Is fishing for Atka mackerel responsible for the decline of Steller sea lions in the western and central Aleutian Islands?

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2010 Biological Opinion

“NMFS concludes that the relative intensity of groundfish fisheries as currently prosecuted in the western and central Aleutian Islands sub-regions, particularly within critical habitat, is negatively associated with Steller sea lion population trends since 2000”

page xxxiii, 2010 Biological Opinion
No negative relationship between fishing & sea lion trends since 2000.
“Recent studies, however, show very inconclusive relationships between fishery removals of prey and SSL sub-population growth (e.g., Trites et al. 2010)”.

2010 BiOp, Page 265
Maybe you missed something?

Lagged effects?
Steller sea lion data
Central & Western Aleutians

- Numbers of sea lions
- Changes in numbers

- non pups
- 13 rookeries
- 60 haulouts
- 2000-2010 pups

Data from NMFS
Steller Sea Lion Rookeries & Haulouts

RCA = Rookery Cluster Area
Steller Sea Lion Rookeries & Haulouts

RCA 1
RCA 2
RCA 3
RCA 4
RCA 5

RCA = Rookery Cluster Area
Average Steller Sea Lion Numbers
Change in Sea Lion Numbers
Change in Sea Lion Numbers

Legend

ChgData_Features
cSSL_6
-191.000000 - -100.000000
-99.999999 - -40.000000
-39.999999 - -0.000100
-0.000099 - 0.000000
0.000001 - 40.000000
40.000001 - 100.000000
100.000001 - 223.000000
continent_Project
RCA5
RCA4
RCA3
RCA2
RCA1

101 – 223
41 – 100
1 – 40
0
-39 – -1
-99 – -40
-192 – -100
Change in Sea Lion Numbers

2004-2002

Legend
ChgData_Features
cSSL_6
-191.000000 - -100.000000
-99.999999 - -40.000000
-39.999999 - -0.000100
-0.000099 - 0.000000
0.000001 - 40.000000
40.000001 - 100.000000
100.000001 - 223.000000

continent_Project
RCA5
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Change in Sea Lion Numbers

Legend
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continent_Project
RCA5
RCA4
RCA3
RCA2
RCA1

101 – 223
41 – 100
1 – 40
0
-39 – -1
-99 – -40
-192 – -100

RCA 1
RCA 2
RCA 3
RCA 4
RCA 5

2005-2004
No Pattern

Change in Sea Lion Numbers
Fisheries Data

- **Catch**
- **Effort**

- All vessels fishing Atka mackerel
- 2000-2010
- Amounts, dates, times & locations by hauls

Data from NMFS; compiled by Sea State Inc.
Fishery

- 4-11 vessels
- 2 observers
- VMS coverage

- 11% exploitation rate on age 3+
- 2010 biomass 844,000 tons

~1 billion fish
~10,000 sea lions
Total catch of Atka within 40nm

Calculated catch within 10, 20 & 40 nm of rookeries and haulouts
Total catch of Atka within 40nm

Legend
AllyrsSSL_atka_all40nm
TOT40NM_27
0.000000 - 0.000100
0.000101 - 600.000000
600.000001 - 5000.000000
5000.000001 - 12000.000000
12000.000001 - 18000.000000
18000.000001 - 26089.000000
continent_Project
RCA1
RCA2
RCA3
RCA4
RCA5

2007
0
1—600
601—5000
5001—12000
12001—18000
18001—26089
Total catch within 40nm

Some sites have had little or no fishing

Fishing Intensity varied in time & space
General Estimating Equation Models (GEEs)

- Extension of ordinary linear regression
- Account for correlations between repeated measures
Conceptually, we used GEEs to test for:

- **Localized Depletion**
  Total catch removed (10, 20 & 40 nm)

- **Prey Availability**
  Average catch per haul as measure of relative stock size

- **Disturbance**
  Number of hauls
GEE Model

\[ \text{SSLcnt}_{ij} = \exp(\beta_0 + \beta_{\text{trawl}}\text{trawl}_{ij} + \beta_{\text{year}}\text{year}_j + \beta_{\text{trawl}\cdot\text{year}}\text{year}\cdot\text{trawl}_{ij} + \beta_{\text{lon}}\text{lon}) \]

- 216 potential models
- assessed spatial independence of data using longitude
- 129 actual models
Possible Findings

NO relationships

NEGATIVE relationships
• more fishing results in fewer sea lions

POSITIVE relationships
• More fishing associated with more sea lions
Results

24 significant relationships

NEGATIVE relationships
• more fishing results in fewer sea lions

POSITIVE relationships
• More fishing associated with more sea lions
“NMFS concludes that the relative intensity of groundfish fisheries as currently prosecuted in the western and central Aleutian Islands sub-regions, particularly within critical habitat, is negatively associated with Steller sea lion population trends since 2000”

page xxxiii, 2010 Biological Opinion
Conclusions

1. Sea lion trends (2000-2010) were not negatively associated with Atka mackerel fishery indices
Conclusions

2. Important to test hypotheses about fishing effects with data
Evaluating Steller sea lion critical habitat in Alaska using dynamic prey distribution models

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Steller sea lion critical habitat

- historic distribution of fishing – 1993
- presumed foraging areas – 1993
How to evaluate critical habitat?

