Lec 01: Analysis of Animal Populations: Theory and Scientific Process

Key Topics

1. Reminder of the basic theory of animal population dynamics
2. Lay the foundation for the analyses we'll do this semester
3. Review elements of good scientific process

<u>What is a population?</u>

Theory of population dynamics

Population state (size and distribution) is driven by four vital rates:

1. Births
2. Deaths
3. Immigration
4. Emigration

The analysis of animal populations concerns estimating the state(s) or the vital rates of a population and the factors that influence those states and rate. **Estimating these states and rates and modeling what influences them will be the focus of this course.**

<u>Why do we care?</u>

1. Contribution to science = learn stuff
    a. Understanding life history & ecology
    b. Population theory

2. Conservation & management = use what we know to achieve goals = make smart decisions
    a. Increase or sustain populations deemed to be too small
    b. Reduce or Control populations deemed to be too large
    c. Maintain numbers at current levels for populations deemed to be at acceptable levels
    d. Manage for a harvestable surplus in harvested populations

For either goal, we must employ good scientific process to progress

Population Analysis and Good Science

1. Are we asking the right questions?
2. Are we answering the questions we think we're asking?
3. Are we measuring what we think we're measuring?
4. How do we know?

Scientific method

1. Theory
2. Hypotheses
3. Prediction
4. Observation (data collection)
5. Comparison of predictions to data (analysis)
6. Start over

Causation and Science

1. Causes – explanations for patterns we observe, i.e., what is "truth?"
2. Science – as we attempt to develop an understanding of the natural world, it is important to use logic to establish causation

The term "Causation" tends to be used loosely in everyday life, but it has strict logical definitions. When 2 events are observed as usually occurring together, it is common to think of one as the 'cause' and the other the 'effect'. However, this can be problematic, for instance if both occur together 1) by chance, or 2) if neither is cause or effect, but both are the result of some other causal process.

The logic of material implication clarifies causation and defines 2 types as reviewed in Chapter 1 (WNC).

1. Necessary causation - occurrence of effect (E) guarantees occurrence of condition (C)

$$E \rightarrow C \quad \text{(If E, then C)} \quad \ldots \quad \text{Equivalently } {\sim}C \rightarrow {\sim}E$$

2. Sufficient causation - logically stronger than necessary causation: C alone ensures E

$$C \rightarrow E \quad \ldots \quad {\sim}E \rightarrow {\sim}C$$

3. Strongest possible causation is *necessary and sufficient causation*. "If and only if C, then E"

Strength of inference (rigor of scientific study)

1. Experimental manipulation
    a. Using appropriate controls, replication & randomization
    b. Impact studies (before and after)
2. Observational studies (most studies in ecological literature)
    a. Based on *a priori* hypotheses
    b. Based on *a posteriori* description (just story telling)

Developing & Testing Biological Hypotheses

1. State a theory {T}
2. Develop *a priori* hypothesis that asserts claim(s) based on the theory.
3. Deduce predictions of what will be observed if the hypothesis is correct
4. Construct alternative hypotheses and predictions
5. Make observations from study *designed to test predictions*
6. Evaluate *a priori* hypotheses by comparing predictions against data
    - <u>With experimentation</u> leads to sufficient causation & scientific rigor
    - Controls allow us to investigate if the absence of C results in the absence of E, thus, establishing necessity
    - <u>With observation</u> leads to necessary causation at best by inducing from repeated observation of associated events
7. Develop new hypotheses = reasonable use of *a posteriori* description
    - Can be used to develop new hypotheses = exploratory phase
    - Sometimes described in derogatory way as 'data dredging'
8. Replication of studies is important

Types of reasoning

<u>Deductive reasoning</u> is commonly described as working from the general to the more specific. To be more precise, in deductive reasoning the conclusion is necessitated by previously known premises. If the premises are true then the conclusion must be true. For instance, beginning with the premises "sharks are fish" and "all fish have fins", you may conclude that "sharks have fins". This is distinguished from inductive reasoning where inferences can be made with some likelihood but never with complete certainty.

<u>Inductive reasoning</u> is the complement of deductive reasoning and often described as the process of working from the specific to the general, e.g., developing hypotheses from a limited set of observations. Formally, it is the process of reasoning in which the premises of an argument are believed to support the conclusion but do not ensure it. Inductive reasoning is crucial in science as a key process in generating new ideas. But, conclusions drawn by such a method are not certain, and thus, the nature of the

process gives rise to the possibility of being false and necessitates that we accommodate and protect against such errors. We repeat our studies and entertain multiple hypotheses.

