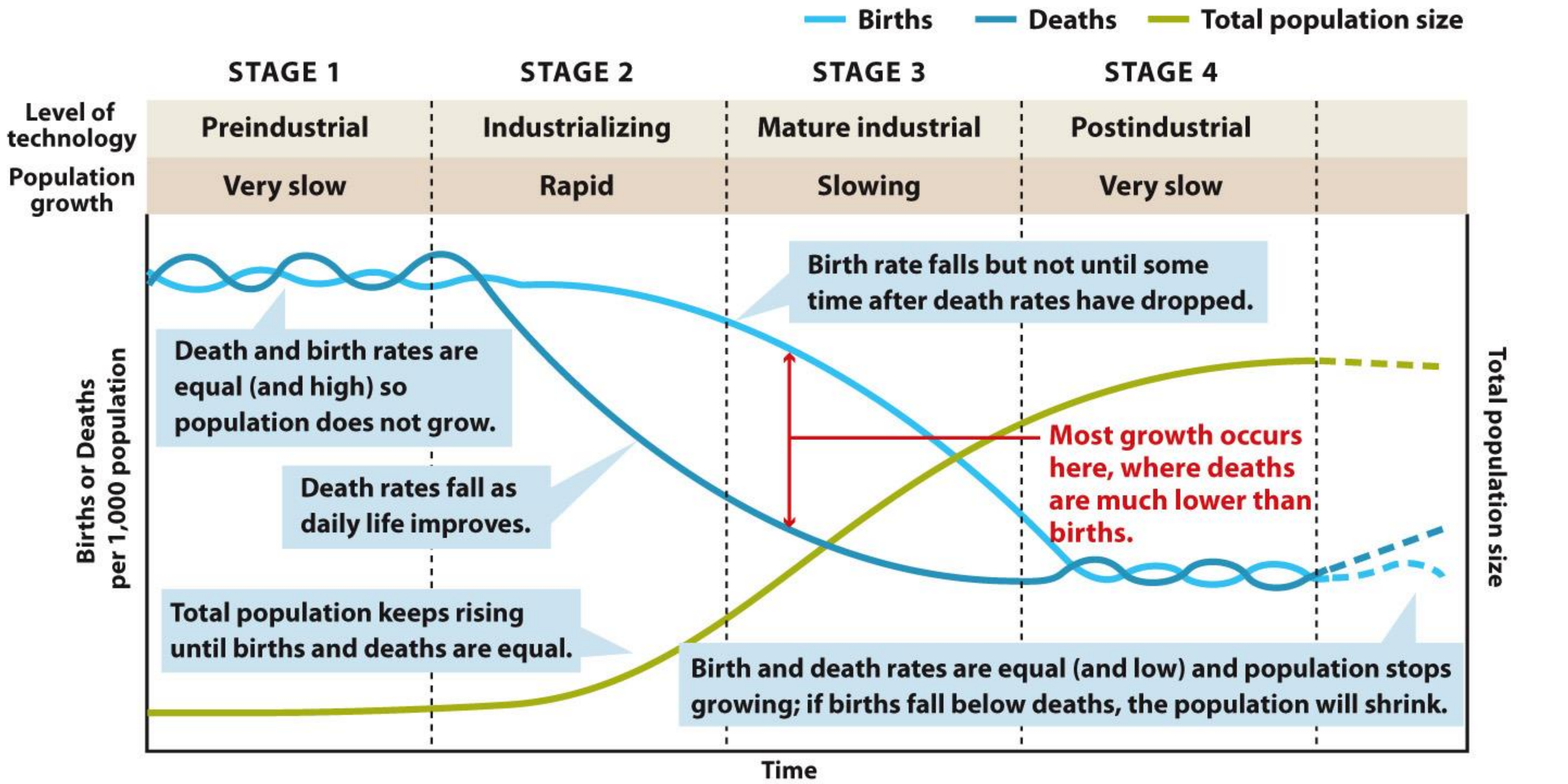
The Global Human Population

Though the population is still growing, the rate of growth has begun to slow.

