Predation impact by juvenile salmon on early life stages of anchovy in the eastern North Pacific Ocean

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Rationale

1) Although predation is thought to be the major source of mortality for early life stages of fish (Bailey and Houde 1984), there have been few attempts to quantify levels of predation on juvenile fishes in marine systems.

2) Surveys of the diets of pelagic marine fish show much piscivory with some species concentrating on focal juvenile fish species.
Ontogenetic Change in Coho Salmon Diet

- Daly et al. (2009)
- TAFS
Ontogenetic Change in Chinook Salmon Diet

N = 94  313  229  471  440  342  241  162  145  93  51  84  58

Daly et al. (2009)
September Subyearling Chinook Salmon Diet (digested fish prey apportioned to identified fish prey groupings)

Diet composition by prey weight

- Anchovy
- Clupeids
- Smelts
- Greenlings
- Sardines
- Rockfish
- Other fishes
- Cancer Crab larvae
- Euphausiids
- Vibilia
- Amphipods


Number of samples: N = 104, 218, 50, 108, 200, 78, 30, 267, 282, 187, 291, 33, 85, 107, 100
Rationale

1) Although predation is thought to be the major source of mortality for early life stages of fish, there have been few attempts to quantify levels of predation on juvenile fishes in marine systems.

2) Surveys of the diets of pelagic marine fish show much piscivory with some concentration on focal juvenile fish prey.

3) Juvenile Pacific salmon are highly piscivorous (70-90%) and a dominant component of the coastal system and thus have the potential to impact prey populations.
Objectives

The goal of this study is to examine juvenile anchovy prey of Chinook and coho salmon in coastal regions of the Northern California Current (Oregon and Washington) by examining:

1) proportions of anchovy prey in the diets of each predator by season and year,
2) overall prey consumption using bioenergetics modeling and estimates of salmon and available prey present in coastal waters from trawl sampling,
3) sizes of anchovy prey consumed compared to available sizes to examine size-selective predation.
Salmon Migration from Columbia River

The Columbia River is a major source of Coho and Chinook salmon along the US West Coast.
Northern Anchovy (*Engraulis mordax*) – Typical Life History

First Feeding Larvae

Depth:
- 25m
- 50m
- 200m
- 500m
- 700m
- 1000m

Size:
- 4.5 - 9 mm
- 9-20 mm
- 20-60 mm

Time:
- Spring
- Summer
- Fall

Move inshore STST

Pelagic Juveniles

Continental shelf
Data Required to Estimate Prey Consumption

- **Salmon diet analysis:** annual time series of prey consumed from BPA seasonal surveys for Chinook and Coho, 2005-2011.

- **Salmon abundance:** annual time series of abundance for 3 months from BPA seasonal Salmon Surveys, 2005-2011 (Pennington 1996).

- **Prey abundance:** annual time series of late juvenile anchovy abundance per tow from NMFS Juvenile Surveys, 2005-2011.

- **Individual consumption estimates:** annual (2005-2011) time series of bioenergetic model runs using predator and prey energy values, growth rates (g/day), and temperature in the upper 20 m integrated across the shelf.
Salmon collected in surface trawls at sea from May to September 2005-2011

Stomachs removed in the laboratory

Stomach contents identified to species, counted and weighed and length estimated for fish prey

Available fish prey from fine-mesh trawl from independent juvenile fish surveys

Methods
Sampling Periods
(May, June and September)
(n > 1000 trawls from 2005 - 2011)

Total Sample Area 17,846 km²

Juvenile Fish Sampling Periods
(May through September)
(n = 585 trawls from 2005 - 2011)
Salmon diet analysis

Northern Anchovy

Month
May June Sept.

Proportion in Diet by weight of prey

0.0 0.1 0.2 0.3 0.4 0.5 0.6

Chinook salmon
Coho salmon

NOAA FISHERIES

Proportion in Diet by weight of prey

May June Sept.

