Importance of Forage Fish in the California Current

Julie A. Thayer, Ph.D.
Overview

- Definitions

- Forage species ecology
  - Population dynamics
  - Climate and other effects
  - Fisheries effects
  - Predators & their needs
CCS forage species
- Small pelagics *(anchovy, sardine, herring, myctophid)*
- Juveniles of predatory fishes *(rockfish, hake)*
- Invertebrates *(krill, shrimp, squid)*

Comprehensive definition
1. Holds key role in the ecosystem *(is important in predator diet)*
2. Feeds predominantly on plankton
3. Forms dense schools
4. Small size (<30cm)
Population dynamics
- Small pelagics’ natural population fluctuations (known, although mechanisms not fully understood)

- Invertebrates are “bugs”
  - some live <1yr, some longer
  - can “shrink & sink”

- Juveniles depend on adult populations
Climate & Other Effects

- Climate effects
  - ENSO, PDO *(warm/cool regimes)*
  - Climate change *(trending temperatures, increasing variability)*
    - Ocean acidification
    - Disease, red-tide outbreaks
    - Ecosystem degradation *(pelagic, tidal/subtidal)*

- Species’ interactions *(competition, predation, non-natives)*

- Other non-fisheries human influences
  - Direct destruction of habitat
  - Increased pollution/runoff
  - Wave energy generation, desalinization, etc.
Effects of Fishing

• Ecological and population "viability"
  - Forage population declines are due much to climate and some to harvest but causes not separable
  - Fishing makes populations more susceptible to climate (Hsieh et al. 2006)

Ultimately, the question is whether fishing has resulted in populations visiting ecological states that would not have occurred naturally.
Who are the Predators?

- Whales & dolphins
- Seals & sea lions
- Seabirds & sea turtles
- Sharks & rays
- Predatory fishes like salmon & tuna
Predator Needs

- Diverse forage base

- Spatio-temporal availability
  \(\text{ predator-prey mis-match more frequent w/ climate change}\)

- How much food? \(\text{ combo of quantification approaches}\)
  - Bio-energetic modeling
  - Functional & numerical responses
  - Ecosystem modeling
## Top 10 CCS Forage Groups

<table>
<thead>
<tr>
<th>Forage species</th>
<th>presence in predator diet</th>
<th>Forage species</th>
<th>&gt;10%</th>
<th>Forage species</th>
<th>&gt;25%</th>
<th>Forage species</th>
<th>&gt;50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific herring (<em>Clupea pallasi</em>)</td>
<td>35%</td>
<td>Anchovy</td>
<td>20%</td>
<td>Anchovy</td>
<td>11%</td>
<td>Squid</td>
<td>6%</td>
</tr>
<tr>
<td>Lantern fish (<em>Myctophidae</em>)</td>
<td>33%</td>
<td>Rockfishes juv.</td>
<td>19%</td>
<td>Squid</td>
<td>11%</td>
<td>Krill</td>
<td>6%</td>
</tr>
<tr>
<td>Codfishes juvenile (<em>Gadidae</em>)</td>
<td>30%</td>
<td>Codfishes juv.</td>
<td>19%</td>
<td>Herring</td>
<td>10%</td>
<td>Anchovy</td>
<td>4%</td>
</tr>
<tr>
<td>Northern anchovy (<em>Engraulis mordax</em>)</td>
<td>29%</td>
<td>Krill</td>
<td>16%</td>
<td>Krill</td>
<td>9%</td>
<td>Herring</td>
<td>3%</td>
</tr>
<tr>
<td>Rockfishes juvenile (<em>Sebastes spp.</em>)</td>
<td>29%</td>
<td>Squid</td>
<td>15%</td>
<td>Codfishes juv.</td>
<td>9%</td>
<td>Codfishes juv.</td>
<td>3%</td>
</tr>
<tr>
<td>Shrimp (Crangon &amp; Mysid)</td>
<td>25%</td>
<td>Lantern fish</td>
<td>15%</td>
<td>Rockfishes juv.</td>
<td>8%</td>
<td>Rockfishes juv.</td>
<td>2%</td>
</tr>
<tr>
<td>Market squid (<em>Loligo opalescens</em>)</td>
<td>24%</td>
<td>Shrimp</td>
<td>10%</td>
<td>Lantern fish</td>
<td>5%</td>
<td>Shrimp</td>
<td>1%</td>
</tr>
<tr>
<td>Sanddabs, juv. halibuts (<em>Paralichthysidae</em>)</td>
<td>20%</td>
<td>Herring</td>
<td>8%</td>
<td>Shrimp</td>
<td>4%</td>
<td>Lantern fish</td>
<td>0.6%</td>
</tr>
<tr>
<td>Krill (<em>Euphausiidae</em>)</td>
<td>19%</td>
<td>Sardine</td>
<td>7%</td>
<td>Sardine</td>
<td>3%</td>
<td>Sardine</td>
<td>0.6%</td>
</tr>
<tr>
<td>Pacific sardine (<em>Sardinops sagax</em>)</td>
<td>14%</td>
<td>Sanddabs</td>
<td>6%</td>
<td>Sanddabs</td>
<td>2%</td>
<td>Sanddabs</td>
<td>0.6%</td>
</tr>
</tbody>
</table>
Important breeding colonies in Central CA (13 seabird, 5 pinniped spp.):