- Overlap with fisheries
- Prey resources

dynamic distributions of fish
Data

NMFS Trawl Survey
walleye pollock
Pacific cod
Atka mackerel

2000-2004
June/July

Bottom Temp
Alternate Critical Habitat

- habitat suitability/availability
- Telemetry data
- at-sea-sightings

Gregr & Trites 2008
Modeling

- Generalized least square models (GLS)
- Three regions
  - Bering Sea
  - Gulf of Alaska
  - Aleutian Islands
Aleutian Islands

- **Atka mackerel**
  - *vertical/horizontal current vectors*
  - temperature (mld, bottom)
  - bathymetry
  - sea surface temperature
  - sea surface height

- **Walleye pollock**
  - bathymetry, sea surface height, bottom temperature, bottom salinity

- **Pacific cod**
  - bathymetry, sea surface height, sea surface temperature, mld temperature, salinity (mld, bottom)
Atka mackerel, walleye pollock and pacific cod combined biomass
Conclusions

• Prey distributions are a good tool to assess critical habitat boundaries

• Efficiency of critical habitat boundaries varies between regions

• Critical habitat should be refined using prey distributions and oceanographic information
Atka Mackerel

Proximate Analysis & Feeding Studies
Historical Overview

- **Act I**
  - Rosen & Trites (2000) – junk food hypothesis
    - Low-Cal or Nutra-Lite Hypothesis
    - First suggestion that quality could be important if animals do not eat enough
    - Perpetual time warp

- **Act II**
  - Rosen & Trites (2004, 2005) – mechanisms
    - Sea lions can do well on low-lipid diet if they can eat enough of it
    - Young (<1) have high energy requirements and small stomachs

- **Act III**
  - Rosen et al. (2007, 2012) – effects of seasons
Captive Feeding Studies

Steller sea lions *Eumetopias jubatus* and nutritional stress: evidence from captive studies

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ABSTRACT
1. Numbers of Steller sea lions *Eumetopias jubatus* in the North Pacific have declined. According to the nutritional stress hypothesis, this decline is due to reduced food availability. Data from studies conducted on pinnipeds in the laboratory are used here to test if the nutritional stress hypothesis can explain the decline of Steller sea lions.
2. Overall, there is strong evidence for biologically meaningful differences in the nutritional quality of major prey species. Steller sea lions can partly compensate for low-quality prey by increasing their food consumption.
3. There appear to be no detrimental effects of low-lipid prey on sea lion growth or body composition when sea lions can consume sufficient quantities of prey. However, the ability to increase consumption is physiologically limited, particularly in young animals. Overall, it is more difficult to maintain energy intake on a diet of low-quality prey than on a normal diet.
4. Under conditions of inadequate food intake (either due to decreased prey availability or quality, or increased energy requirements) the overall impacts of nutritional stress are complex, and are dependent upon season, prey quality, age and the duration and intensity of the nutritional stress event.
5. Studies on pinnipeds in the laboratory have been instrumental in identifying the conditions under which changes in sea lion prey can result in nutritional stress and the nature of the physiological impacts of nutritional stress events.

Keywords: conservation, diet, metabolism, nutrition, pinnipeds

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INTRODUCTION
The precipitous decline of Steller sea lions *Eumetopias jubatus* in the North Pacific has generated a tremendous scientific effort to understand the reasons for the population change, supported by an unprecedented level of funding for conservation-directed research (see Morell, 2008). The numerous individual hypotheses put forward to explain the decline are concerned with both proximate and ultimate factors that range in scale from ecosystem changes to individual sea lion physiology (Anonymous, 2008). To make things more complex, many of these hypotheses are inter-related (Guenette et al., 2006; Atkinson, DeMaster & Calkins, 2008b).

