Estimating Predation Mortality with a Three-Species Model in the Gulf of Alaska

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General Approach

Construct a set of simplified single-species models and connect them through predation.

- **SSM: Single-species models**
  - Designed to match stock assessment output
  - $Z = F + M$

- **MSM: Multispecies model**
  - Calculates predation from gut data assumed to be measured without error
  - $Z = F + M + P$

- **MSASA: Multispecies Age-Structured Assessment**
  - Estimates predation from a series of model parameters
  - $Z = F + M + P$
Three species with close predator-prey links

Pacific Cod (Gadus macrocephalus)
Three species with close predator-prey links

Pacific Cod (Gadus macrocephalus)

- Arrowtooth Flounder (Atheresthes stomias)
- Walleye Pollock (Theragra chalcogramma)
Three species with close predator-prey links

**Pacific Cod** (*Gadus macrocephalus*)

Arrowtooth Flounder (*Atheresthes stomias*) → Walleye Pollock (*Theragra chalcogramma*)
Three species with close predator-prey links

Pacific Cod (Gadus macrocephalus)

Arrowtooth Flounder (Atheresthes stomias)

Walleye Pollock (Theragra chalcogramma)
Work forward from Age 1 cohort

\[ N_{i,a+1,t+1} = N_{i,a,t} e^{(-Z)} \]

- No recruitment function: Age 1 is a model parameter.
Deconstruct Z into:

- Fishing mortality $F$
- Predation mortality $P$
- Residual natural mortality $M$

$$N_{i,a+1,t+1} = N_{i,a,t} e^{(-M-F-P_1-P_2-\ldots-P_n)}$$

The Multispecies Model (MSM) and the Multispecies Age-Structured Assessment (MSASA) are simply extensions of the SSM in which $Z = F + M + P$
**Natural Mortality**

- **SSM:** Set to values used in the stock assessments
- Ages 1 and 2 for prey species set higher to mimic P

<table>
<thead>
<tr>
<th></th>
<th>SSM</th>
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<tbody>
<tr>
<td>ATF 1</td>
<td>0.45</td>
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<tr>
<td>ATF 2</td>
<td>0.4</td>
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<tr>
<td>ATF 3+</td>
<td>0.24</td>
</tr>
<tr>
<td>COD</td>
<td>0.37</td>
</tr>
<tr>
<td>PLK 1</td>
<td>0.9</td>
</tr>
<tr>
<td>PLK 2</td>
<td>0.8</td>
</tr>
<tr>
<td>PLK 3+</td>
<td>0.3</td>
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Natural Mortality

- **MSM / MSASA**: Set all ages to stock assessment values.

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Modeling predation

\[ P_{i,a,t} = \frac{1}{N_{i,a,t} W_{i,a}} \sum_j \sum_b I_{j,b} N_{j,b,t} \left( \frac{\phi_{i,a,j,b,t}}{\phi_{j,b,t}} \right) \]

- Annual Ingestion
- Predator abundance

- Total ingestion by predator \( j \)
- Proportion of the ingested food that is prey \( i \), age \( a \)

\[ \sum \text{ Total amount of prey } i \text{ consumed by predator } j \]

\[ P_{i,a,t} = \frac{\text{Total amount of prey } i \text{ consumed by all predators}}{\text{Biomass of prey } i} \]
Predation for the MSM

\[ P_{i,a,t} = \frac{1}{N_{i,a,t} W_{i,a}} \sum_{j} \sum_{b} I_{j,b} \frac{N_{j,b,t}}{\phi_{j,b,t}} \frac{\phi_{i,a,j,b,t}}{\phi_{j,b,t}} \]

Proportion of ingested food for predator \( j,b \) composed of prey \( i,a \) taken directly from gut studies.
Predation for the MSASA

Estimating stomach contents

SIZE-PREFERENCE: Defined by the gamma function

SUITABILITY: size-preference * prey vulnerability
• Scaled to 1 to create a distribution of gut contents for each predator

AVAILABILITY: suitability * prey biomass

\[
\text{Stomach} = \frac{\text{Biomass of prey } i,a \text{ available to predator } j,b}{\text{Total food available to predator } j,b}
\]
YEAR ONE

Age-Specific Fishing Mortality

Residual Natural Mortality

Age-Specific Predation Mortality

YEAR TWO

Age 1 Abundance

YEAR ONE

YEAR TWO
Likelihood Components

- Catch-at-age
- Survey-at-age
- Total Annual Catch
- Estimated survey biomass

Additional MSASA component:

- Gut data
Results

The SSM is a valid baseline for evaluating predation.

Matches stock assessment ranges for:

• Catch and Survey data
• Values for $F$ and $Q$
• Gear selectivity patterns
• Estimates of abundance

We assume that stock assessment estimates of biomass, abundance, $Q$, $F$, and gear selectivities are essentially correct.
Results

Abundance

Cod Abundance

No predation = no change in abundance from SSM
Results

Abundance

Flounder Abundance

Abundance

Age

SSM
MSM
MSASA
Results

Abundance

Pollock abundance

SSM  MSM  MSASA
Predation Mortality

P on Pollock

Age

P

MSASA

MSM
Predation Mortality

P on Flounder

Age

P

0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

MSASA

MSM
# Catch and Survey Factors

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<th>MSASA</th>
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<tbody>
<tr>
<td>ATF Q</td>
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<td>1</td>
<td>0.88</td>
</tr>
<tr>
<td>PLK Q</td>
<td>0.75</td>
<td>0.0009</td>
<td>0.46</td>
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<tr>
<td>ATF F</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>PLK F</td>
<td>0.15</td>
<td>0.0002</td>
<td>0.1</td>
</tr>
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1. Weak forcing from gut data: too many zeroes

2. Large majority of predation on Age 1 Pollock skews model predictions
Issues: Natural Mortality

Traditional single-species models have included predation under the umbrella of $M$.

By separating $P$ from $M$, values for $M$ should decrease.

When set as model parameter, $M$ increases with the addition of predation. Why?
In Sum

**OBSERVED**
- Predation mortality is separable from natural mortality
- Predation mortality is estimable
- The MSASA is both computationally workable and biologically sound

**REQUIRED**
- Improved assessment of gut data and its integration into model function
- Improved understanding of relationship between M, P, and cohort dynamics
What's going on down there??