• Southeast Farallon Island (~100,000 birds & 6,000 pinnipeds)

• Año Nuevo Island (~9,000 birds & 18,000 pinnipeds)

From Thayer & Sydeman 2007
Seasonal Prey Importance

Central CA Chinook salmon diet

From Thayer et al. submitted
## Inter-Annual Prey Importance

<table>
<thead>
<tr>
<th>Predator</th>
<th>N (years)</th>
<th>Source</th>
<th>Krill</th>
<th>Market squid</th>
<th>Anchovy</th>
<th>Sardine</th>
<th>Herring</th>
<th>Rockfish (juv.)</th>
<th>Gadid (juv.)</th>
<th>Myctophid</th>
<th>Sanddab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandt's cormorant</td>
<td>9</td>
<td>Ainley et al. 1981</td>
<td>0-0.2</td>
<td>0-28</td>
<td>0-73</td>
<td>0-91</td>
<td>0-15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>California sea lion</td>
<td>3</td>
<td>Weise and Harvey 2008</td>
<td>5-19</td>
<td>7-13</td>
<td>61-68</td>
<td>0.2</td>
<td>3-6</td>
<td>2-6</td>
<td>0-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>11</td>
<td>Thayer et al. submitted</td>
<td>0-48</td>
<td>0-20</td>
<td>1-90</td>
<td>0-28</td>
<td>0-51</td>
<td>0-70</td>
<td>0-7</td>
<td>0-1</td>
<td></td>
</tr>
<tr>
<td>Common murre</td>
<td>4</td>
<td>Matthews 1983</td>
<td>0-36</td>
<td>0-15</td>
<td>0-47</td>
<td>1-24</td>
<td>1-43</td>
<td>9-30</td>
<td>0-11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elegant tern</td>
<td>8</td>
<td>Velarde et al. 1994</td>
<td></td>
<td></td>
<td></td>
<td>35-98</td>
<td>2-59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacific hake</td>
<td>2</td>
<td>Livingston 1983</td>
<td>0-93</td>
<td>0-16</td>
<td></td>
<td>0-67</td>
<td>0-4</td>
<td>0-1.3</td>
<td>0-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhinoceros auklet</td>
<td>17</td>
<td>Thayer &amp; Sydeman 2007</td>
<td>0-27</td>
<td>8-100</td>
<td>0-18</td>
<td>0-8</td>
<td>0-61</td>
<td>0-1</td>
<td>0-12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sooty shearwater</td>
<td>2</td>
<td>Gould et al. 2000</td>
<td>0-1</td>
<td>0-2</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td>1-40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellowtail rockfish</td>
<td>2</td>
<td>Brodeur and Pearcy 1984</td>
<td>0-28</td>
<td>2-15</td>
<td></td>
<td>0-18</td>
<td>0-0.4</td>
<td>0-3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Bio-energetic modeling

Seabird prey needs – *Common Murre*

- Pt. Conception, CA to Cape Blanco, OR

- Estimated prey consumption (2004) = \(225,235\) t

- Included consumption of:
  
  \(~58,000\) t market squid
  
  \(~55,000\) t juvenile hake
  
  \(~23,000\) t anchovy
  
  \(~21,000\) t juvenile rockfish

*From Roth et al. 2008*
Functional Responses

- Single predator parameter vs. forage parameters
- Determines threshold at which predator parameters are compromised

Double-crested cormorants and juvenile rainbow trout

Below threshold, likelihood of bird encountering fish decreased

From Enstipp et al. 2007
Numerical Responses – CCS Data

Seabird productivity and prey abundance

From Field et al. 2010
Ecosystem modeling – current

- Allows integration of multiple predators in a comprehensive ecosystem context

- ECOPATH w/ECOSIM, ATLANTIS

- But has NOT been able to replicate population cycling of coastal pelagics

From Field & Francis 2006
Ecosystem modeling - needs

- Stochastic models best represent predator use of prey (which varies seasonally, inter-annually, spatially) (e.g., End-to-End Models: ROHMS->NPZ->IBM)

- Get away from abundance as metric of predator response (the LEAST responsive measure, may underestimate needs)

- Incorporate variance (averages do not accurately represent how predators respond to prey availability)
Ecosystem-Based Approach

• Many of top 10 forage groups in the CCS are exploited

• Ecological importance of forage species is not new issue, but improved acknowledgement and explicit management guidance needed *(particularly in light of increasing climate variability)*

• First step - data does exist to quantify predator forage needs in the CCS – needs synthesis!
Summary

- Forage species are more than just small pelagics
- Forage species ecology affected by climate & fishing
- Whales to seabirds rely on these forage species
- Important to have diverse forage community (species richness, space & time)
- Data exist to quantify predator needs; need to be synthesized
- Ecosystem-Based Management