One hypothesis that has received a great deal of attention has become known as the nutritional stress hypothesis. Calkins & Goodwin (1988) are generally credited with first providing evidence of nutritional concerns among wild Steller sea lions. They noted:

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General Conclusions

• Sea lions can adjust intake in response to changes in prey quality
• Lower prey quality requires eating more
• **But** the amount of prey they can consume is limited by physiological constraints and finite foraging time
• Young sea lions are the most constrained, especially <1 year
General Conclusions

- **IF** intake is **SUFFICIENT**, prey quality doesn’t affect body mass or health
- **IF** intake is **INSUFFICIENT**, sea lions can make physiological adjustments to dampen effects
General Conclusions

• **However**, these adaptations are finite and depend upon season, age, etc.

• If intake remains insufficient, there are physiological consequences due to prey quality in addition to energy deficits.
**Predictions**

**QUESTION 4:** Are there certain times of the year when the quality of Atka mackerel may make it difficult for Steller sea lions to meet their energetic requirements? Discuss the implications. Show your work [30 points]*

The quality of Atka mackerel might have an effect if the amount sea lions require exceeds their physical digestive/ingestion capacity (i.e., food mass per body mass is too high to sustain long-term).

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The available data suggests that the high energy requirements of sea lions and low prey quality of Atka mackerel in the spring (regardless of abundance) might make things difficult for Steller sea lions. This interaction is potentially greatest for younger sea lions, such as those that wean in their first year!

*Abstract title: Lacka mackerel? Is Atka mackerel "good enough" for Steller sea lions?*

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Junk Food Hypothesis / Mechanism

Energy required (per kg body mass) / Fish Energy density (per kg fish mass) = Food required (as % body mass)

- Range of values due to sex differences and natural variation in metabolism as observed in captive Stellers
- Unpublished data from monthly samples of fish stomachs analyzed by bomb calorimetry
- Apparent ingestion limit for young Stellers as per Rosén & Trites 2004
- Traditional spring warming data

Age of sea lion (months) | Jun Aug Oct Dec Feb Apr | Year 1 | SSL Year 1
---|---|---|---
0 | 6 | 12 | 18 | 24 | 30 | 36
Energy required (kJ/d) | Energy density (MJ/kg) | Food required (% body mass) | Jun Aug Oct Dec Feb Apr | Year 2 & 3
Energy density of Atka mackerel by month
MA 541, 542, 543
Steller sea lion Atka mackerel feeding trials

• Four Steller sea lions
• Isocaloric Atka mackerel and herring diets
• Altering levels of energetic intake.

• Monitor body mass, composition, and blood chemistry (incl. RNA markers of nutritional stress).

• Experiment repeated spring and fall with seasonally appropriate Atka mackerel.
Steller sea lion Atka mackerel feeding trials

(Spring results)

Goal: Normal growth 10% mass loss No growth

<table>
<thead>
<tr>
<th></th>
<th>Normal diet</th>
<th>Restriction</th>
<th>Maintenance</th>
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<tbody>
<tr>
<td>Gross Energy Intake (kJ/d)</td>
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Week
Normal diet:
Slightly greater growth on herring with same gross energy intake (reflecting differences in net energy calculations)

Mass change:
- Herring +2.9%
- Atka +0.0%

Goal:
- Normal growth
- 10% mass loss
- No growth

<table>
<thead>
<tr>
<th>Week</th>
<th>Normal diet</th>
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<tbody>
<tr>
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<td>5500</td>
<td>5000</td>
<td>4500</td>
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</tbody>
</table>
Restriction:
Slightly greater mass loss on AM with same gross energy intake

Mass change:
- Herring: +2.9%  - Herring: -7.2%
- Atka: +0.0%    - Atka: -10.1%

Goal:
- Normal growth
- 10% mass loss
- No growth

Graph showing gross energy intake over weeks with different scenarios:
Mass change:
- Herring +2.9%
- Herring -7.2%
- Atka +0.0%
- Atka -10.1%

Goal:
- Normal growth
- 10% mass loss
- No growth

Graph showing gross energy intake (kJ/d) over weeks for different diets and species.
Maintenance:
Requires >25% more gross energy to maintain body mass after restriction

<table>
<thead>
<tr>
<th>Mass change:</th>
<th>Herring +2.9%</th>
<th>Herring -7.2%</th>
<th>Herring +2.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atka</td>
<td>+0.0%</td>
<td>-10.1%</td>
<td>-0.7%</td>
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Goal:
- Normal growth
- 10% mass loss
- No growth

Goal: Normal growth 10% mass loss No growth

Week

Gross Energy Intake (kJ/d)

Normal diet | Restriction | Maintenance

Week
Energy density of Atka mackerel by month
MA 541, 542, 543
Other Studies


“Cod were almost unknown until the sea lion herds diminished in 1873; now they are very common. The Atka mackerel was unknown on Attu before 1875, when it appeared unexpectedly. The natives say that it drove the sea lions away.”

Weissinger (1961)