Methods of Science

1. Hypothetico- deductive
    a. Null and alternative hypotheses
    b. Seeks disconfirmation of predicted response
    c. Difficulties
        i. Based on assumptions of a single operative hypothesis
        ii. Competitors get eliminated one at a time
        iii. Asymmetry of null and alternative hypotheses
            1. Evidence contrary to hypothesis logically sufficient to disconfirm hypothesis
            2. Evidence supporting hypothesis not logically sufficient to confirm hypothesis
2. Complementary hypotheses
    a. Consider multiple hypotheses simultaneously
    b. Considered reasonable by many in ecology because our science is replete with examples of complementary factors interacting in complex ways to produce observed effects.
    c. Many factors may be operating simultaneously, playing important but unequal roles in influencing population dynamics.
    d. Paradigm of single hypothesis may not be useful and more recently we've seen more emphasis on identifying plausible mechanisms and evaluating their relative contributions by evaluation of multiple competing models. We've also seen a de-emphasis of H_0 testing (see Johnson, D. H. 2002. Journal of Wildlife Management 63:763-772.)
    e. Increased emphasis on
        i. Building a set of competing models, where models represent hypotheses
        ii. Evaluating support for each model from empirical data
        iii. Basing conclusions on set of models
3. Be aware that statistical hypotheses are not the same thing as biological hypotheses. We should start with biological hypotheses.

Models

1. "All models are wrong; some are useful." (G. Box 1979)
2. Models are approximations of reality and don't capture full reality.
3. There are many types of models and uses for models.
4. Models can vary from the conceptual to the physical to the mathematical.
5. A statistical model is a mathematical expression that helps us predict a response (dependent) variable from a hypothesis as a function of explanatory (independent) variables based on a set of assumptions that allow the model not to fit exactly.

6. In applied work, we typically search for the best approximating model by
    a. Building a set of competing models
    b. Collecting data according to a design that will help us discern amongst our models
    c. Confront the models with the data
    d. Evaluate how strongly the data support the various models
    e. Employing the *principle of parsimony*
        i. Defined - Economy in the use of means to an end.
        ii. " … [using] the smallest number of parameters possible for adequate representation of the data." Box and Jenkins (1970:17)
        iii. In the context of our analyses, we strive to be economical in the use of parameters to explain the variation in data.
        iv. We recognize that there is a trade-off between precision and bias when choosing how complex to make our models. If the model is too simple, we will obtain highly precise wrong answers, which are quite dangerous if applied to important problems. In this course, we will use Information-theoretic methods for making the tradeoff.

Modeling

1. What kinds of models exist or what are some ways of categorizing models?
    a. Conceptual models – a set of ideas about how a particular system works
    b. Verbal models – ideas translated into words,
    c. Physical models, and
    d. Mathematical models – ideas translated into mathematical equations
2. What are the uses of mathematical models?
    a. Theoretical uses
    b. Decision-theoretic uses
    c. Empirical uses
        i. either a single or a multiple hypothesis approach
        ii. natural selection of hypotheses
3. How do we confront hypotheses stated as mathematical models with data? This will be one focus of the course.
    a. Use statistical models that contain parameters that can be estimated from data
    b. Start with ideas or conceptual models and convert them to scientific hypotheses
    c. Create statistical hypotheses and models that have observable quantities in them
    d. Collect data and confront competing statistical models with the data
    e. Make inferences about how we think the system works
    f. Science is a progressive endeavor!
    g. Consider carefully past studies and competing hypotheses
    h. Design studies to have maximum ability to discriminate among competing hypotheses

4. When building models:
    a. Define the objective of the modeling effort carefully
    b. Try to retain those variables and processes that are essential
    c. Do not let nature's complexity prevent you from searching for patterns
    d. Consider whether you will be working with descriptive models or mechanistic models and if that choice is reasonable for the given objective

Progress in science and management is strongly conditional on an iterative process of hypothesis development and evaluation.

Our observations combined with our knowledge of existing theory and relevant literature lead us to generate hypotheses that can be evaluated through observational studies, experiments, or both.

Typically, we will need to consider multiple hypotheses expressed as competing models. That is, most problems of interest are complex, and the answers are not readily obvious!

"…**often the critical issue in data analysis is the selection of a good approximating model that best represents the inference supported by the data**…" Burnham and Anderson (1988: vii).

Thus, it is important to consider objective and appropriate methods for finding a good approximating model of empirical data and on making statistical inference from empirical data on a variety of population state variables or vital rates. You will see examples of how to do so for diverse types of mark-recapture data.