Accounting for spatial structure in length-and-age-based stock assessment models: An example from South Australia

Jonathan Smart, John Feenstra and Rick McGarvey
CAPAM – spatial structure workshop
4th October 2018
Outline

• King George Whiting (KGW) SA fishery
• Stock assessment model structure
• Slice partition formalism
• Movement submodel
• Stock Assessment outcomes
• Conclusions
Marine Scalefish Fishery (MSF)

- Multi-species, multi-gear, multi-area fishery
- Spans entire coastline of South Australia
- Stock assessments performed for three primary species:
  - King George Whiting (*Sillaginodes punctatus*)
  - Southern Garfish (*Hyporhamphus melanchoir*)
  - Snapper (*Chrysophrys auratus*)
Marine Scalefish Fishery (MSF)

• Multi-species, multi-gear, multi-area fishery

• Spans entire coastline of South Australia

• Stock assessments performed for three primary species:
  – King George Whiting (*Sillaginodes punctatus*)
  – Southern Garfish (*Hyporhamphus melanchoir*)
  – Snapper (*Chrysophrys auratus*)
King George Whiting (KGW) in South Australia

- Highest value fish by weight in South Australia

- Taken by several gear types:
  1. Hand line
  2. Haul net
  3. Gill net

- Three spatial regions:
  1. West Coast (WC)
  2. Spencer Gulf (SG)
  3. Gulf St Vincent (GSV)

- Managed by:
  - Legal minimum size (region specific)
  - Limited entry
  - Gear restrictions
  - Seasonal closures on spawning grounds

- Complex life history – ontogenetic migration
Stock Assessment Model

Model fits to:
- catch totals (kg)
- catch proportions-at-age-and-sex
- recreational survey data.
- Tag-recapture movement rates

Estimates key performance indicators for stock status:
- Annual harvestable biomass
- Annual harvest fraction
- Yearly recruitment.

Recruitment is a free parameter – no stock recruitment relationship.
Model structure

- Monthly time steps
- Effort conditioned
- Population numbers broken into:
  - month
  - region
  - sex
  - cohort
  - length bin (‘slice’) within each cohort

Slice Partition Approach: How does it work?

- Within each cohort length is normally distributed.

- At each time step, we compute the proportion of the cohort that grown above legal size.

- These slice proportions are all we need to implement a length- and age-based model.

- Better account for individuals lost through mortality and either lost or gained via movement.
Slice Partition Approach: How does it work?

- Within each cohort length is normally distributed.
- At each time step, we compute the proportion of the cohort that grown above legal size.
- These slice proportions are all we need to implement a length- and age-based model.
- Better account for individuals lost through mortality and either lost or gained via movement.
Slice Partition Approach: How does it work?

- Within each cohort length is normally distributed
- At each time step, we compute the proportion of the cohort that grown above legal size
- These slice proportions are all we need to implement a length- and age-based model
- Better account for individuals lost through mortality and either lost or gained via movement
Slice Partition Approach: Advantages

- Differentiates between legal and sublegal fish in the model
- Models partial recruitment to the fishery as cohorts grow above LML
- Incorporates growth into model-predicted catch proportions-at-age
- Applied in South Australia to the 3 major fish stocks
Slice Partition Approach

- Applied to KGW as monthly time steps
  - KGW have seasonally varying growth
  - Incorporates this variability into the length-at-age pdf giving more precise slices
Slice Partition Approach

- Applied to KGW as monthly time steps
  - KGW have seasonally varying growth
  - Incorporates this variability into the length-at-age pdf giving more precise slices

- Provides narrower slices in slow-growing months when fewer fish recruit above LML
Slice Partition Approach

- Applied to KGW as monthly time steps
  - KGW have seasonally varying growth
  - Incorporates this variability into the length-at-age pdf giving more precise slices

- Provides narrower slices in slow-growing months when fewer fish recruit above LML

- Fishing mortality is then applied to each slice in each time step

- The older the slice, the greater its exposure to fishing and therefore fewer individuals remain
Gulfs
KGW migrate back to spawning grounds at ages 2–4 years

Three regions included in Stock Assessment
West Coast (WC)
Gulf St Vincent (GSV)
Spencer Gulf (SG)

KGW undergo age-dependent migration from nursery areas to spawning grounds:

- GSV and SG KGW move south at 2 – 4 years
- WC – KGW move offshore at 4 years to the “mystery cell”
- All movement occurs in summer (November – January)
Spatial Distribution of Catches

Catches vary both spatially and temporally

- Highest in winter (May – July)
- Highest in northern gulfs
- Failure to model movement will lead to under or overestimation of F in different areas

