Monitoring in Adaptive Management

Chapter 6

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Session Objectives: **By the end of this session, participants will be able to:**

- Frame the role of monitoring in natural resources science and management
- Discuss the roles of monitoring in adaptive resource management
- Address geographic variation and detectability in monitoring programs
- Critique some existing monitoring approaches

Three Key Questions in Monitoring

- Why monitor
    - For what purpose, to address what management/ scientific issue?

- What to monitor
    - What biological/ecological variables to focus on, what attributes to measure over what areas

- How to monitor
    - What techniques to use, sampling designs to employ, analyses to conduct

Why Monitor?

<u>Generically, two reasons</u>

- Science
  - To help us improve scientific understanding
  - i.e., to learn stuff
- Management/conservation
  - To help us make conservation decisions
  - i.e., to manage stuff

<u>Monitoring and Science</u>

- Scientific Process
  - Develop alternative hypotheses
  - Deduce predictions from hypotheses
  - Design experiment or observe system dynamics
  - Collect and analyze data
  - Evaluate hypotheses (did they predict well?)

- Key Component of Science: Confront Predictions with Data
  - <u>Predictions</u> derived from hypotheses
  - <u>Observations</u> of system features via monitoring
  - Confrontation of Predictions vs. Observations
    - Ask whether observations correspond to a hypothesized prediction (single-hypothesis)
    - Use correspondence between observations and predictions to help discriminate among hypotheses (multiple-hypothesis)

- How Do We Generate System Dynamics to Test Hypotheses?
  - Study design that involves direct manipulation of some sort
    - Manipulative experiment (randomization, replication, controls)
    - Impact study (lacks randomization and perhaps replication, but includes time-space structure)
  - Observational study without manipulation
    - Prospective study (confrontation with predictions from *a priori* hypotheses)
    - Retrospective study (*a posteriori* story-telling)

- Opinions About Retrospective Story-telling
  - Claims:
    - It is easy to view a time series of abundance estimates and build a story about the stochastic process that generated it.
    - It is unwise to place much confidence in such a story.
  - Phaedrus' Law:
    - "The number of rational hypotheses that can explain any given phenomenon is infinite." (Pirsig 1974, Zen and the Art of Motorcycle Maintenance)

- Strength of Inference
  - Manipulative experiment > Impact study > Observational study
  - Within observational studies:
    - Prospective (*a priori* hypotheses) > Retrospective (*a posteriori* stories)

Monitoring and Management

- Roles of Monitoring
  - State-dependent decision making: To assess the current state of the system, in order to determine which action to take
  - Evaluation of management performance
  - Learning, to increase understanding of ecological dynamics and the effects of management on them
  - Parameter estimation for current and future models

- Technical Elements in Adaptive Management
  - Objective(s): what do you want to achieve
  - Management alternatives: stuff you can do
  - Models to generate predictions of how the system will respond to management actions
  - Measures of credibility for the models
  - Monitoring program to estimate system state and other relevant variables

- Adaptive Management Process
  - Identify management objectives and management options
  - Use models to predict hypothesized responses to management
  - Select management action based on:
    - (1) objectives
    - (2) available management options
    - (3) estimated state of system
    - (4) predicted response to management actions
  - Apply the selected management action
  - Use monitoring to estimate system response to management
  - Compare estimated and predicted responses
    - To evaluate predictive ability of models

Science	Management
• Develop alternative hypotheses	• ID objectives and options
• Deduce predictions using models representing hypotheses	• Deduce predicted system response using models representing hypotheses
• Implement experiments/surveys	• Select and apply management action(s)
• Collect data and estimate system dynamics/response	• Use monitoring to estimate system response to management
• Compare estimated and predicted responses (evaluate hypotheses)	• Compare estimated and predicted responses

What to Monitor?

- Depends on management or science questions
  - variables being measured must be relevant to management objectives and/or science hypotheses
- Depends on geographic and temporal scale
  - larger scale typically means more variability, but may also mean less need for detailed site-specific or time-specific information
- Depends on fiscal resources and personnel that are available for monitoring
  - less effort required for species richness, patch occupancy; more effort required for abundance

How to Monitor?

Two Basic Sampling Issues

- Geographic variation
  - Counts/observations often cannot be conducted over an entire area of interest
  - Proper inference requires a spatial sampling design that:
    - Permits inference about entire area based on a sample, and/or
    - Provides good opportunity for discriminating among competing hypotheses
- Detectability
  - Counts represent some unknown fraction of organisms in a sampled area
  - Proper inference requires information on detection probability

Issue 1: Geographic Variation

- Spatial sampling designs
  - Simple random sampling
  - Stratified random sampling
  - Systematic sampling
  - Cluster sampling
  - Double sampling
  - Adaptive sampling
  - Dual-frame sampling
- All approaches are designed to allow inferences to places you don't sample, based on information from places where you do

Issue 2: Detectability

- Monitoring is almost always based on counts
  - Ungulates seen while walking a line transect
  - Tigers detected with camera-traps
  - Birds heard in point counts
  - Small mammals captured on a trapping grid
  - Bobwhite quail harvested during hunting season
  - Kangaroos observed while flying aerial transects

Detectability: Conceptual Basis

- N = abundance
- C = count statistic
- p = detection probability; P(member of N appears in C)

$$E(C) = pN$$

Detectability: Inference

- Inferences about N require inferences about p

$$\hat{N} = \frac{C}{\hat{p}}$$

Monitoring Methods and Detectability

- Many estimation methods (e.g., Seber 1982, Williams et al. 2002)
- Each estimation method is simply a way of estimating detection probability for the count statistic of interest
- Final step is always:

$$\hat{N} = \frac{C}{\hat{p}}$$

So how about using indices?

