Using bioenergetics models to estimate sensitivity of California Current groundfish to temperature anomalies

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Climate anomalies that affect co-occurring groundfish

- Interannual variation (e.g., El Niño)
- Interdecadal shifts (e.g., PDO)
- Long-term trends (e.g., climate change)

How do groundfish with different life histories respond to these changes?
Core bioenergetics processes:

\[ \Delta B = C - R - SDA - F - U - G \]

\[ \Delta B = CA \cdot W^{CB} \cdot CV^{CX} \cdot e^{(CX \cdot (1 - CV))} - RA \cdot W^{RB} \cdot RV^{RX} \cdot e^{(RX \cdot (1 - RV))} \cdot ACT \cdot oxycal \cdot ED \]

\[ - (SDA + U) \cdot (C - F) - F - W \cdot (GSI_{\text{max}} - GSI_{\text{min}}) \]
English sole, *Parophrys vetulus*  
(photo: Wes Nicholson)

Sablefish, *Anoplopoma fimbria*  
(photo: Wade D. Smith)

Spiny dogfish, *Squalus acanthias*  
(photo: Andrew J. Martinez)

Yelloweye rockfish, *Sebastes ruberrimus*  
(photo: Victoria O’Connell)
## Species characteristics

<table>
<thead>
<tr>
<th>Species</th>
<th>$L_\infty$ (cm)</th>
<th>Max age</th>
<th>Age 50%$_M$</th>
<th>Fecundity</th>
<th>Est. B/B$_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>English sole</td>
<td>39</td>
<td>20</td>
<td>3.5</td>
<td>150,000 to 2,000,000 eggs / yr</td>
<td>~0.9</td>
</tr>
<tr>
<td>Yelloweye rockfish</td>
<td>60</td>
<td>120</td>
<td>14</td>
<td>100,000 to 2,000,000 larvae / yr</td>
<td>~0.18</td>
</tr>
<tr>
<td>Sablefish</td>
<td>66</td>
<td>55</td>
<td>5.5</td>
<td>75,000 to 450,000 eggs / yr</td>
<td>~0.35</td>
</tr>
<tr>
<td>Spiny dogfish</td>
<td>153</td>
<td>75</td>
<td>21</td>
<td>1 to 20 pups / 2 yr</td>
<td>?</td>
</tr>
</tbody>
</table>
Which species are most sensitive to temperature in terms of...

...first year consumption?

...lifetime consumption?

...age at 50% maturity?

...lifetime egg production?
Consumption required to reach observed size at age 1

Temperature (°C)

Prey consumed (kg)

sablefish

rockfish

sole

dogfish

\[ y = 0.0367e^{0.0793x} \quad R^2 = 0.9984 \]

\[ y = 0.6973e^{0.0264x} \quad R^2 = 0.9952 \]

\[ y = 0.0433e^{0.0297x} \quad R^2 = 0.9969 \]

\[ y = 0.3156e^{0.0663x} \quad R^2 = 0.9997 \]
Which species are most sensitive to temperature in terms of...

...first year consumption?

...lifetime consumption?

...age at 50% maturity?

...lifetime egg production?

most

least

sole
dogfish
rockfish
sablefish
Lifetime cumulative consumption (assuming VBGF)

- **Sole**
  - Equation: $y = 25.864e^{0.0148x}$
  - $R^2 = 0.9222$

- **Rockfish**
  - Equation: $y = 344.21e^{0.0225x}$
  - $R^2 = 0.9614$

- **Sablefish**
  - Equation: $y = 283.83e^{0.0238x}$
  - $R^2 = 0.9628$

- **Dogfish**
  - Equation: $y = 366.84e^{0.0631x}$
  - $R^2 = 0.9999$

Temperature (°C) vs. Lifetime consumption (kg prey)
Which species are most sensitive to temperature in terms of...

...first year consumption?

...lifetime consumption?

...age at 50% maturity?

...lifetime egg production?
Index of relative consumption to reach $t_{50\%M}$

- **sablefish**
- **sole**
- **rockfish**
- **dogfish**

**Temperature (°C)**

**Consumption index**
Which species are most sensitive to temperature in terms of...

...first year consumption?

...lifetime consumption?

...age at 50% maturity?

...lifetime egg production?
Lifetime egg production by average female

- **Sablefish**
  - Formula: $y = 33.799e^{-0.1144x}$
  - $R^2 = 0.9873$

- **Dogfish**
  - Formula: $y = 32.95e^{-0.0703x}$
  - $R^2 = 0.9932$

- **Rockfish**
  - Formula: $y = 101.58e^{-0.0536x}$
  - $R^2 = 0.9674$

- **Sole**
  - Formula: $y = 317.63e^{-0.009x}$
  - $R^2 = 0.9338$

Temperatures (°C):
- 0 5 10 15 20
Which species are most sensitive to temperature in terms of...

...first year consumption?

...lifetime consumption?

...age at 50% maturity?

...lifetime egg production?
Life history strategies of some Pacific fishes (King and MacFarlane 2003)

Longest lived
Slowest growing
Most fecund
Smallest
Shortest lived
High fecundity

Largest body
Longest age_m
Largest progeny
How might groundfish express sensitivity?

• Changes in growth rates
• Changes in feeding rates (depletion, release, competition)
• Changes in foraging time (= changes in predation risk)
• Move to more optimal temperatures (depth, latitude)
• Recruitment peaks/drops
• Compensatory changes in life history parameters
• Changes in population size

• It may depend on the actual extent of the anomaly…
Possible future direction:
Maps of groundfish growth and reproduction sensitivity?

Depth specific temperature ranges
+ Age specific depth distributions
+ Age specific sensitivities to temperature

= Diagnostic map of sensitivity across a species’ life history

We could then overlay those maps spatially with where source/sinks are thought to be; overlay them temporally with when good/bad recruitment occurred...