Management of populations under uncertainty

Katriona Shea
The Pennsylvania State University
k-shea@psu.edu
Applied Theoretical Ecology

- Ecological theory
- Application to systems of special concern
- Conservation
- Harvesting
- Invasions and pest control
Management in an uncertain world:

• **process uncertainty**
  natural processes are inherently variable

• **model uncertainty**
  uncertainty about underlying biological processes

• **observation uncertainty**
  sampling errors while monitoring
Presentation overview

- Conservation of harvested species
- Captive breeding
- Biological control releases
- Management of invasive thistles
- Active adaptive management
Conservation of harvested saiga under uncertainty

Saiga antelope (Saiga tatarica) in Kazakhstan
Approach

- First developed by International Whaling Commission
- Use a simulation model to explore the performance of management strategies under a broad range of assumptions
- Tested on a hidden population model
Performance criteria over 50 years

• Conservation
  – Probability of falling below 200,000 individuals at any time <5%
• Revenue
  – Maximize total discounted revenue
• Variability
  – Minimize variability in revenue
    (both within and between realizations)
Management Strategy
(operates only through data)

Abundance estimates (flawed)

Population model

Harvest Limits

Add poaching

Harvest data (legal only)

Actual harvest (legal and illegal)

Conservation Performance Indicator (threshold)

Harvest rate

Response to harvest

Economic Performance Indicator (profit & CVs)
Performance criteria over 50 years

- Conservation
- Revenue
- Variability

All three indicators are used to assess performance – combining into one summary statistic is subjective.
Process

• Junior authors submitted strategies
• Given access to data on biology, climate and harvest BUT NOT the model structure or parameters
  
  Ensured separation of strategies and model
• Strategies tested under a base case scenario
  – Most failed!
• Managers given feedback about own strategies
• Testing of revised strategies against robustness criteria
• Then given information about other managers strategies
• Testing and feedback repeated
Robustness trials - combinations of:

- **Population model**
  - Carrying capacity, trends in K, density dependence
- **Abundance and sex ratio estimates**
  - Bias, error and trends in estimates
- **Economic variables**
  - Discount rates, horn:meat price differentials
- **Poaching**
  - As a percentage of legal take or of actual population size
Results: insights

• It is possible to have high revenue and low variability
• Performance in base scenario no indicator of robustness
• Some strategies recommended from simple theory perform very poorly
Results: poor performers

- Harvesting all above a threshold
- Any heavy harvesting strategy (even when the population is large)
- Strategies reliant on climate and sex ratio
Results: good performers

- Strategies reliant on growth rates
- Simpler strategies (added benefit of being easier to implement)
- Relatively small harvests
- Harvest high proportion of males (harem breeder)
Captive breeding

Brigitte Tenhumberg, Drew Tyre, Katriona Shea and Hugh Possingham. Linking wild and captive populations to maximize species persistence: optimal translocation strategies
Identifying Optimal Captive Breeding Strategies

1. Captures:
   - When should we start a captive population?
   - How many animals should we capture?

2. Releases:
   - When should we start releasing animals?
   - How many animals should we release?
Managing Two Populations

$1^{st}$ Order Markov Chain Models

Captive Population  Wild Population
Arabian oryx
Historical Distribution in 1800
History

- **Overhunting**
  - hunting by Bedouin for meat and hides
  - sport hunting by motorized parties
  - The last animal in the wild was shot in 1972

- **Re-introductions**
  - Oman (1982)
    - poaching started in 1996
  - Jordan, Israel and Saudi Arabia.
Stochastic dynamic programming (SDP)

SDP is a formal approach to decision theory.

It is a mathematical programming algorithm for solving complex, stochastic, state-dependent optimization problems.
Stochastic Dynamic Programming (SDP) - Model

- **Objective**
  - minimize the extinction probability of the species in the wild

- **State variables**
  - captive population, $c$
  - wild population, $w$
  - time, $t$

- **Management decision**
  - changes the state variables
State Space

- $t$: time
- $c$: captive population
- $w$: wild population

$F(t, w, c)$

- **Do Nothing**
  - $F(t+1, w, c)$

- **Release**
  - $F(t+1, w+1, c-1)$

- **Capture**
  - $F(t+1, w-1, c+1)$
Stochastic Dynamic Programming (SDP) - Model

- Calculating extinction probability associated with each decision from a set of possible decisions for each combination of states

- Lowest extinction probability \( \rightarrow \) optimal management decision
Assumptions I

- Propagation in captivity is successful
- Population dynamics are influenced only by demographic stochasticity
  - No environmental stochasticity (droughts in the wild, no disease outbreak in captive population)
- No long-term effects of captivity
  - No inbreeding depression
  - 1 yr after releasing an animal it is identical to wild animals
Assumptions II

• Carrying capacity, $K$
  – captivity = 20 animals
  – wild = 50 animals
• Each translocation costs = 0.05 (increased mortality rate)
Assumption: $r_{\text{captive}} = 1.3$

$r_{\text{wild}} = 0.85$

Striped area: captures = wild population
Comparison of two Scenarios

Red: Captures; Green: Releases

$r_{\text{Wild}} = 0.85$

$r_{\text{Wild}} = 1.13$
Rules of thumb

• Capturing entire wild population at relative large population sizes
  – even if wild population is growing
• Preserve captive population during releases
What if ....