Chinook salmon
Coho salmon

Salmon diet analysis
Juvenile Chinook Abundances on Shelf

May

2005 2006 2007 2008 2009 2010 2011
Total Abundance
0
1x10^6
2x10^6
3x10^6
4x10^6

June

2005 2006 2007 2008 2009 2010 2011
Total Abundance
0
1x10^6
2x10^6
3x10^6
4x10^6

September

2005 2006 2007 2008 2009 2010 2011
Total Abundance
0
1x10^6
2x10^6
3x10^6
4x10^6

Salmon abundance: (estimates courtesy of Jim Ruzicka)
Salmon abundance: (estimates courtesy of Jim Ruzicka)
Used Wisconsin (V3.0) Fish Bioenergetic Model adjusting Chinook and Coho parameters based on recent studies.

Used seasonal changes in predator weight, diet data, and mean temperature (upper 20 m) by year for May, June and September cruises from 2005-2011.

Ran simulations over 30 days (May 25 to June 25) and 93 days (June 25 to Sept. 25).

Converted weight to number consumed per day using mean prey weights.

Bionergetic Modelling Estimates

Individual consumption estimates
Estimation of Daily Food Consumption

May to June Daily Ration

<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Ration (%BW d(^{-1}))</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

June to September Daily Ration

<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinook Salmon</td>
<td>Coho Salmon</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Individual consumption estimates
Age-0 Anchovy Abundances on Shelf

June

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>4x10^8</td>
</tr>
<tr>
<td>2006</td>
<td>0</td>
</tr>
<tr>
<td>2007</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>0</td>
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<tr>
<td>2009</td>
<td>6x10^8</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
</tr>
<tr>
<td>2011</td>
<td>3x10^7</td>
</tr>
</tbody>
</table>

September

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td>3x10^7</td>
</tr>
<tr>
<td>2007</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>0</td>
</tr>
<tr>
<td>2009</td>
<td>9x10^7</td>
</tr>
<tr>
<td>2010</td>
<td>1x10^8</td>
</tr>
<tr>
<td>2011</td>
<td>2x10^8</td>
</tr>
</tbody>
</table>
Juvenile Anchovy Consumption

**June**

- Chinook Salmon
- Coho Salmon

<table>
<thead>
<tr>
<th>Years</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Consumed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Mean

- $\bar{X} = 3.9$
- $\bar{X} = 1.8$

**September**

<table>
<thead>
<tr>
<th>Years</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Consumed</td>
<td>20</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

Mean

- $\bar{X} = 12.9$
- $\bar{X} = 2.1$

Total Consumption by Year
Estimating % of Available Anchovy Consumed by Month

- Salmon prey field sampled monthly (May – Sep) in 2011 and 2012
- Proportion of anchovy in diets determined from gut contents
- Bioenergetics model (R version) converted proportion of anchovy consumed to average number consumed per day
Consumption of northern anchovy by Chinook Salmon

**June - July**
- 2011: 0.1 anchovy/day
- 2012: 1.6 anchovy/day

**July - August**
- 2011: 0.1 anchovy/day
- 2012: 1.4 anchovy/day

**August - September**
- 2011: 1.6 anchovy/day
- 2012: 0.2 anchovy/day

Litz et al. (MS)
Juvenile Anchovy Consumed by Subyearling Chinook from the Upper Columbia River Summer/Fall Group by Month (2011 and 2012)

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>% Consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0.50</td>
<td>8.53 %</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0.28</td>
<td>&gt;100 %</td>
</tr>
</tbody>
</table>

Values based on bioenergetics model estimates of consumption combined with field measurements of salmon abundance, anchovy biomass, and anchovy size.
Relationships between size of Juvenile Anchovy Consumed and Predator Size
Chinook Salmon

Coho Salmon

Northern Anchovy

Predator Size (mm)

Prey Size (mm)

June
Sept
Northern Anchovy

Predator Size (mm)

Prey Size (mm)

June
Sept
Northern Anchovy

Predator Size (mm)
Anchovy Lengths in September

Trawls (n = 247)

Chinook Diets (n = 1007)

Coho Diets (n = 116)
Size-selective predation of northern anchovy by subyearling Chinook Salmon