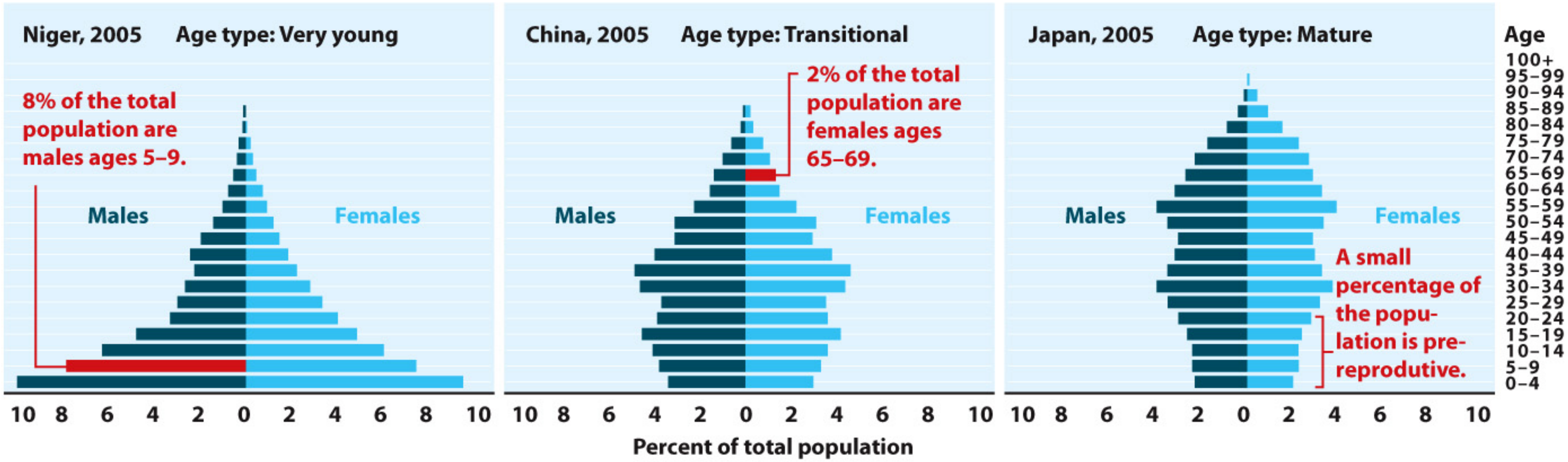


Regional Patterns of Population Change

Demographic Transition: Theoretical model describing expected drop in population growth as economic conditions improve.