Average monthly catch in each spatial cell 1984 - 2016
Movement Submodel

- Movement is estimated and included as a likelihood component
- Submodel is recapture conditioned
  - Mortality in original cell (until time of movement), reporting rate, tag shedding rate all cancel out
  - Key assumption is that reporting rate, tag mortality and tag loss are approximately uniform across areas
- Provides estimates of predicted movement proportions to each area
- Refines estimates of $F$ and $Z$ in the migration cells

Tag and recapture data

<table>
<thead>
<tr>
<th>Age Tagged (months)</th>
<th>Age Recaptured</th>
<th>Area Tagged</th>
<th>Area Recaptured</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>31</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>36</td>
<td>49</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>24</td>
<td>33</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Predicted n. recaptures**

$$\hat{N}_{i,j,a_t,a_r} = n_i^{r} (1 - m_{tag})S_{i[a_r, a_m]}P_{a_m, i, j}S_{j[a_m, a_r]} \times \left(1 - e^{-\frac{z}{12}}\right)^2$$

**Predicted prop recaptures**

$$f_1(j|i, a_t, a_r) = \frac{\hat{N}_{i,j,a_t,a_r}}{\sum_{k=1}^{n_c} \hat{N}_{i,k,a_t,a_r}} P_{i, j} e^{-\frac{z_{jm}}{12}} \left(1 - e^{-\frac{z_{jm}}{12}}\right)^2 \frac{F_{j,m}}{Z_{j,m}}$$

$$f(j|i, a_r) = \frac{\hat{N}_{i,j,a_t,a_r}}{\sum_{k=1}^{n_c} P_{i, k} e^{-\frac{z_{km}}{12}} \left(1 - e^{-\frac{z_{km}}{12}}\right)^2 \frac{F_{k,m}}{Z_{k,m}}}$$

$N$ = number of individuals, $t =$ month of tagging, $r =$ month of recapture, $a =$ age, $m =$ month of movement, $P =$ probability of movement, $S =$ survivorship, $F =$ fishing mortality, $Z =$ total mortality, $m_{tag} =$ tagging mortality, $f_{report} =$ tag report rate
Movement Submodel

- Movement is estimated and included as a likelihood component

- Submodel is recapture conditioned
  - Mortality in original cell (until time of movement), reporting rate, tag shedding rate all cancel out
  - Key assumption is that reporting rate, tag mortality and tag loss are approximately uniform across areas

- Provides estimates of predicted movement proportions to each area

- Refines estimates of $F$ and $Z$ in the migration cells

---

**Tag and recapture data**

<table>
<thead>
<tr>
<th>Age Tagged (months)</th>
<th>Age Recaptured</th>
<th>Area Tagged</th>
<th>Area Recaptured</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>31</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>36</td>
<td>49</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>24</td>
<td>33</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Annual time invariant movement matrix**

<table>
<thead>
<tr>
<th>MC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>0.55</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.00</td>
<td>0.45</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.67</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.33</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Smoothed monthly movement matrix**

<table>
<thead>
<tr>
<th>MC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>0.82</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.00</td>
<td>0.18</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.87</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.13</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Equations and Variables:**

- $N$ = number of individuals
- $t$ = month of tagging
- $r$ = month of recapture
- $a$ = age
- $m$ = month of movement
- $P$ = probability of movement
- $S$ = survivorship
- $F$ = fishing mortality
- $Z$ = total mortality
- $m_{tag}$ = tagging mortality
- $f_{report}$ = tag report rate
Stock Assessment Outcomes

• Movement rates are smoothed across the 3 summer months for gradual emigration

• At age 4, all remaining fish in northern Gulfs are moved.

• West Coast movement is not estimated as this only happens at age 4
Benefits of modelling movement and using slice partitions

Accounting for movement in tandem with slice partitions, refines the mortality estimates.

Create Slices  
Apply mortality  
Account for movement
Stock Assessment outcomes

Increased precision in the population array provides:

• Precise fits to catch in all areas
Stock Assessment outcomes

Increased precision in the population array provides:

- Precise fits to catch in all areas
- Good fits to Age Comp. data
  - Note older ages occur in SSG and SGSV compositions.
Stock Assessment outcomes

Increased precision in the population array provides:

- Precise fits to catch in all areas
- Good fits to Age Comp. data
  - Note older ages occur in SSG and SGSV compositions.
- This leads to reasonable estimates of Biomass, harvest fraction and recruitment
Conclusions

• Accounting for movement in this example greatly avoids issues of overestimating and underestimating $F$, leading to improved model outputs.

• The slice partition approach complements the movement submodel as the age of movement is concurrent with ages that are fished the heaviest.

• A recapture conditioned movement model provides a simple mechanism to include tag data in stock assessments and avoids issues regarding estimation of tag reporting (if assumptions are valid).
Acknowledgements

• Rick McGarvey and John Feenstra – the developers of this approach

• The Marine Scalefish team – Mike Steer, Tony Fowler and all of their staff