Outline

1. Bad news
   • Variation and uncertainties
     - Are widespread
     - Create risks

2. Good news
   • Research is reducing uncertainties

3. Bad news
   • Large variation remains

4. Good news
   • Methods to deal with remaining uncertainties
Acknowledgments

- Fisheries management agencies
  - Alaska Dept. of Fish and Game
  - Canada Dept. of Fisheries and Oceans
  - Washington Dept. of Fish and Wildlife
1. Bad news

- Variation and uncertainties are pervasive
- Uncertainties create risks
  - Biological risks (fish populations)
  - Economic risks (industry)
  - Social risks (coastal communities)
"Variation in survival rates of salmon stocks across space and time: how much of it can we expect to explain or forecast?"

Randall M. Peterman

School of Resource and Environmental Management (REM)
Simon Fraser University,
Burnaby, British Columbia, Canada
Sockeye salmon, Bristol Bay, Alaska

Number of adult salmon returning (millions)

- Forecast returns
- Actual returns

Year

- 1996
- 1997
- 1998
- 1999

- !!!
- ….?
Natural Aquatic System

Variability

Measurement error

Sampling, data collection

Scientific research

What we know

What we don't know

Management objectives

Partial knowledge

Stakeholders

Decision makers

Fishing regulations (closed areas, harvest goals, ...)

Harvesting

Implementation error

Non-compliance

Lack of clarity

What we don't know
Scientific research

What we know

What we don't know

Natural Aquatic System

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Harvesting

Non-compliance
• Variation over time in productivity and abundance
• Variation over space in """"""""""""""
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2. **Good news**

- Some patterns exist in the variation over time and across space
**Pattern or structure over time**

Relative productivity (Standardized deviation of log recruits per spawner from expected)

**Naknek R. sockeye**

- Brood Year
- Relative productivity
- $P < 0.02$

**Wood R. sockeye**

- Brood Year
- Relative productivity
- $P < 0.001$
Productivity estimates

Signal + Noise

Data

Standard method

Productivity estimates

Signal

Noise

Kalman filter method
• Used Kalman filter to reconstruct historical variation in productivity
  (Maximum recruits per spawner, or Ricker 'a' parameter)
Historical productivity of Bristol Bay sockeye using a Kalman filter

Productivity (Ricker 'a' parameter)

Egegik

Kvichak

Brood Year
Historical productivity of Bristol Bay sockeye

Branch

Egegik

Igushik

Kvichak

Naknek

Togiak

Ugashik

Wood
Pattern or structure across space

• Compiled data (1950s through 2001) on productivities of numerous salmon stocks

• Compared time series to look for patterns of similarity
120 salmon stocks; averaging 31 years of data

Pink salmon
- 43 stocks

Chum salmon
- 40 stocks

Sockeye salmon
- 37 stocks
Chignik pink salmon productivities

Relative productivity (standardized)

Brood Year

r = 0.67
**Pattern or structure across space**

- Relative productivities of different salmon stocks are correlated...
  but only to a limited spatial extent
**Pink** salmon stocks

Spatial pattern or structure: Correlations among stocks' relative productivities
Regions of positive correlation in productivity of pink salmon stocks

- Norton Sound
- Bristol Bay
- Alaska Peninsula
- Cook Inlet
- Chignik
- Kodiak
- Prince William Sound
- Yakutat
- Southeast Alaska
- Northern B.C.
- Central B.C.
- Mainland B.C.
- Fraser River
- Washington

500 km
Summary of salmon spatial scales

• Regional-scale positive correlation in productivities (~500 to 800 km)
  - pink, chum, sockeye

• Likely arises during early life in ocean
  - Summer sea-surface temperature (SST)
• Multi-stock statistical models of salmon productivity using region-specific summer SST as explanatory variable

- Advantage: used information from many stocks simultaneously
43 pink salmon stocks

Change in salmon productivity per degree increase in summer sea-surface temperature

Single-stock model
Multi-stock model
Multi-stock model with summer SST helps explain variation in productivity

But:
Can this model improve annual forecasts of abundance?
- Looked at past changes ("retrospective analyses")
- Compared multi-stock model's forecasts to other models
Sibling model for Egegik sockeye

Age-3 recruits in year $t$ (millions)

Age-4 recruits in year $t+1$ (millions)
Pink-index model for Prince William Sound chum

Chum salmon productivity index

Pink salmon productivity index

$r = 0.71$
Pink-index model for Prince William Sound chum

Chum salmon productivity index

Pink salmon productivity index


$r = 0.71$

Lead time
Sockeye salmon, Ugashik R., Alaska

Abundance of adult recruits (millions)

Return year

- Observed
- Multi-stock forecast
Sockeye salmon (Alaska)

Mean % error in forecasts of recruits

Type of forecasting model

- R(t-1)
- R(t-5)
- 5-yr Avg
- Std. Ricker
- Ricker+SST
- Ricker AR(1)
- Multi-stock
- KF-RW
- Pink Index
- Sibling
Chum salmon (Wash., B.C., Alaska)

Mean % error in forecasts of recruits

Type of forecasting model
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3. **Bad news**

**Large uncertainties remain**

- Despite more complex models:
  - Sibling age-class models
  - Between-species models *(pink-chum)*
  - Kalman filter
  - Multi-stock models, including SST
If we cannot forecast very well even one year ahead, can we at least track changes in productivity close to when changes occur?