Age Structure: Future Trends of Population Growth

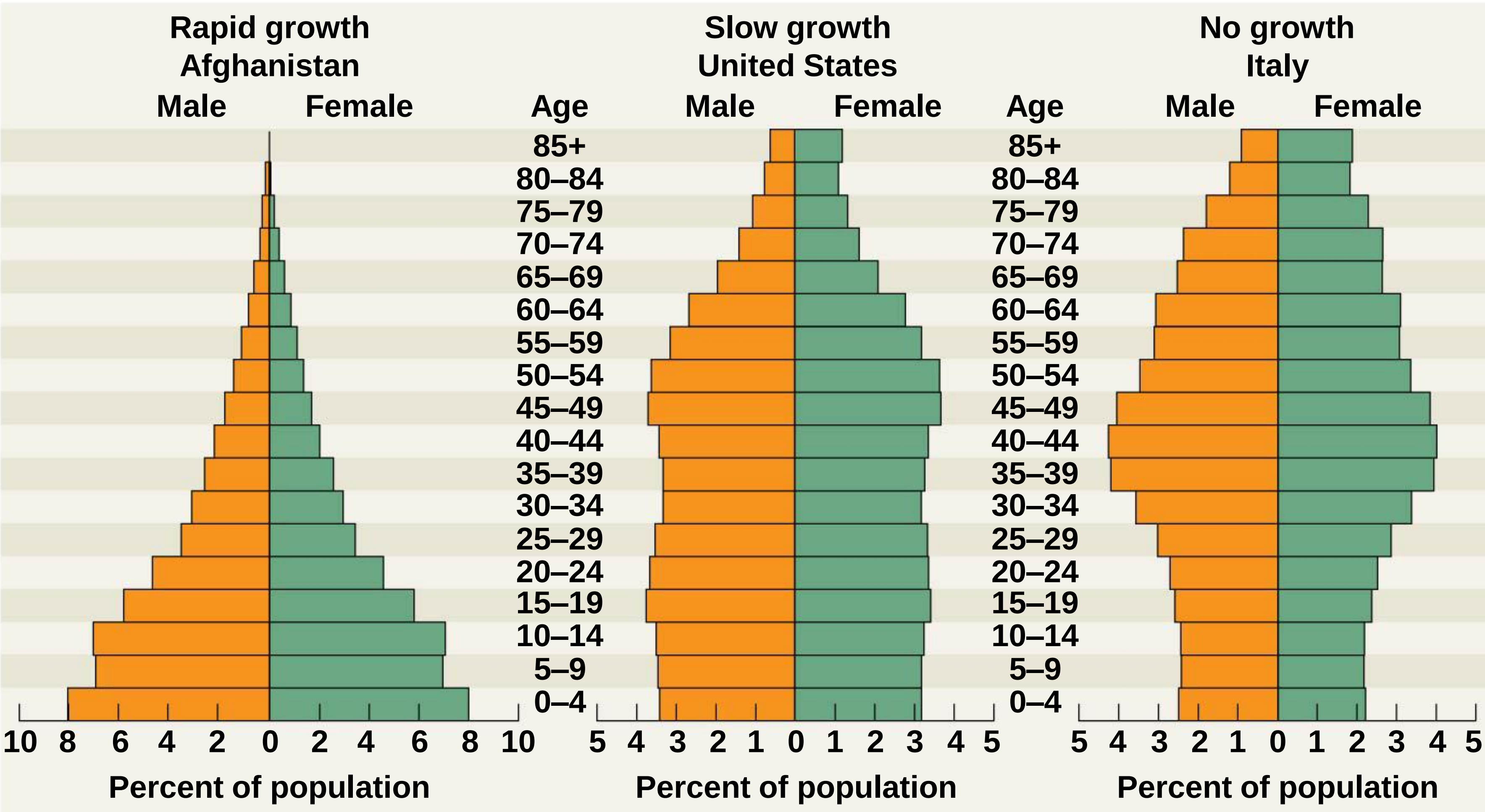


<u>Population Momentum:</u> Populations that are bound to increase for another generation.

*Niger- Most of the population are under 30 (high capacity for growth)

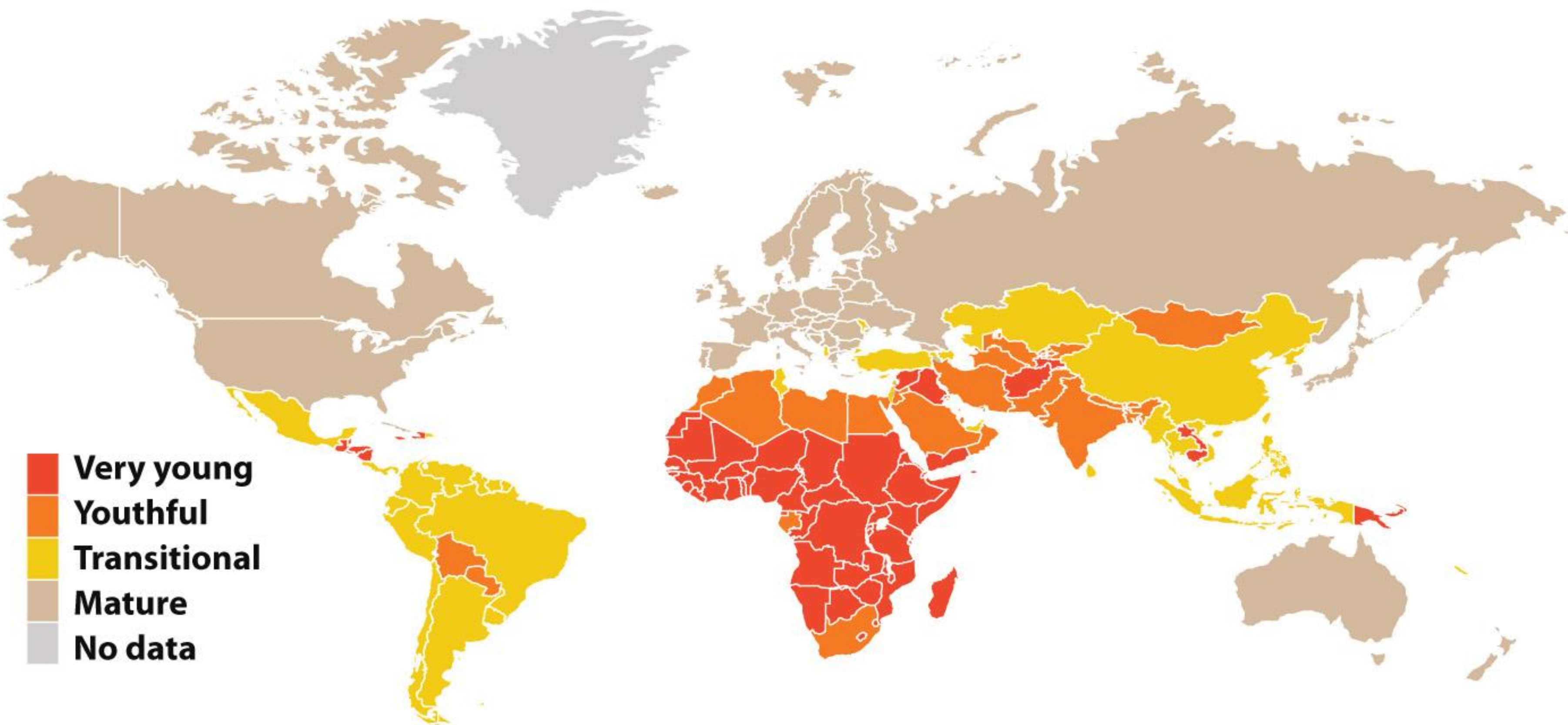
<u>Transitional Population</u>: China's pre-reproductive and reproductive cohorts are not as dramatic. Population rise bound to slow. There are noticeably more males than females.