August 2011

September 2011

August 2012

September 2012

n = 120 field
n = 2 gut
n = 240 field
n = 58 gut
n = 90 field
n = 4 gut
n = 11 field
n = 3 gut
Conclusions

- Chinook and coho salmon are highly piscivorous and have the potential to impact anchovy populations during some years in the northern California Current.
- Can be substantial interannual and seasonal variability in utilization of these important prey by juvenile salmon.
- Similar prey size range between size of prey consumed and those available but some apparent selection for larger (or smaller) prey available.
Future studies:

- Refine predation estimates with error bounds
- Examine growth differences between consumed prey and available individuals (otoliths)
- Compare salmon consumption rates to other potential predators in the NCC.
Salmon are not the only predators....
# Dominant Predators of Northern Anchovy in the California Current

<table>
<thead>
<tr>
<th>Category</th>
<th>Predators</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FISH</strong></td>
<td>(75%)</td>
</tr>
<tr>
<td>Pacific hake adults</td>
<td>(35%)</td>
</tr>
<tr>
<td>Jack mackerel</td>
<td>(14%)</td>
</tr>
<tr>
<td>Albacore</td>
<td>(13%)</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>(5%)</td>
</tr>
<tr>
<td>Halibut</td>
<td>(3%)</td>
</tr>
<tr>
<td>Sablefish</td>
<td>(2%)</td>
</tr>
<tr>
<td>Other Fish (&lt; 1%)</td>
<td></td>
</tr>
<tr>
<td>Spiny dogfish</td>
<td></td>
</tr>
<tr>
<td>Pacific bluefin tuna</td>
<td></td>
</tr>
<tr>
<td>Pacific bonito</td>
<td></td>
</tr>
<tr>
<td>Thresher shark</td>
<td></td>
</tr>
<tr>
<td>Black rockfish</td>
<td></td>
</tr>
<tr>
<td>Soupfin shark</td>
<td></td>
</tr>
<tr>
<td><strong>MAMMALS</strong></td>
<td>(16%)</td>
</tr>
<tr>
<td>California sea lion</td>
<td>(7%)</td>
</tr>
<tr>
<td>Short-beaked common dolphin</td>
<td>(3%)</td>
</tr>
<tr>
<td>Other Mammals (&lt;1%)</td>
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<tr>
<td>Humpback whale</td>
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<tr>
<td>Harbor porpoise</td>
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<tr>
<td>Pacific white-sided dolphin</td>
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<tr>
<td>Long-beaked common dolphin</td>
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<tr>
<td>Fin whale</td>
<td></td>
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<tr>
<td>Harbor seal</td>
<td></td>
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<tr>
<td>Sperm whale</td>
<td></td>
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<tr>
<td>Northern fur seal</td>
<td></td>
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<tr>
<td><strong>CEPHALOPODS</strong></td>
<td></td>
</tr>
<tr>
<td>Jumbo squid</td>
<td>(2%)</td>
</tr>
<tr>
<td><strong>SEABIRDS</strong></td>
<td>(7%)</td>
</tr>
<tr>
<td>Shearwaters</td>
<td>(3%)</td>
</tr>
<tr>
<td>Common murre</td>
<td>(2%)</td>
</tr>
<tr>
<td>Other Seabirds (&lt;1%)</td>
<td></td>
</tr>
<tr>
<td>Heermann’s gull</td>
<td></td>
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<tr>
<td>Brown pelican</td>
<td></td>
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<tr>
<td>Black-vented shearwater</td>
<td></td>
</tr>
<tr>
<td>California gull</td>
<td></td>
</tr>
<tr>
<td>Brandt’s cormorant</td>
<td></td>
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<tr>
<td>Marbled murrelet</td>
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<tr>
<td>Western gull</td>
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<tr>
<td>Double-crested cormorant</td>
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<tr>
<td>Caspian tern</td>
<td></td>
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<tr>
<td>Xantus’ murrelet</td>
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<tr>
<td>Rhinoceros auklet</td>
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<tr>
<td>Elegant tern</td>
<td></td>
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<tr>
<td>Least tern</td>
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</table>

Szoboszlai et al. (in prep.)
Acknowledgements

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