Integrated analysis: the worst thing that happened to fisheries stock assessment

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Outline

• What is integrated analysis?
• Data conflict and model misspecification
• The problem with catch composition data
• What we know about population processes
• What processes change over time
• Diagnostics
• Conclusions
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Introduction

Steven X. Cadrin and Mark Dickey-Collas

Stock assessment methods for sustainable fisheries


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Original Articles

Mark N. Maund and Kevin R. Piner

Contemporary fisheries stock assessment: many issues still remain


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Simulation testing the robustness of stock assessment models to error: some results from the ICES strategic initiative on stock assessment methods


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What is integrated analysis?
What is integrated analysis?
What is integrated analysis?

Diagram:
- Juveniles
  - Natural Mortality
  - Growth
  - Recruitment
- Adults
  - Natural Mortality
  - Fishing
  - Movement
  - Recruitment

Elements:
- Growth
- Fishing
- Movement
What is integrated analysis?

- Juveniles
  - Natural Mortality
  - Growth
  - Recruitment
  - Index of abundance
  - Tagging

- Adults
  - Natural Mortality
  - Fishing
  - Movement
  - Index of abundance
  - Tagging

- Age-length data
- Catch
- Index of abundance
Why not analyze each data set separately?

• Information may be lost when data are summarized.
• Difficulty in fully accounting for uncertainty.
• The different analyses may be logically inconsistent.
• Reduced diagnostic ability.

What is integrated analysis?

- Juveniles
  - Natural Mortality
  - Length frequencies
  - Age-length
  - Tagging
  - Recruitment
- Adults
  - Natural Mortality
  - Tagging
  - Fishing
  - Movement

Tagging

Growth

Age-length
What is integrated analysis?

- Juveniles
  - Natural Mortality
  - Growth
  - Recruitment
  - Catch-at-age data

- Adults
  - Natural Mortality
  - Fishing
  - Movement
  - Catch-at-age data
Why is integrated analysis the worst thing that happened to fisheries stock assessment?

• We have adopted the mindset in which sophisticated statistical models that integrate diverse types of data and information (e.g. Bayesian priors) can overcome lack of data and biological information
• We do not collect the right data or do the right research
• We rely too much on catch-at-length data
• We use the separability assumption and McAllister and Ianelli’s (1997) iterative reweighting of catch composition data

Why is integrated analysis the best thing that happened to fisheries stock assessment?

• Makes assumptions consistent and explicit
• Facilitates testing of different assumptions
• Allows us to identify data conflict and investigate model misspecification
Data conflict and model misspecification
Data Conflict

• Multiple data types provide information on the same processes
• Sometimes the different data types support substantially different values of the same parameter: data conflict
• Which data set should we believe?
The law of conflicting data

Axiom
Data is true

Implication
Conflicting data implies model misspecification

Caveat
Data conflict needs to be interpreted in the context of random sampling error

Significance
Down weighting or dropping conflicting data is not necessarily appropriate because it may not resolve the model misspecification
Guidelines

• Guideline 1: Do not naively down-weight or drop data
Reasons for data conflict

• Random sampling error
• Observation model misspecification
• System dynamics model misspecification
  – Parameters fixed at wrong values
  – Wrong model structure
  – Unmodeled temporal variation in parameter values
Data conflict: indices of abundance
Data conflict: sampling error
Data conflict: sampling error

\[ I = q \times B \times \exp(\varepsilon) \]
\[ \varepsilon \sim N(0, \sigma^2) \]
Data conflict: sampling error

\[ I = q \times B + \varepsilon \]
\[ \varepsilon \sim N(0, \sigma^2) \]
Data conflict: Observation model misspecification
Data conflict: Observation model misspecification

Change in catchability
Data conflict: Process model misspecification
Data conflict: Process model misspecification
Data conflict: Process model misspecification (bias)

\[ R = R_0 \text{ (h = 1)} \]

\[ R = \beta \times S_{\text{bio}} \text{ (h = 0.2)} \]
Data conflict: Process model misspecification (systematic temporal variation in environment-recruitment)
Data conflict: Process model misspecification (systematic temporal variation in environment-recruitment)
Reasons for data conflict

• Random sampling error
  – Not conflict

• Observation model misspecification
  – Dropping data appropriate

• System dynamics model misspecification
  – Dropping data probably not appropriate
The problem with composition data

• Composition data provides information on abundance trends and absolute abundance
• Information in composition data is highly sensitive to model misspecification
• Temporal variation in population and fishery processes influence composition data
• Information in composition data often conflicts with information from abundance index data
• Most integrated stock assessments are substantially biased because composition data has too much influence on absolute abundance and the model is misspecified
Guidelines

• Guideline 1: Do not naively down-weight or drop data

• Guideline 2: Do not over-weight composition data
Age composition data: abundance information

B ≈ C/F

Concept: If you can estimate fishing mortality and you know catch, then you can estimate abundance
Catch curve

\[ N_a = Re^{-Z} \]

\[ Z = F + M \]
Length composition: asymptotic length

![Graph showing the frequency distribution of length compositions. The x-axis represents length, ranging from 5 to 19, and the y-axis represents frequency, ranging from 0 to 0.035. The peak frequency occurs around length 13.]
Length composition: asymptotic length
Requirements for Interpreting composition data

• Natural mortality
• Recruitment
  – Stock-recruitment relationship
  – Annual variation
• Growth
• Selectivity
• Sampling error
What we know about population processes
Selectivity

Blue marlin in the Pacific Ocean

Blue marlin in the Pacific Ocean

Guidelines

• Guideline 1: Do not naively down-weight or drop data
• Guideline 2: Do not over-weight composition data
• Guideline 3: Use flexible fishery selectivity curves
Growth
Uncertainty in growth estimates: Mahi mahi

Modes in length frequency data differ from otolith aging: Pacific cod
Pacific bluefin growth

FIGURE 8. Comparison of mean length-at-age (dots) used in the ISC assessment model and the Japanese length-composition data.