Age Structure: Future Trends of Population Growth



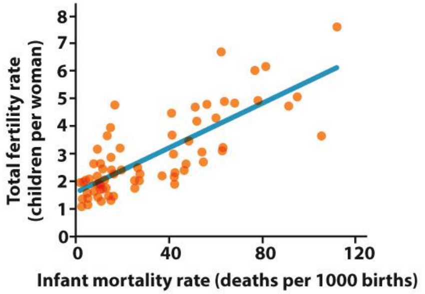
Age Structure: Future Trends of Population Growth

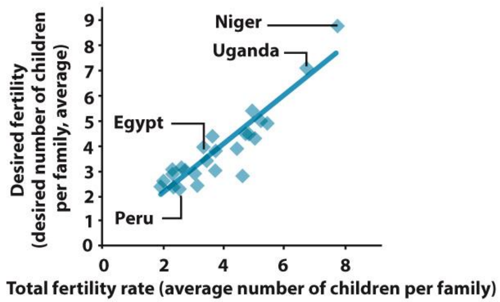
The fastest growing regions are those with a youthful or very young population.

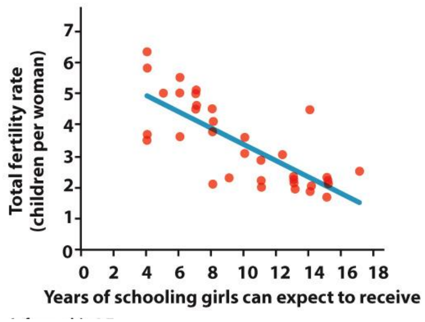


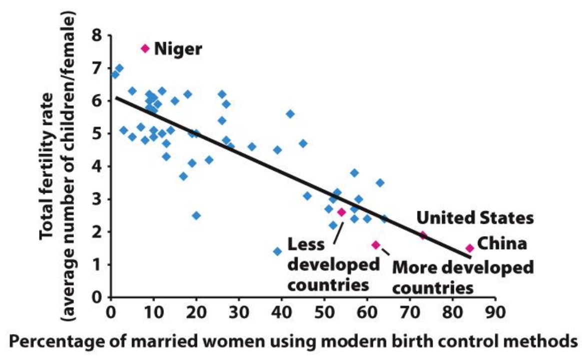
Regional Patterns of Population Change

Ultimate goal is to achieve **zero population growth** (ZPG), when the number or people being born is equal to the number dying—**replacement fertility rate.**









<u>zero population growth</u>

(1) Identify why birthrates are high.
- no contraceptives
- pronatalist pressure
- low opportunity

(2) Take steps to ratify those birth rates.
- education
- economic stability
- health care

- The single celled algal dinoflagellate *Alexandrium fundyense* is a toxic species capable of exponential population growth in replete nutrient conditions. A sample taken off the coast of North Carolina revealed an average of 22 cells of *A. fundyense* per liter of seawater just prior to a large storm event which resulted in nutrient rich water pouring into coastal waters. Ten days later *A. fundyense* counts were estimated at 450,000 cells per liter. Calculate the per capita rate of increase (r) for this population.

