Introduction to South African sardine: Assessment and Management

International Stock Assessment Workshop
Cape Town
27\textsuperscript{th} November 2017

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History of Fishery

Sardine have also been commercially harvested off the south coast since the 1990s.
South African Sardine Distribution and Stock Structure

Composite egg distribution
November 1986 - 2009

Eggs.m\(^{-2}\)
- 1,000
- 2,000
- 3,000

Orange River mouth
Hondeklop Bay
Doring Bay
Lambert’s Bay
Cape Columbine
Cape Town
Cape Agulhas
Mossel Bay
Port Elizabeth
Port Alfred

West coast spawning grounds
South coast spawning grounds
Parasite Bio-tagging

• For SA sardine, the digenean “tetracotyle” type metacercariae found in sardine eyes showed greatest bio-tag potential
• 1st intermediate host endemic to west coast
• No fish-to-fish transmission
South coast sardine infected with parasite must have previously been on west coast
• Differences in the prevalence, mean infection intensity and mean abundance of the parasite Sardine are NOT homogeneously distributed
Parasite Bio-tagging

- Parasite prevalence on west coast higher than on south coast
- Parasite prevalence increases with length on both west and south coasts
  
  Sardine must move at older ages

Weston et al. 2015  Fisheries Research 164
IBM + hydrodynamic model

Eggs/larvae from south coast successfully reach west coast nursery areas

Average 8%
Assessment Details

• Age-structured production method framework, incorporating key elements of Statistical catch-at-age and Integrated Analysis methods
• Fit to survey estimates of recruitment and total abundance, catch data and length frequencies
• Estimate time-invariant growth curve with variability about length-at-age
• Bayesian analysis, with integration implemented numerically using ADMB
Model Fit to Survey Abundance Indices

- **November biomass survey**
  - **Single Stock**
  - **West Component**
  - **South Component**

- **May recruit survey**
  - **Single Stock Hypothesis**
  - **Two Component Hypothesis**
Movement of west recruits to south had a greater impact on the south biomass than years of above-average south recruitment.
Stock Recruitment Relationships

Different curves estimated for each component

West component

South component

No stock-recruitment relationship

West component is substantially more productive than the south component
Key Question 1

• Have we an adequate reference set of operating models for sardine? How do we best report performance statistics for this set?
• Primary doc #6
• Two mixing component hypothesis
  - West to south movement
  - South contribution to west recruitment
Key Question 1

- Proportion of 1-year olds that annually move from the west to the south component
- (Proportion of 2+ that move is linked to this)
Key Question 1

- Proportion of south component $B^{sp}$ that forms part of west component effective $B^{sp}$:

$$R_{west} = f(B^{sp}_{west} + p B^{sp}_{south})$$

$$R_{south} = f((1-p) B^{sp}_{south})$$

$p = 0\%, 8\%, 20\%, 60\%$

Hydrodynamic model + variability

Fits to SR ‘data’
Key Question 1

- 2016 recommendations -> don’t weight

<table>
<thead>
<tr>
<th></th>
<th>$p = 0.0$</th>
<th>$p = 0.08$</th>
<th>$p = 0.2$</th>
<th>$p = 0.6$</th>
<th>MoveR</th>
<th>0.5MoveR</th>
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<tbody>
<tr>
<td>Option 1</td>
<td>0.05</td>
<td>0.50</td>
<td>0.35</td>
<td>0.10</td>
<td>0.75</td>
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<tr>
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<td>0.25</td>
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<td>0.01</td>
<td>0.04</td>
<td>0.30</td>
<td>0.65</td>
<td>0.30</td>
<td>0.70</td>
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<td>Option 4</td>
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<td>0.30</td>
<td>0.10</td>
<td>0.80</td>
<td>0.20</td>
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<tr>
<td>Option 5</td>
<td>0.20</td>
<td>0.50</td>
<td>0.20</td>
<td>0.10</td>
<td>0.80</td>
<td>0.20</td>
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<tr>
<td>Average</td>
<td>0.064</td>
<td>0.376</td>
<td>0.310</td>
<td>0.250</td>
<td>0.68</td>
<td>0.32</td>
</tr>
<tr>
<td>Median</td>
<td>0.050</td>
<td>0.500</td>
<td>0.300</td>
<td>0.100</td>
<td>0.75</td>
<td>0.25</td>
</tr>
<tr>
<td>Renormalised Median</td>
<td>0.053</td>
<td>0.526</td>
<td>0.316</td>
<td>0.105</td>
<td>0.75</td>
<td>0.25</td>
</tr>
</tbody>
</table>

