Monitoring in Adaptive Management

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Objectives of Presentation

- 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 natural resources monitoring
- Critique some existing monitoring approaches
- Make a few simple recommendations about resource monitoring
3 Key Questions in Monitoring

- What to monitor
  - What biological/ecological structures 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
  - For what purpose, to address what management/scientific issue?
Why Monitor? Generically, Two Reasons

- **Science**
  - To improve scientific understanding of resources
  - 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)
  - Discriminate among competing 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 (comparison of data against predictions from \textit{a priori} hypotheses)
  - Retrospective study (\textit{a posteriori} story-telling)
Opinions About Retrospective Story-telling

- Claims:
  - (1) It is easy to view a time series of abundance estimates and build a story about the stochastic process that generated it.
  - (2) 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 Adaptive Management

Roles

- **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 models
- Monitoring program: to estimate system state and other relevant variables
Adaptive Management

Process

- Identify management objectives and management options
- Use models to predict 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 performance and improve predictive ability
Science and Management

Science
- Develop alternative hypotheses
- Deduce predictions using models representing hypotheses
- Implement experiments/surveys
- Collect data and estimate system dynamics/response
- Compare estimated and predicted responses (evaluate hypotheses)

Management
- ID objectives and options
- Deduce predicted system response using models representing hypotheses
- Select and apply management action
- Use monitoring to estimate system response to management
- 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 observations:

- 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

What is observed differs from what is actually there!
Detectability: Conceptual Basis

- $N = \text{abundance}$
- $C = \text{count statistic}$
- $p = \text{detection probability, i.e., Prob(member of } N \text{ appears in } C)$

$$E(C) = pN$$
Detectability: Inference

- Inferences about $N$ require inferences about $\rho$:

$$\hat{N} = \frac{C}{\hat{\rho}}$$
Abundance and Detectability

- Traditional monitoring focus:
  - Variation over time: trend
  - Variation over space or species: relative abundance

- 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 \( i \)
- \( p_i = \) detection probability for \( i \)
- \( C_i = \) count statistic for \( i \)

\[
\lambda_{ij} = \frac{N_j}{N_i}
\]

\[
\hat{\lambda}_{ij} = \frac{C_j}{C_i}
\]

Then

\[
E(\hat{\lambda}_{ij}) = E\left(\frac{C_j}{C_i}\right) \approx \frac{p_j N_j}{p_i N_i} = \lambda_{ij} \left(\frac{p_j}{p_i}\right)
\]
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!**
What Happens if You Don’t Estimate Detection, $p$?

- $N$ is underestimated to an unknown degree
  \[\hat{N} = \frac{C}{\hat{p}}\]
- Density-dependent effects are misrepresented to an unknown degree
- Estimated population trends and other rate parameters are biased in an uncertain direction, to an uncertain degree
- Population comparisons across areas are unsupportable without further assumptions
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

- 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
Trend Detection 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 resource attributes that allow for
    - State-specific decisions
    - Assessing success of management relative to objectives
    - Discriminating among competing hypotheses about management effects
Recommendations: 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
Recommendations: 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 what and how you monitor depend on why you choose to conduct monitoring in the first place.

- So don’t forget to ask the key question, “why”, and responses to “what” and “how” will come more easily.

- 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.