- A population of 24 rabbits is introduced to Midway Island and immediately begins to grow rapidly. Researchers estimate that the population doubles every 6 weeks. How long will it take the population, assuming the per capita rate of increase does not change, to reach 10,000 individuals?

My observations

- Displayed graphical model of year vs. wolves and moose population on Isle Royale. Predator-Prey interactions shown as growth and crash of populations.
- Instructor guides the QI for graph, with classwide input from the students. Student ask questions on density independent and dependent.
- Predator and prey boom and bust cycle example of lynx and snowshoe hares. Graph model of cycle.

QM BUGS Assessment QI Translation

QM Bugs Assessment Items are removed since research with assessment is in progress.

QI includes translating between models of the same phenomena. Have students compare and contrast the 6 models for world population growth. Do they contradict one another? If so what do you think is causing the contradiction?

QM BUGS Assessment Meta-modeling Purpose and Nature of Models

QM Bugs Assessment Items are removed since research with assessment is in progress.

Meta-modeling includes determining if the model is acceptable, including explaining the observations made by the researcher. For the population cycle models, have students discuss in small groups if the graphs support the observations/conjectures made by the researchers.

Question	Concept	% Correct/ Mode	
Q1	Analyze - Anchoring Phenomena	62.3	
Q2	Construct Model drawing	19.9	
Q3	Meta-modeling - Purpose and nature of models	19.9	
Q4	Meta-modeling - Purpose and nature of models	60.3	
Q5	Inductive Reasoning - Hypothesis development, Variation	58.3	
Q6	QA Variable Quantification		
Q7	QA Variable Quantification measure	11.3	
Q8	QA Variable Quantification measure	30.5	
Q9	QM Create Model - phenomenological	44.4	
Q10	QM Create Model	35.8	
Q11	QM Create Model	49.0	
Q12	QM Create Model from theory: mechanistic	21.9	
Q13	Empirical Test of Model	14.6	
Q14	Meta-modeling, Nature of Models	21.2	
Q15	Model comparison	44.4	
Q16	Model Application QI Trends	20.5	
Q17	Model Application QI Translation	51.0	
Q18	Model Application QI Prediction	58.9	
Q19	QI Revision	48.3	
Q20	Confidence - QA Variable quantification	4	
Q21	Confidence - QM hypothesis development	4	
Q22a	Confidence - QM hypothesis testing	4	
Q22b	Confidence - QM hypothesis testing	4	
Q22c	Confidence - QM hypothesis testing	4	
Q23a	Confidence - QM creating and reasoning; QI refining	4	
Q23b	Confidence - QM creating and reasoning; QI refining	4	
Q23c	Confidence - QM creating and reasoning; QI refining	4	
Q24	Confidence - QI predictions	4	
Q25	Confidence - QI trends	4	
Q26	Confidence - QI translation	4	
Total		7.23	

QM BUGS Assessment

QM Understanding Q1-19

QM Attitude Q20-26

Cell Collective Resource

Description

- The purpose of this training model is to introduce you to Cell Collective. Cell Collective is a web-based technology designed to aid students in learning about complex biological systems by allowing them to explore biological processes on the computer. Students can create, modify, and simulate components that comprise a process. Cell Collective is also designed to enable students to think about biological processes as a 'system' - by activating and deactivating components, student can visualize the extent to which a single change impacts the entire system.

Learning Objectives

- Students will be able to add components.
- Students will be able to add relationships between components.
- Students will be able to rename components.
- Students will be able to save your work.
- Students will be able to simulate a computational model.
- Students will be able to interpret simulation results in Cell Collective.
- Students will be able to switch between different Cell Collective workspaces.