1. ... breeding success changes?
2. ... conditions in the wild change?
1. Breeding Success in Captivity

$\hat{r}_{\text{Wild}} = 0.85$

Releases: green
Captures: red

Striped area:
captures = wild population
1. Breeding Success in Captivity

\[ r_{\text{Captivity}} = 1.0, 1.1, 1.2, 1.3 \]

\[ r_{\text{wild}} = 0.85 \]

The thicker the lines the higher \( r_{\text{captivity}} \).
What if …

<table>
<thead>
<tr>
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<th>Releasing</th>
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<tbody>
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<td>1. $r_{\text{captivity}}$</td>
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<td>↓</td>
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<tr>
<td>2. $r_{\text{wild}}$</td>
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2. Growth Rate in the Wild

\[ r_{\text{Wild}} = 0.9, 0.8, 0.7 \]

\[ r_{\text{captivity}} = 1.3 \]

- The thicker the lines, the higher \( r_{\text{Wild}} \).

- Releases
- Captures

What if …

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Rules of thumb

- **Captures**
  
  Entire wild population at relative large population sizes
  
  Robust over a wide range of
  
  \( r_{\text{wild}} : r_{\text{captivity}} \) combinations

- **Releases**
  
  Preserve captive population during releases
  
  no releases if:
  
  \[
  \begin{align*}
  r_{\text{captivity}} & = 1.0 \\
  r_{\text{wild}} & < 0.85
  \end{align*}
  \]
Optimal Release Strategies for Biological Control Agents

We have limited natural enemies for biological control. We want to establish secure populations target sites in the next few years.

- Strategy 1: many small
- Strategy 2: mixed
- Strategy 3: few large
Stochastic
Dynamic
Programming

Established

Insecure

Empty

$g$

$p(x)$

$e_s$

$e_n$
Probability of establishment \( p(x) = (1 - e^{-ax^2})^2 \)
Strategy 1: many small
Strategy 2: mixed
Strategy 3: few large

Probability of establishment of small releases = low

Number of insecure populations, n

Number of established populations, s
Strategy 1: many small
Strategy 2: mixed
Strategy 3: few large

Number of insecure populations, \( n \)

Number of established populations, \( s \)

Probability of establishment of small releases = medium
Strategy 1: many small

Strategy 2: mixed

Strategy 3: few large

Number of insecure populations, $n$

Number of established populations, $s$

Probability of establishment of small releases = high
Learning

Single optimal release sizes exist for most states of the system
Learning

Single optimal release sizes exist for most states of the system

The problem: you don’t know what they are
Learning

Single optimal release sizes exist for most states of the system

The problem: you don’t know what they are

Mixed strategies allow you to learn about your system.
Management of *Carduus nutans* (nodding or musk thistle)

Collaborators:

Dave Kelly, Andrew Sheppard and Tim Woodburn
Carduus nutans: origin and status

• native of Europe, Asia Minor and North Africa
• exotic weed in:
  • North and South America
  • New Zealand
  • Australia (invaded from NZ populations)
  • Southern Africa
Carduus nutans: life history

- monocarpic perennial
- dispersal - wind, water, animals
- long-lived seedbank
Ecological models for management of nodding thistle

- New Zealand
  Shea & Kelly (1998) *Ecological Applications*

- Australia
  Andy Sheppard & Tim Woodburn (*in review*)
Carduus nutans - annual transitions
Elasticity

• The proportional change in the population growth rate resulting from a proportional change in a given transition
Major differences in size dependent flowering and fecundity

- **Graph 1:**
  - X-axis: size (cm²)
  - Y-axis: probability of flowering
  - Data points for Australia and New Zealand

- **Graph 2:**
  - Bar chart showing fecundity of flowering plants
  - Categories: small, medium, large
  - Data for Australia and New Zealand
Why the differences?

Theory of invasions
Management implications

• Management of the same species may be context dependent
• Cannot immediately extrapolate from elsewhere
Biological control history

- Seed feeder (*Rhinocyllus conicus*) reported effective in North America.
- Released into NZ - less successful
- In Australia, a rosette feeder (*Trichosirocalus horridus*) is providing control
Trichosiocalus horridus damage

Sampled 31 October 96

Larger plants (15cm) in February

Attacked Plants

Control Plants
Management implications

- Management of the same species must perforce be context dependent
- Cannot immediately extrapolate from elsewhere

How can we accommodate this uncertainty?
Saiga and Oryx

Accommodate uncertainty with “robust” management strategies
Biocontrol and invasions
Active adaptive management


Approaches to management

- **passive**
  keep doing the same thing

- **reactive**
  deal with events as arise

- **passive adaptive**
  modify management on basis of previous outcomes

- **active adaptive**
  plan to learn: experimental management
Active adaptive management: AAM

Ecological intervention with a plan for learning about the system

Most useful when there will be a high number of replicates in space and time
AAM process

develop competing models
(acknowledge uncertainties)
assign measures of likelihood
(Bayesian prior probabilities)
choose system variables to measure
design management options
assess expectations
try the management
monitor outcomes
update model credibility
Active Adaptive Management

Huge scope for learning as we manage