- Comparisons across time (trend)
- Comparisons across space (relative abundance)
- Comparisons across species (relative abundance)
- Comparisons based on habitat attributes

The problem is that indices must assume equal detectability

- N_i = abundance for time/place *i*
- p_i = detection probability for *i*
- C_i = count statistic for *i*

$$\lambda_{ij} = N_j / N_j \qquad \hat{\lambda}_{ij} = C_j / C_i$$

$$E(\hat{\lambda}_{ij}) = E\left(\frac{C_j}{C_i}\right) \approx \frac{p_j N_j}{p_i N_i} = \lambda_{ij}\left(\frac{p_j}{p_i}\right)$$

Rate Parameters that are relevant to changes in abundance

- Population growth rate
- Survival rate, harvest rate
- Reproductive rate (young per breeding adult)
- Breeding probability
- Movement rate
- Process variance
- Slope parameters for functional relationships

Detectability included in estimating all of the above

What Can be Done to Deal with Variation in Detectability?

- Use <u>standardization</u> to control sources of variation that can be identified
- Use <u>covariates</u> for variation sources that can be identified and measured, *and* are independent of the quantity of interest
- Use <u>hope and faith</u> for variation sources that cannot be identified, controlled, or measured
- ESTIMATE DETECTABILITY!

Observation-based Count Statistics

- Distance sampling
- Double sampling
- Marked subsets
- Multiple observers (dependent, independent)
- Sighting probability modeling
- Temporal removal modeling

Detectability factors directly into all of the above

Capture-based Count Statistics

- Closed-population capture-recapture models
- Open-population capture-recapture models
- Removal models (constant and variable effort)
- Trapping webs with distance sampling
- Change-in-ratio models

Detectability factors directly into all of the above

Summary on Detectability

- Detectability permeates methodologies for estimating community and single species dynamics
- To reliably address biologically interesting questions about population and community dynamics, detectability must be treated in some way

Surveillance Monitoring

- Monitoring in the absence of guiding hypotheses about system behavior
- Scientific approach: retrospective study of observations
- Objective:
  - Determine if population is going up or down
  - To learn about a system and its dynamics by observing time series of system state variables
- Many existing programs were designed as surveillance programs
- New programs: should not be default approach

- Surveillance Monitoring and Science
  - "Biology, with its vast informational detail and complexity, is a 'high-information' field , where years and decades can easily be wasted on the usual type of 'low-information' observations and experiments if one does not think carefully in advance about what the most important and conclusive experiments would be." (Platt 1964)

- Surveillance monitoring can be a form of intellectual displacement behavior
  - Lots easier to suggest collection of more data than to think hard about the most relevant data to collect for science or management
- At cynical worst, surveillance monitoring can be a political delaying tactic
  - "We must collect more information before we can act."
- Regardless of motivation
  - Feeds anti-science view of science as never-ending story with few answers and little interaction with real world decision-making

Trend detection

- In Science: of most use when
  - o Different trends are expected before and after some event that is hypothesized to dominate post-event dynamics
  - o Different trends are expected for exposed and unexposed locations
  - o But note that such comparisons are not the basis for sample size and design considerations proposed by many existing monitoring programs

- In Management:
  - o Not designed to provide estimates of state for:
    - State-dependent decisions
    - Comparison with model-based predictions
  - o Trend most likely to be useful when management involves a single intervention
    - where trends can be compared before and after action
    - and trends can be compared for locations exposed to a management action and other locations not exposed to the action

Recommendations

Why Monitor?

- Monitoring is most useful when integrated into efforts to do science or management
- Role of monitoring in science
  - o Comparison of data with model predictions to discriminate among competing hypotheses
- Role of monitoring in management
  - o Estimation of system variables that allow for
    - State-specific decisions
    - Assessing success of management relative to objectives
    - Discriminating among competing hypotheses about management impacts

What to Monitor?

- The decision should be based on overall program objectives (i.e., determined by the scientific or management context)
- Decision should consider required scale and effort
- Decision should focus on reasonable state variables
  - Species richness
  - Patch occupancy
  - Abundance

How to Monitor?

- Account for geographic variation
  - When counts/observations cannot be conducted over entire area of interest
  - And proper inference requires well designed spatial sampling
    - To permit inferences about entire area based on a sample
    - To provide the opportunity for discriminating among competing hypotheses
- Focus on detectability
  - Because counts/observations represent some unknown fraction of organisms in sampled area
  - And proper inference requires information on detection probability

Final Reminders

- Don’t forget that answers to “what?” and “how?” are largely dictated by the answer to why?
- Don’t forget to tailor your monitoring efforts to the answers you give these questions
- Don’t forget about spatial sampling and detectability
- Don’t forget to tie your design to the key roles the monitoring plays in adaptive management (this course)