https://learn.cellcollective.org/

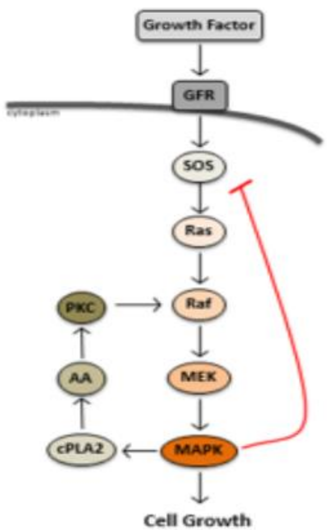
Cell Collective Resource

PI Tomas Halikar, Developer Joseph Dauer

Positive and Negative Feedback Loops and Cell Growth

version 1.0

Components: **13** Interactions: **14**



Author: **Audrey Crowther**

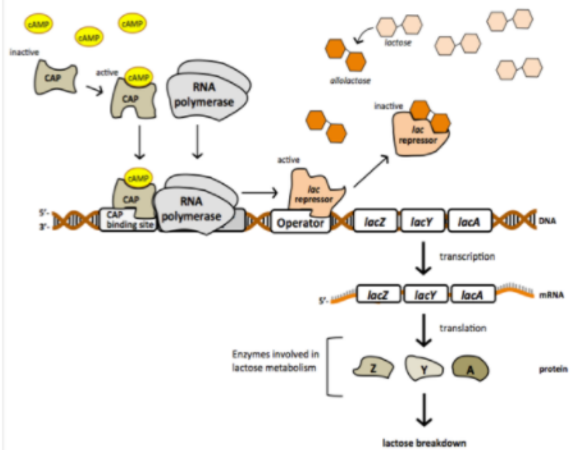
Freshmen (UG) Time:

Created: **12/14/2017** Updated: **12/14/2017**

Regulation of the Lac Operon

version 1.0

Components: **12** Interactions: **11**



Author: **Nicholas Galt**

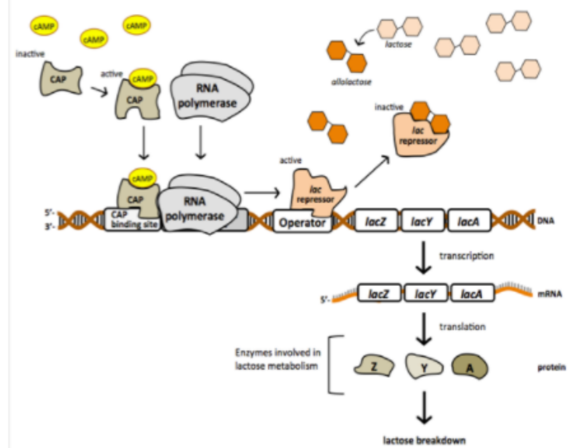
Freshmen (UG) Time: **~ 90 minutes**

Created: **12/14/2017** Updated: **12/15/2017**

Lac Operon Construction

version 1.0

Components: **3** Interactions: **0**



Author: **Nicholas Galt**

Freshmen (UG) Time: **~ 60 minutes**

Created: **12/14/2017** Updated: **12/14/2017**

QUBES QR Survey
Fall 2017-Spring 2018

- We invite you to join our team
- Provide feedback on items
- Create and share items
- Implement survey in your course as part of national study

Thank you

Robert Mayes
rmayes@georgiasouthern.edu

Achievement Level	QR Progress Variable		
	Quantification Act	**Quantitative Interpretation**	**Quantitative Modeling**
Level 4 (Upper Anchor)	**4a** Variation: reasons about covariation of 2 or more variables; comparing, contrasting, relating variables in the context of problem **4b** Quantitative Literacy: reasons with quantities to explain relationships between variables; proportional reasoning, numerical reasoning; extend to algebraic and higher math reasoning (MAA) **4c** Context: situative view of QR within a community of practice (Shavelson); solves ill-defined problems in socio-political contexts using ad-hoc methods; informal reasoning within science context (Steen & Madison; Sadler & Zeidler) **4d** Variable: mental construct for object within context including both attributes and measure (Thompson); capacity to communicate quantitative account of solution, decision, course of action within context	**4a** Trends: determine multiple types of trends including linear, power, and exponential trends; recognize and provide quantitative explanations of trends in model representation within context of problem **4b** Predictions: makes predictions using covariation and provides a quantitative account which is applied within context of problem **4c** Translation: translates between models; challenges quantitative variation between models as estimates or due to measurement error; identifies best model representing a context **4d** Revision: revise models theoretically without data, evaluate competing models for possible combination (Schwarz)	**4a** Create Model: ability to create a model representing a context and apply it within context; use variety of quantitative methods to construct model including least squares, linearization, normal distribution, logarithmic, logistic growth, multivariate, simulation models **4b** Refine Model: extend model to new situation; test and refine a model for internal consistency and coherence to evaluate scientific evidence, explanations, and results; (Duschl) **4c** Model Reasoning: construct and use models spontaneously to assist own thinking, predict behavior in real-world, generate new questions about phenomena (Schwarz) **4d** Statistical: conduct statistical inference to test hypothesis (Duschl)