- Major model/data changes considered during next OMP cycle
Key Question 2

• How do we best choose risk thresholds in terms of biomass levels for sardine and anchovy?
• Primary doc #2
• Sardine: previously used avg 91-94 total biomass
• OMP-14 tuned $p(\text{Risk}^S)<0.18$
Key Question 2

- Anchovy – previously used 10% of avg 84-99 total biomass

Average 1991-1994 biomass

10% of average 1991-1994 biomass
Key Question 2

- \( \text{Risk}^S_{2007} \): lowest historical median \( B_{\text{west}} \)
- \( \text{Risk}^S_{70} \): 70,000t \( B^{sp} \)
- \( \text{Risk}^S_{100} \): 100,000t \( B^{sp} \)
- \( \text{Risk}^S_{\text{hinge}} \): \( B^{sp} \) at Hockey-stick hinge point
- \( \text{Risk}^A_{1996} \): lowest historical median
  \( \rightarrow \) 25% of this level due to wide future PIs
Updated Operating Model

Recruits (billions)

Spawner Biomass (million t)

Data up to 2011

Data up to 2015

Single Stock Hypothesis
How Reliably is the Hockey Stick Hinge Point Estimated?

Joint Posterior Mode

Is this hinge point precisely estimated? Can we base management decisions on it?
How Reliably is the Hockey Stick Hinge Point Estimated?

Joint Posterior Mode

Is this hinge point precisely estimated?
Can we base management decisions on it?

"True" hinge point
Management too conservative
How Reliably is the Hockey Stick Hinge Point Estimated?

Individual Posterior Realisations

Only 'non-pulse' points plotted
Let The Data Speak For Themselves!

Use of a Smoother

Gaussian kernel smoother + straight line from origin to lowest $B_{sp}$

Lower $\theta$ - matches data points more closely
Considering risk - shape of curve at lower spawner biomass levels.

Joint Posterior Mode

$$N(SSB_j) = \exp \left[ \frac{\sum_{y=1986}^{2014} \ln(N_{j,y}) \times \exp \left\{ -\frac{[\ln(SSB_{j,y}) - \ln(SSB_j)]^2}{\theta^2} \right\}}{\sum_{y=1986}^{2014} \exp \left\{ -\frac{[\ln(SSB_{j,y}) - \ln(SSB_j)]^2}{\theta^2} \right\}} \right]$$
Let The Data Speak For Themselves!

Use of a Smoother

Individual Posterior Realisations

Only ‘non-pulse’ points plotted
How Reliably is the Hockey Stick Hinge Point Estimated?

\[ B^{sp} \text{ at which } R = 0.9 \times R_{Bsp=0.3} : \]

~74 000t for Hockey Stick
~92 000t for non Parametric Smoother
How Reliably is the Hockey Stick Hinge Point Estimated?