FIGURA 8. Comparación de la talla media por edad (puntos) usada en el modelo de evaluación del ISC y los datos japoneses de composición por talla.

Tropical tuna aging

Aires-da-Silva et al. (submitted) Improved growth estimates from integrated analysis of direct aging and tag-recapture data: an illustration with bigeye tuna (Thunnus obesus) of the eastern Pacific Ocean with implications for management. Fisheries Research.
BET growth (get L2 sensitivity analysis estimates)

Aires-da-Silva et al. (submitted) Improved growth estimates from integrated analysis of direct aging and tag-recapture data: an illustration with bigeye tuna (Thunnus obesus) of the eastern Pacific Ocean with implications for management. Fisheries Research.
Natural mortality
“None of the 30 can provide accurate estimates for every species, and none appears sufficiently precise for use in analytical stock assessments, while several perform so poorly as to have no practical utility” (Kenchington 2013).

What processes change over time

• Recruitment
  – Most variable process
  – Relative strength of a cohort generally persists for several years and is observed in multiple years of composition data
  – Usually estimated reasonably well in integrated assessment models with composition data
• Natural mortality
  – More variable for younger fish and species with small body size
  – Low variability for species that are captured at a relatively large size
  – Information from composition data indirect
• Growth
  – Low to moderate variability
  – Density dependent and environmentally driven
  – Spatial variation
  – Most variable for young fish
  – Direct information from age-length
• Fishing mortality
  – Moderate variability
  – Estimated from catch data
• Selectivity
  – Low to moderate variability
  – Directly links dynamics to composition data
  – Cohort targeting
  – Information from both age and length compositions
Guidelines

• Guideline 1: Do not naively down-weight or drop data
• Guideline 2: Do not over-weight composition data
• Guideline 3: Use flexible fishery selectivity curves
• Guideline 4: Model time varying fishery selectivity
Bigeye tuna application

• Longline and purse seine fisheries
• Sampling error and time varying selectivity applied to purse seine fisheries
Estimated mean size (line) compared to the observed mean size using McAllister and Ianelli.
## Sample size

<table>
<thead>
<tr>
<th>Fishery</th>
<th>Number of wells sampled</th>
<th>Sampling error</th>
<th>McAllister and Ianelli</th>
<th>Pennington with temporal variation in selectivity</th>
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</table>
Spawning biomass

Number of Wells sampled
McAllister and Ianelli
Pennington
Sampling error
Sampling error and time varying selectivity

Scaled spawning biomass

Numbers of wells sampled
Mcallister and Ianelli
Pennington
Sampling error
Sampling error and time varying selectivity
Guidelines

- Guideline 1: Do not naively down-weight or drop data
- Guideline 2: Do not over-weight composition data
- Guideline 3: Use flexible fishery selectivity curves
- Guideline 4: Model time varying fishery selectivity
- Guideline 5: Estimate composition sampling error from sample design
Computation

• Methods
Diagnostics
Francis' mean age/length diagnostic

Comparing composition data with abundance index data – R0 profile: selectivity

Correctly specified

Misspecified selectivity

Age-structured Production Model Diagnostic

Maunder and Piner 2015
Likelihood distribution

Data 1

Data 2

Retrospective analysis

Figure 5. Sample results showing retrospective patterns for cod for fishing mortality “fish down and recovery”. Growth is time varying in the OM, with results for scenario 2 (a; recent, negative, gradual change) and scenario 3 (b; old, positive, gradual change).

Guidelines

- Guideline 1: Do not naively down-weight or drop data
- Guideline 2: Do not over-weight composition data
- Guideline 3: Use flexible fishery selectivity curves
- Guideline 4: Model time varying fishery selectivity
- Guideline 5: Estimate composition sampling error from sample design
- Guideline 6: Apply diagnostics to identify model misspecification
Optimal

- Survey index of absolute abundance (or F) (by age).
  - Can we estimate q inside stock assessment or
    - Contrast in index of abundance caused by catch
    - Survey age-composition data
  - Estimate q from non-sock assessment source

- Catch-at-age data for major fisheries
  - Growth, selectivity, and recruitment from catch-at-age

- Problem is M and Stock-Recruitment
  - S-R steepness = 1 for many species within range of where you would like the stock to be
  - Is M estimable or do we need tagging data?
• Conclusions
  – Conflicting data indicates model misspecification
  – Down weighting or dropping conflicting data is not necessarily appropriate because it may not resolve the model misspecification.

• Modeling Recommendations
  – Estimate the sampling variance outside the model
  – Model time varying selectivity for all fisheries
  – Use flexible selectivity curves
  – Consider modelling temporal variability in growth if have catch-at-age data
  – Conduct diagnostic tests and model structure and parameter sensitivity analysis to identify possible model misspecification

• Data recommendations
  – Design surveys to have constant asymptotic selectivity
  – Collect age data
  – Estimate M
  – Estimate q
CAPAM research

- Selectivity workshop 2013
- Growth workshop 2014
- Data conflict and weighting, likelihood functions, and process error 2015
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