The potential impact of a shifting Pacific sardine distribution on U.S. West Coast landings

James Smith, SWFSC La Jolla
james.smith@noaa.gov
Projecting Landings

2000 - 2100

Sardine abundance
Sardine location
Fishing effort
Fishing location

Future Landings
Projecting Landings

Climate projection of a sardine SDM
Projecting Landings

Sardine abundance
Sardine location
Fishing effort
Fishing location

Impact of sardine habitat change on future landings

2000 2100
Projecting Landings

- Future abundance based on recent abundance
- Future effort based on recent effort, but responds to sardine habitat and quota
- Future fishing locations (ports) same as recent

2000 2015 2100
The best way to interpret our analysis:

Whatever the future landings will be, *this* is the impact that ocean change and the subsequent redistribution of sardine will have on those landings.
1. Model sardine habitat suitability (SDM)
2. Relate the habitat suitability near port to observed monthly sardine landings (landings GAM), while accounting for landings of other CPS, sardine price etc
3. Project the sardine habitat out to 2100, using ESM climate projections
4. Input this future habitat into landings GAM to calculate landings to 2100, while using a ‘reference period’ to input the other information
5. Use a simulation to allow the fishery to close dynamically based on projected landings (i.e. the ACL is fixed, but how quickly that ACL is reached depends on future habitat)
Step 1. Model sardine habitat
Step 2. Relate sardine habitat to landings

\[ \text{Landings} \sim s(\text{SDM60}: \text{port}) + s(\text{ACL}) + s(\text{Squid}: \text{port}) + s(\text{Anch}: \text{port}) + \text{port} \]
Step 3. Project sardine habitat out to 2100

- This shows the mean change in sardine habitat suitability, as the change from 2000-15 to 2040-55
- Green indicates an increase in habitat suitability, and red a decrease
Step 4. Input future habitat into landings model

- This shows the projected change in habitat suitability near each port (SDM60)
- This is inputted into the landings GAM
Step 5. Results

- This shows the range of landings expected in each year, based on habitat suitability near port, with everything else from the 2000-15 period.
- The linear trend is due to change in habitat suitability only.
- The relative (%) change in this trend is the key result.
Step 5. Results

- Landings increase in the north, decrease in the south
- Total landings can do down (20%), go up (10%), or go up and then down
Step 5. Results

- Fishing season may start earlier and get longer
- Fishing closures may become more frequent (ACL reached earlier)
## Sardine 3 ways – benefits and limitations

<table>
<thead>
<tr>
<th>Benefits</th>
<th>SDM-Landings</th>
<th>IBM</th>
<th>MICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>- SDMs are robust for long term projection</td>
<td>- Mechanistic understanding of bottom up effects on population dynamics</td>
<td>- Age-structured population dynamics</td>
<td>- Environmental driving of biological processes</td>
</tr>
<tr>
<td>- Avoids projecting sardine abundance or management</td>
<td>- Represents age structure and early life stages explicitly</td>
<td>- Fine time-step (1 week)</td>
<td>- Fast run-time</td>
</tr>
<tr>
<td>- Explores interplay of fishery constraints (e.g. other species, quota allocation)</td>
<td>- Includes growth, mortality, reproduction, behavior explicitly</td>
<td>- Uncertainty and sensitivity analyses</td>
<td></td>
</tr>
<tr>
<td>Benefits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Estimates only relative change in landings (%)</td>
<td>- Typically underestimates observed variability</td>
<td></td>
<td>- Coarse/simplified spatial resolution</td>
</tr>
<tr>
<td>- Uses correlative models, so less insight into processes and assumes past correlations persist</td>
<td>- Calibration of many biological parameters can be time intensive</td>
<td></td>
<td>- No individual-level processes</td>
</tr>
<tr>
<td>- Doesn’t yet propagate all uncertainty through to results</td>
<td>- Population dynamics can be overly sensitive to early life mortality</td>
<td></td>
<td>- No detailed fleets/ports (yet?)</td>
</tr>
<tr>
<td>Limitations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SDM / landings</td>
<td>IBM</td>
<td>MICE</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------------------------------</td>
<td>----------------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td><strong>Sardine distribution</strong></td>
<td>Northward shift (Nth subpop)</td>
<td>Northward shift</td>
<td>Northward shift (rule-based forcing)</td>
</tr>
<tr>
<td><strong>Biomass trends</strong></td>
<td><em>Does not project sardine biomass</em></td>
<td>Multi-decadal variability in adult biomass; periods of higher biomass in 2000-20 and 2080-2100, lower in 2040-60</td>
<td>General increasing trend in biomass; interannual variability same or higher; more biomass and uncertainty for HAD &amp; IPSL</td>
</tr>
<tr>
<td><strong>Total catch trends</strong></td>
<td>Increases (IPSL), decreases (HAD), or increases then decreases (GFDL) [to 2080]</td>
<td>Follows trend of biomass</td>
<td>Follows trend of biomass</td>
</tr>
<tr>
<td><strong>Catch distribution</strong></td>
<td>Increase in the north, decrease in the south</td>
<td>Increase in the north, decrease in the south (GFDL) and central (HAD, ISPL)</td>
<td><em>Catches not resolved at region/port level</em></td>
</tr>
<tr>
<td><strong>Main drivers</strong></td>
<td>Temperature and Chl; seasonal ACL allocation; timing of other CPS</td>
<td>Temperature through increased early life survival; Prey availability through reproductive output</td>
<td>Temperature, prey availability</td>
</tr>
</tbody>
</table>