Risk\textsuperscript{S70}, Risk\textsuperscript{S100}, Risk\textsuperscript{Shinge}

Only 'non-pulse' points plotted
Key Question 2

Risk_{100}^S = 100,000 t
Key Question 2

- Don’t currently consider a risk threshold for south component
- Some risk threshold can be more easily translated to single stock than others
Key Question 3

• How do we best select the acceptable probability of dropping below a risk threshold?
• Primary doc #3
• “risk level” = probability of dropping below a pre-defined risk threshold
Key Question 3

- Previous OMPs:
  \[ \text{risk}_S = \text{the probability that simulated total sardine 1+ biomass falls below the average total sardine 1+ biomass between Nov 91-94 at least once during the projection period of 20 years} \]

- \[ \text{risk}_S < 0.10 \text{ (OMP-04)} \]
- \[ \text{risk}_S < 0.18 \text{ (OMP-08)} \]
- \[ \text{risk}_S < 0.21 \text{ (OMP-14)} \]

Changes in OMs:
- Increase/decrease in M or \( \sigma_R \)
- Increase/decrease in resilience of resource to reduction to a low level
Risk Level: SA sardine

Maintain a similar level of downward shift under proposed new MP

Consider lower percentiles of $B_{OMP}/B_{F=0}$

2002

Sardine 1+ Biomass in 2020 ('000t)

No catch
OMP-02

2004

Sardine 1+ Biomass in 2023 ('000t)

No catch
OMP-04

2008

Sardine 1+ Biomass in 2027 ('000t)

No catch
OMP-08
**Risk Level: SA sardine**

- **Higher levels of risk**

**$risk_s$** – the probability that adult sardine biomass falls below the average adult sardine biomass over Nov 91-94 at least once during the projection period of 20 years.

<table>
<thead>
<tr>
<th></th>
<th>$B_{OMP-04}/B_{F=0}$</th>
<th>Options for $B_{OMP-08}/B_{F=0}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$risk_s&lt;0.15$</td>
</tr>
<tr>
<td>10%ile</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>20%ile</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>30%ile</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>40%ile</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>median</td>
<td>0.72</td>
<td></td>
</tr>
</tbody>
</table>
**Risk Level: SA sardine**

Aim:
- Match ratios at 20%ile
- Similar ratios at other lower %iles

**Higher levels of risk**

- \( \text{risk}_S < 0.15 \)
- \( \text{risk}_S < 0.18 \)
- \( \text{risk}_S < 0.20 \)

**Options for \( B_{\text{OMP-08}/B_{F=0}} \):**

<table>
<thead>
<tr>
<th>%ile</th>
<th>( B_{\text{OMP-04}/B_{F=0}} )</th>
<th>( \text{risk}_S &lt; 0.15 )</th>
<th>( \text{risk}_S &lt; 0.18 )</th>
<th>( \text{risk}_S &lt; 0.20 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%ile</td>
<td>0.59</td>
<td>0.60</td>
<td>0.49</td>
<td>0.45</td>
</tr>
<tr>
<td>20%ile</td>
<td>0.68</td>
<td>0.76</td>
<td>0.68</td>
<td>0.62</td>
</tr>
<tr>
<td>30%ile</td>
<td>0.69</td>
<td>0.80</td>
<td>0.72</td>
<td>0.68</td>
</tr>
<tr>
<td>40%ile</td>
<td>0.71</td>
<td>0.80</td>
<td>0.73</td>
<td>0.68</td>
</tr>
<tr>
<td>median</td>
<td>0.72</td>
<td>0.80</td>
<td>0.72</td>
<td>0.68</td>
</tr>
</tbody>
</table>

\( \text{risk}_S \) – the probability that adult sardine biomass falls below the average adult sardine biomass over Nov 91-94 at least once during the projection period of 20 years.

**Legend:**
- Green – less
- Black – same
- Red – more
Key Question 3

- i) probability of being below the risk threshold at least once during the projection period
  - High given biomass currently relatively low?
  - Doesn’t taken probability of recovery into account

- ii) the probability of being below the risk threshold during the projection period
  - Average risk over the projection period

- iii) the probability of being below the risk threshold at the end of the projection period
  - Considers risk once transient influence of starting point has dissipated
  - Together with i) and ii) could inform on some probability of recovery
Key Question 4

• Can one dispense with risk and simply consider catch over the medium-to-long term as sufficient to incorporate any negative consequences of undue depletion of the population? (This because future catches should be reduced if the stock is depleted such that future recruitment drops.)

