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
  o For what purpose, to address what management/ scientific issue?

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

• How to monitor
  o What techniques to use, sampling designs to employ, analyses to conduct
Why Monitor?

Generically, two reasons

- **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

Monitoring and Science

- **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**
  - Predictions derived from hypotheses
  - Observations 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 \textit{a priori} hypotheses)
    - Retrospective study (\textit{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
  o Identify management objectives and management options
  o Use models to predict hypothesized responses to management
  o Select management action based on:
    ▪ (1) objectives
    ▪ (2) available management options
    ▪ (3) estimated state of system
    ▪ (4) predicted response to management actions
  o Apply the selected management action
  o Use monitoring to estimate system response to management
  o Compare estimated and predicted responses
    ▪ To evaluate predictive ability of models

<table>
<thead>
<tr>
<th>Science</th>
<th>Management</th>
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<tbody>
<tr>
<td>• Develop alternative hypotheses</td>
<td>• ID objectives and options</td>
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<td>• Deduce predictions using models representing hypotheses</td>
<td>• Deduce predicted system response using models representing hypotheses</td>
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<td>• Implement experiments/surveys</td>
<td>• Select and apply management action(s)</td>
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<tr>
<td>• Collect data and estimate system dynamics/response</td>
<td>• Use monitoring to estimate system response to management</td>
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<tr>
<td>• Compare estimated and predicted responses (evaluate hypotheses)</td>
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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; \( P(\text{member of } N \text{ appears in } C) \)

\[
E(C) = pN
\]

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

- $N_i = \text{abundance for time/place } i$
- $p_i = \text{detection probability for } i$
- $C_i = \text{count statistic for } i$

$$\lambda_{ij} = \frac{N_j}{N_j} \quad \hat{\lambda}_{ij} = \frac{C_j}{C_i}$$

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

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 standardization to control sources of variation that can be identified

- Use covariates for variation sources that can be identified and measured, and are independent of the quantity of interest

- Use hope and faith 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
  - Different trends are expected before and after some event that is hypothesized to dominate post-event dynamics
  - Different trends are expected for exposed and unexposed locations
  - But note that such comparisons are not the basis for sample size and design considerations proposed by many existing monitoring programs

- **In Management:**
  - Not designed to provide estimates of state for:
    - State-dependent decisions
    - Comparison with model-based predictions
  - 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
  - Comparison of data with model predictions to discriminate among competing hypotheses
- Role of monitoring in management
  - 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
  o Species richness
  o Patch occupancy
  o Abundance

How to Monitor?
• Account for geographic variation
  o When counts/observations cannot be conducted over entire area of interest
  o 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
  o Because counts/observations represent some unknown fraction of organisms in sampled area
  o 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)