- Compared various models
- Looked at future changes
Tracking changes

• Simulated hypothetical changes in productivity (e.g. climatic change or freshwater habitat)

• Tested methods in "operating model" (analogous to a flight simulator)
  - Based on real data
Variability
Natural Aquatic System
Measurement error
Sampling, data collection
Scientific research
What we know
What we don't know
Partial knowledge
Management objectives
Lack of clarity
Decision makers
Fishing regulations (closed areas, harvest goals, ...)
Harvesting
Implementation error
Non-compliance
"Operating model"
Index of Productivity (Ricker 'a')

"True"
Standard method (Ricker)
Kalman Filter

Index of Productivity (Ricker 'a')
Long-term benefits in harvests

Relative harvest of fish

Kalman filter  Standard method

With implementation error and non-compliance
Conclusions from simulations

• Kalman filter
  - Can improve tracking compared to standard approach

• But... considerable uncertainty remains
Outline

1. **Bad news**
   - Variation and uncertainties
     - Are widespread
     - Create risks

2. **Good news**
   - Reducing uncertainties through research

3. **Bad news**
   - Large variation remains

4. **Good news**
   - Methods to deal with remaining uncertainties
With research appropriately cautious harvesting & management actions

Relative magnitude

High
Uncertainty
Risk

Uncertainty
Risk

Uncertainty
Risk
To further reduce risks

• When providing scientific advice to
  - Alaska Board of Fish
  - Fishing industry
  - Fisheries management agencies,

Must include:
  -- Statements of uncertainties and risks
  -- Sensitivity analyses
  -- Management implications of uncertainties

• Risk assessments
• Decision analysis
• Precautionary approach
Consider uncertainties and risks

Example #1:
• Invest now in a C.D. in your retirement account with:
  - Historically highly variable interest rate
  - Interest rate unknown until C.D. comes due!

• Result:
  - Manage cash flow cautiously
    -- Consider large uncertainties and risks when evaluating withdrawals
Consider uncertainties and risks

Example #2:

• Invest now in salmon spawners with:
  - Highly variable productivity (~interest rate)
  - Productivity unknown until adults return!

• Result:
  - Manage harvest (~cash flow) cautiously
    -- Consider large uncertainties and risks when evaluating harvesting options.
Precautionary principle (no cash withdrawals) and
Precautionary approach (moderate cash withdrawals)

- Choosing appropriate level of precaution

Precaution:
"An action taken in advance to protect against possible danger; a safeguard"
Apply precautionary principle
- Ban dumping of wastes in oceans
- Ban ozone-depleting substances
- Ban fishing (B.C. coho salmon)

Apply precautionary approach
- Allow fishing but use safety margins for harvest regulations
- Monitor and adjust actions
Precautionary actions

Take action, even in presence of uncertainties, but...

• Take uncertainties into account

• Apply prudent foresight

• Reduce chance of irreversible changes

• *Give priority to maintaining biological productivity over long term*
Precautionary actions in fisheries management

See:

United Nations' Food and Agriculture Organization (FAO)
Other fisheries applications of **precautionary actions**

- Commission for Conservation of Antarctic Marine Living Resources
- FAO *"Code of Conduct for Responsible Fisheries"
- 1995 United Nations *"Agreement on Highly Migratory and Straddling Fish Stocks"*
How choose appropriate level of **precaution**?

Restrictions imposed on human activities

Severe

None

- Action 1?
- Action 2?
- Action 3?

Choose:
- Arbitrarily
- With support of quantitative risk analyses
Quantitative analyses to support decision making

Risk assessment (Risk analysis)
- System processes
- Indicators of risks
- Uncertainties

Decision analysis
- Management objectives
- Ranking of management options

Risk management (make decision)
- Consider other factors
- Make tradeoffs
Effect of uncertainty on recommended action

- **Recommended harvest rate (%)**
- **Safety margin (reflects uncertainty)**

Uncertainty in abundance estimate (Coefficient of Variation)
Conclusions

1. Variation and uncertainties
   - Common and large
   - Create risks

2. Researchers are making progress; scientific understanding is improving.
Conclusions (continued)

3. Still have large variation and uncertainties

4. To reduce risks,
   Fishing industry and management agencies must account for uncertainties through:
   - Precautionary actions
   - Risk assessments and decision analyses
Relevant publications

For survival rates:
- Mueter et al. (2002) CJ FAS 59:456 (all 3 species)

For oceanographic variables:

CJ FAS* = Canadian Journal of Fisheries & Aquatic Sciences