• Primary doc #9
Key Question 5

• What would be the best way to simulation test the impact of a single area directed sardine TAC in a situation of two spatially distinct sardine population components?

• Primary doc #4
### Key Question 5

<table>
<thead>
<tr>
<th>The underlying sardine stock OM</th>
<th>The type of sardine TAC arising from the candidate MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single sardine stock</td>
<td>Single area TAC</td>
</tr>
<tr>
<td></td>
<td>All catch taken from single stock</td>
</tr>
<tr>
<td>Two mixing sardine components</td>
<td>Add TACs, and subsequent catch taken from single stock</td>
</tr>
<tr>
<td></td>
<td>Greater proportion of TAC caught from west component when TAC/WC biomass low</td>
</tr>
<tr>
<td></td>
<td>West/south TAC taken from west/south component</td>
</tr>
</tbody>
</table>

**Diagram:**
- **Two sardine components**
- **TAC for whole area**
- **Agulhas**
- **Proportion of catch west of Cape Agulhas**

**Graph:**
- X-axis: West coast biomass (y-1) : TAC (y)
- Y-axis: Proportion of catch west of Cape Agulhas
Key Question 6

• The 2016 panel recommended OMP variants that include spatial management be considered. Is spatial management of the sardine TAC necessary? If we consider explicit spatial management to be necessary during “concerning periods” only, how do we best determine the “flags” for switching such spatial management on and off?

• Primary doc #7
Focussing on the West Component

Harvest proportion on west component much higher

Of concern given poor recruitment to west component in recent decade if this is a “feeder” to both coasts.
Key Question 6

- **Single area management**
  - “implicit” spatial management if we assume “fishing as in the past” (key question #5)

- **Two area management**
  - Fixed proportion of TAC west/east of Cape Agulhas each year
  - Variable proportion of TAC west/east of Cape Agulhas each year (e.g. based on survey proportions west/east of Cape Agulhas)
  - “Gentleman’s Agreement”
  - Only required during ‘concerning’ periods?
    - ‘concerning’ defined as i) a low west coast survey estimate of biomass or ii) high proportions of catch on west coast in preceding years
For each OM the MPs tested are:
1 area (with catch split by component for 2 component OMs)
2 area (variable by proportion Bobs west)
2 area (100% west)
2 area (80% west)
2 area (60% west)
2 area (40% west)
Increases with increasing WC proportion

For each OM the MPs tested are:

1 area (with catch split by component for 2 component OMs)
2 area (variable by proportion Bob's west)
2 area (100% west)
2 area (80% west)
2 area (60% west)
2 area (40% west)
For each OM the MPs tested are:

1. Single Stock
   - p=0
   - p=0.2
   - p=0.6
   - p=0.2 & MoveR/2
   - p=0.6 & MoveR/2
   - p=0 & MoveR/2

2. 1 area (with catch split by component for 2 component OMs)
   - 2 area (variable by proportion Bobs west)
     - 2 area (100% west)
     - 2 area (80% west)
     - 2 area (60% west)
     - 2 area (40% west)

3. 2 area (100%w) > 1area & others

- F=0
- F=0.1
- F=0.15
- OMP-14
### Key Question 6

<table>
<thead>
<tr>
<th>MoveR</th>
<th>( p(B_{\text{west},y &lt; Risk^{s}_{2007}}) )</th>
<th>( p(B_{\text{sp},y &lt; Risk^{s}_{\text{hinge}}}) )</th>
<th>Average weight</th>
<th>Average weight</th>
<th>Median weight</th>
<th>Median weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p = 0.0 )</td>
<td>0.12</td>
<td>0.15</td>
<td>0.064</td>
<td>0.044</td>
<td>0.053</td>
<td>0.040</td>
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<tr>
<td>( p = 0.08 )</td>
<td>0.10</td>
<td>0.22</td>
<td>0.376</td>
<td>0.256</td>
<td>0.526</td>
<td>0.395</td>
</tr>
<tr>
<td>( p = 0.2 )</td>
<td>0.07</td>
<td>0.23</td>
<td>0.310</td>
<td>0.211</td>
<td>0.316</td>
<td>0.237</td>
</tr>
<tr>
<td>( p = 0.6 )</td>
<td>0.06</td>
<td>0.31</td>
<td>0.250</td>
<td>0.17</td>
<td>0.105</td>
<td>0.079</td>
</tr>
</tbody>
</table>

