Evidence of declining fecundity in the Central Gulf of Alaska

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The basic idea

- Develop models for the population based on data and knowledge about SSL life-history.

- Fit to time series data 1976 to 2004: pup, non-pup, and juvenile fraction

- Estimate maximum likelihood fits juvenile survivorship, adult survivorship and fecundity in different time periods

- Statistically quantify the fits
Data are derived mainly from the aerial survey data

AN AGE-STRUCTURE METRIC

NON-PUPS on TRENDSITES (Br SEASON)

TOTAL CGA PUP COUNT
Basic life history can be estimated from 1970s age and pregnancy data from Marmot Is.
Fitting models to total population trends alone does not rapidly detect change
Changes in age-structure is more sensitive to perturbations

- Perturbation was a 20% increase in juvenile survivorship
- Most extreme values occur 4-yrs following a change
- Ratio stabilizes 10 yrs following the change
Changes in juvenile fraction allow us to see perturbations quickly

AN AGE-STRUCTURE METRIC

NON-PUPS on TRENDSITES

TOTAL CGA PUP COUNT
We used this approach to estimate demographic perturbations in the CGOA

- Can you explain the data with only one early 1980s perturbation?
- How have demographic parameters been changing 1980-2004?
- What demographic parameter change is most consistent with the recent non-pup increases?
We focused on the CGOA
Is the analysis sensitive to the model?
We compared 3 life-history models, all based on the 1970s Marmot Island data.
We allowed demographic rates to change through the 1980’s and 1990’s

For \( t = 1976 \) to \( 1982 \),
\[
\mathbf{\tilde{N}}_{t+1} = \mathbf{Y}_{76} \cdot \mathbf{\tilde{N}}_t
\]
For \( t = 1983 \) to \( 1987 \),
\[
\mathbf{\tilde{N}}_{t+1} = \mathbf{Y}_{83} \cdot \mathbf{\tilde{N}}_t
\]
For \( t = 1988 \) to \( 1992 \),
\[
\mathbf{\tilde{N}}_{t+1} = \mathbf{Y}_{88} \cdot \mathbf{\tilde{N}}_t
\]
For \( t = 1993 \) to \( 1998 \),
\[
\mathbf{\tilde{N}}_{t+1} = \mathbf{Y}_{93} \cdot \mathbf{\tilde{N}}_t
\]

Matrices with period specific juvenile surv., fecundity, adult surv.

14-17 free parameters
Three scaling parameters

Survivorship

- #1 Scale juvenile survivorship
- #2 Scale adult survivorship

Fecundity

- #3 Scale fecundity

14-17 free parameters
We allowed demographic rates to change through the 1980’s and 1990’s

For $t = 1976$ to $1982$,

$$\tilde{N}_{t+1} = Y_{76} \cdot \tilde{N}_t$$

For $t = 1983$ to $1987$,

$$\tilde{N}_{t+1} = Y_{83} \cdot \tilde{N}_t$$

For $t = 1988$ to $1992$,

$$\tilde{N}_{t+1} = Y_{88} \cdot \tilde{N}_t$$

For $t = 1993$ to $1998$,

$$\tilde{N}_{t+1} = Y_{93} \cdot \tilde{N}_t$$

Matrices with period specific juvenile surv., fecundity, adult surv.

14-17 free parameters
Distance between the model and the data: negative log-likelihood

\[ S(\theta) = \frac{1}{2\sigma_{\ln N}^2} \sum_{i=1}^{k} \left( \ln(N_i) - \ln(0.524(\hat{J}_i + \hat{A}_i)) \right)^2 \]

\[ + \frac{1}{2\sigma_{\ln P}^2} \sum_{i=1}^{n} \left( \ln(P_i) - \ln(0.95\hat{P}_i) \right)^2 \]

\[ + \frac{1}{2\sigma_J^2} \sum_{i=1}^{m} \left( (J/T)_i - (0.8\hat{J}_i / (\hat{J}_i + 0.21\hat{A}_i)) \right)^2 \]

+ a constant

**Model**

**Data**

**Relationship between the indices and true value**
We had to construct plausible time periods for when demographic rates changed. We did this 2 different ways.

- Oceanographic
- Analysis of rookery trends (York 1994)
- Known management actions
- Treat each year as a possible change point
Methodology overview

- Location
- Life-history models
- Temporal changes
- Fitting models
- Historical age-structure proxy
We had to develop a practical proxy for age-structure

- Use models to explore what are sensitive proxies
  - Ratio of pups to non-pups
  - Ratio of rookery to haul-out non-pups
  - Ratio of juveniles to adults
- Develop a practical way to measure the proxy: the ratio of small to large individuals
- Test it
The data
Measurements

11 years
7000-2000 animals per year
15-20 haul-outs
31,000 total measurements
Juvenile fraction has been changing

**AN AGE-STRUCTURE METRIC**

**NON-PUPS on TREND SITES**

**TOTAL CGA PUP COUNT**
We used this approach to estimate demographic perturbations in the CGOA

- Can you explain the data with only one early 1980s perturbation?
- How have demographic parameters been changing 1980-2004?
- What demographic parameter change is most consistent with the recent non-pup increases?
One change in demographic rates or multiple?

From Holmes & York 2003
Data are best fit by 4 demographic changes.
Fit of model indicates rising survivorship and declining fecundity.
The different models vary in their ability to fit the data.
Models agree on declining fecundity and rising juvenile survivorship.
Agreement among models is driven by declining pup-to-non-pup ratios.
It is difficult to explain the sum total of CGOA demographic data available since 1980 without a drastic decline in SSL fecundity.