Achievement Level	QR Progress Variable		
	Quantification Act	Quantitative Interpretation	Quantitative Modeling
Level 3	**3a** Variation: recognizes correlation between two variables without assuming causation, but provides a qualitative or isolated case account; lacks covariation **3b** Quantitative Literacy: manipulates quantities to discover relationships; applies measure, numeracy, proportions, descriptive statistics **3c** Context: display confidence with and cultural appreciation of mathematics within context; practical computation skills within context (Steen); lacks situative view **3d** Variable: object within context is conceptualized so that the object has attributes, but weak measure (Thompson); capacity to communicate qualitative account of solution, decision, course of action within context, but weak quantitative account	**3a** Trends: recognize difference between linear vs. curvilinear growth; discuss both variables, providing a quantitative account **3b** Predictions: makes predictions based on two variables, but relies on qualitative account; uses correlation but not covariation. **3c** Translation: attempts to translate between models but struggles with comparison of quantitative elements; questions quantitative differences between models but provides erroneous qualitative accounts for differences **3d** Revision: revise model to better fit evidence and improve explanatory power (Schwarz)	**3a** Create Model: create models for covariation situations that lack quantitative accounts; struggle to apply model within context or provide quantitative account **3b** Refine Model: extend model based on supposition about data; do not fully verify fit to new situation **3c** Model Reasoning: construct and use multiple models to explain phenomena, view models as tools supporting thinking, consider alternatives in constructing models (Schwarz) **3d** Statistical: use descriptive statistics for central tendency and variation; make informal comparisons to address hypothesis

Achievement Level	QR Progress Variable		
	Quantification Act	**Quantitative Interpretation**	**Quantitative Modeling**
Level 2	**2a** Variation: sees dependence in relationship between two variables, provides only a qualitative account; lacks correlation, erroneously assumes causation **2b** Quantitative Literacy: poor arithmetic ability interferes with manipulation of variables; struggle to compare or operate with variables **2c** Context: lack confidence with or cultural appreciation of math within context; practical computation skills are not related to context **2d** Variable: object within context is identified, but not fully conceptualized with attributes that are measurable; fails to communicate solution, decision, course of action within context; qualitative account without quantitative elements (Thompson)	**2a** Trends: identify and explain single case in model; recognize increasing/ decreasing trends but rely on qualitative account or change in only one variable **2b** Predictions: makes predictions for models based on only one variable, provides only qualitative arguments supporting prediction **2c** Translation: indicate preference for one model over another but do not translate between models ; acknowledge quantitative differences in models but do not compare **2d** Revision: revise model based on authority rather than evidence, modify to improve clarity not explanatory power (Schwarz)	**2a** Create Model: constructs a table or data plot to organize two dimensional data ;create visual models to represent single variable data, such as statistical displays (pie charts, histograms) **2b** Refine Model: extends a given model to account for dynamic change in model parameters; provides only a qualitative account **2c** Model Reasoning: construct and use model to explain phenomena, means of communication rather than support for own thinking (Schwarz) **2d** Statistical: calculates descriptive statistics for central tendency and variation but does not use to make informal comparisons to address hypothesis

Achievement Level	QR Progress Variable		
	Quantification Act	**Quantitative Interpretation**	**Quantitative Modeling**
Level 1 (Lower Anchor)	**1a** Variation: does not compare variables; works with only one variable when discussing trends, **1b** Quantitative Literacy: fails to manipulate and calculate with variables to answer questions of change, discover patterns, and draw conclusions; **1c** Context: does not relate quantities to context or exhibit computational skills **1d** Variable, fail to relate model to context by identifying objects no attempt to conceptualize attributes that are measurable; discourse is force-dynamic; avoids quantitative account, provides weak qualitative account	**1a** Trends: do not identify trends in models **1b** Predictions: avoids making predictions from models **1c** Translation: fail to acknowledge two models can represent the same context **1d** Revision: view models as fixed, test to see if good or bad replicas of phenomena (Schwarz)	**1a** Create Model: does not view science as model building and refining so does not attempt to construct models **1b** Refine Model: accepts authority of model, does not see as needing refinement **1c** Model Reasoning: construct and use models that are literal illustrations, model demonstrates for others not tool to generate new knowledge (Schwarz) **1d** Statistical: does not use statistics; no calculation of even descriptive statistics