| 0.5MoveR | \( p = 0.0 \) | 0.01 | 0.01 | 0.064 | 0.02 | 0.053 | 0.013 |
| \( p = 0.08 \) | 0.00 | 0.01 | 0.376 | 0.12 | 0.526 | 0.131 |
| \( p = 0.2 \) | 0.00 | 0.03 | 0.310 | 0.099 | 0.316 | 0.079 |
| \( p = 0.6 \) | 0.00 | 0.06 | 0.250 | 0.08 | 0.105 | 0.026 |

**Avg MoveR** | 0.08 | 0.24 |
**Avg 0.5MoveR** | 0.00 | 0.03 |
**Avg** | 0.06 | 0.17 |
**Median MoveR** | 0.09 | 0.23 |
**Median 0.5MoveR** | 0.00 | 0.02 |
**Median** | 0.07 | 0.18 |

*No future directed sardine catch*
### Key Question 6

<table>
<thead>
<tr>
<th>MoveR</th>
<th>( p = 0.0 )</th>
<th>( p = 0.08 )</th>
<th>( p = 0.2 )</th>
<th>( p = 0.6 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p(B_{\text{west,y}} &lt; \text{Risk}^{s}_{2007}) )</td>
<td>0.21</td>
<td>0.18</td>
<td>0.13</td>
<td>0.10</td>
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<tr>
<td>( p(B_{\text{sp,west,y}} &lt; \text{Risk}^{s}_{\text{hinge}}) )</td>
<td>0.25</td>
<td>0.33</td>
<td>0.33</td>
<td>0.41</td>
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<tr>
<td>Median ( C_{\text{west}} )</td>
<td>77</td>
<td>78</td>
<td>81</td>
<td>82</td>
</tr>
<tr>
<td>Median ( \text{AAV}_{\text{tot}} )</td>
<td>13.9</td>
<td>13.2</td>
<td>11.2</td>
<td>10.3</td>
</tr>
<tr>
<td>Average weight</td>
<td>0.064</td>
<td>0.376</td>
<td>0.310</td>
<td>0.250</td>
</tr>
<tr>
<td>Average weight</td>
<td>0.044</td>
<td>0.256</td>
<td>0.211</td>
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<tr>
<td>Median weight</td>
<td>0.040</td>
<td>0.395</td>
<td>0.237</td>
<td>0.079</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>0.5MoveR</th>
<th>( p = 0.0 )</th>
<th>( p = 0.08 )</th>
<th>( p = 0.2 )</th>
<th>( p = 0.6 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p(B_{\text{west,y}} &lt; \text{Risk}^{s}_{2007}) )</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>( p(B_{\text{sp,west,y}} &lt; \text{Risk}^{s}_{\text{hinge}}) )</td>
<td>0.01</td>
<td>0.03</td>
<td>0.05</td>
<td>0.11</td>
</tr>
<tr>
<td>Median ( C_{\text{west}} )</td>
<td>86</td>
<td>86</td>
<td>87</td>
<td>87</td>
</tr>
<tr>
<td>Median ( \text{AAV}_{\text{tot}} )</td>
<td>9.0</td>
<td>8.9</td>
<td>8.7</td>
<td>8.9</td>
</tr>
<tr>
<td>Average weight</td>
<td>0.064</td>
<td>0.376</td>
<td>0.310</td>
<td>0.250</td>
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<tr>
<td>Average weight</td>
<td>0.02</td>
<td>0.12</td>
<td>0.099</td>
<td>0.08</td>
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<tr>
<td>Median weight</td>
<td>0.053</td>
<td>0.526</td>
<td>0.316</td>
<td>0.105</td>
</tr>
<tr>
<td>Median weight</td>
<td>0.013</td>
<td>0.131</td>
<td>0.079</td>
<td>0.026</td>
</tr>
</tbody>
</table>

| Avg MoveR | 0.15 | 0.34 | 80 | 11.9 |
| Avg 0.5MoveR | 0.01 | 0.05 | 87 | 8.8 |
| Avg | 0.10 | 0.25 | 82 | 10.9 |
| Median MoveR | 0.16 | 0.33 | 79 | 12.3 |
| Median 0.5MoveR | 0.01 | 0.04 | 86 | 8.8 |
| Median | 0.12 | 0.26 | 81 | 11.4 |

Future catches according to OMP-14 with single area management
### Key Question 6

#### Choice of risk thresholds and risk levels
(key questions 2 and 3)

<table>
<thead>
<tr>
<th>p=0.2 and MoveR</th>
<th>( p(B_{\text{west,y}} &lt; \text{Risk}^S_{2007}) )</th>
<th>( p(B_{\text{sp,west,y}} &lt; \text{Risk}^S_{70}) )</th>
<th>( p(B_{\text{sp,west,y}} &lt; \text{Risk}^S_{100}) )</th>
<th>( p(B_{\text{sp,west,y}} &lt; \text{Risk}^S_{\text{hinge}}) )</th>
<th>( p(B_{\text{west,y}} &lt; \text{Risk}^S_{2007}) )</th>
<th>( p(B_{\text{sp,west,y}} &lt; \text{Risk}^S_{70}) )</th>
<th>( p(B_{\text{sp,west,y}} &lt; \text{Risk}^S_{100}) )</th>
<th>( p(B_{\text{sp,west,y}} &lt; \text{Risk}^S_{\text{hinge}}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>F=0</td>
<td>0.32</td>
<td>0.69</td>
<td>0.89</td>
<td>0.68</td>
<td>0.07</td>
<td>0.14</td>
<td>0.23</td>
<td>0.23</td>
</tr>
<tr>
<td>Single Area</td>
<td>0.44</td>
<td>0.86</td>
<td>0.96</td>
<td>0.76</td>
<td>0.13</td>
<td>0.25</td>
<td>0.37</td>
<td>0.33</td>
</tr>
<tr>
<td>100:0</td>
<td>0.46</td>
<td>0.87</td>
<td>0.96</td>
<td>0.77</td>
<td>0.14</td>
<td>0.26</td>
<td>0.38</td>
<td>0.34</td>
</tr>
<tr>
<td>70:30</td>
<td>0.44</td>
<td>0.85</td>
<td>0.96</td>
<td>0.76</td>
<td>0.13</td>
<td>0.24</td>
<td>0.36</td>
<td>0.33</td>
</tr>
<tr>
<td>40:60</td>
<td>0.42</td>
<td>0.84</td>
<td>0.96</td>
<td>0.74</td>
<td>0.12</td>
<td>0.22</td>
<td>0.34</td>
<td>0.31</td>
</tr>
<tr>
<td>Variable (GA)</td>
<td>0.41</td>
<td>0.84</td>
<td>0.96</td>
<td>0.75</td>
<td>0.11</td>
<td>0.21</td>
<td>0.34</td>
<td>0.31</td>
</tr>
</tbody>
</table>
Key Question 7

- How might one best specify the November survey estimate of abundance below which the directed sardine fishery should be closed?
- Primary doc #5
Key Question 7

• Remain part of the HCR
• No need for a step function from TAC>0 to TAC=0; indications are industry will catch even a very small TAC
• Ecosystem considerations (escapement threshold?)
Introduction to South African sardine: Assessment and Management

Thank you for your attention