Integrating environmental data into the assessment of eastern North Pacific gray whales

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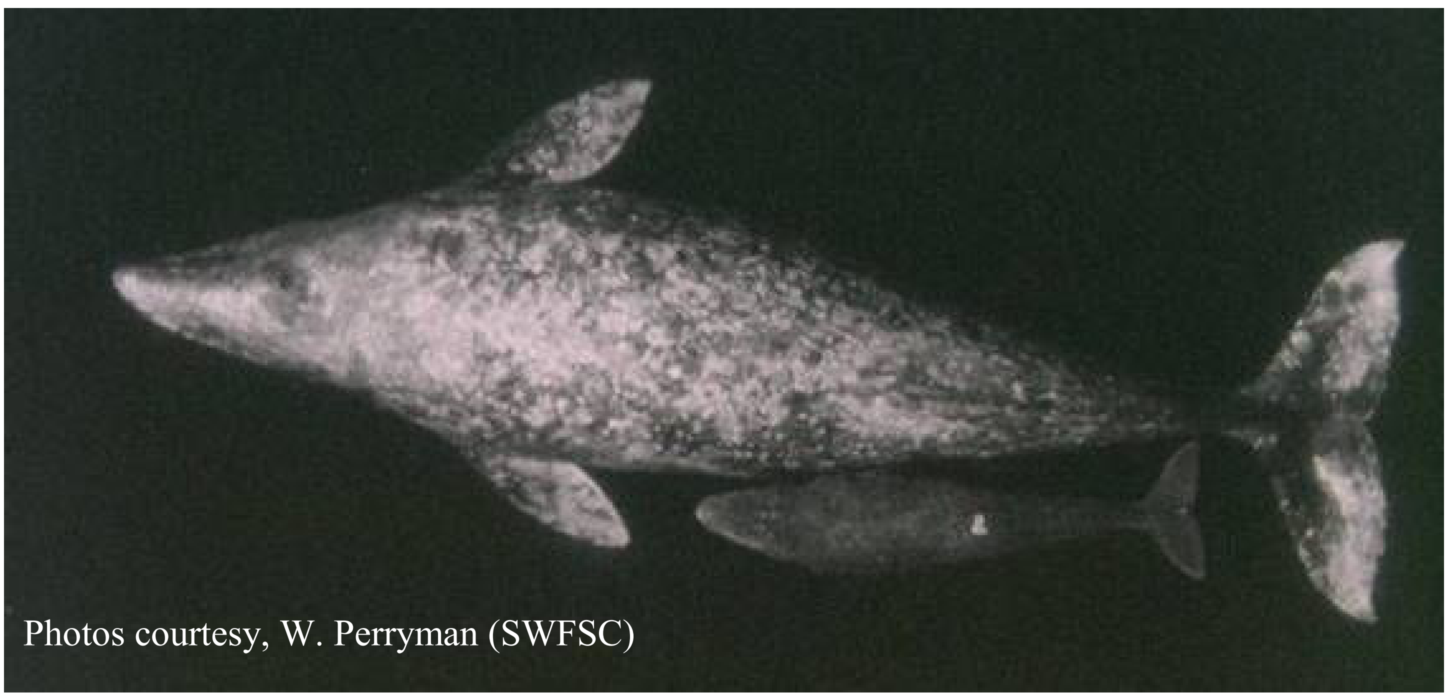
Motivation

Increase understanding of population dynamics.

Provide more precise estimates of management quantities.

Framework to test management procedures given climate forecasts.


Photos courtesy, W. Perryman (SWFSC)

Outline

Sea ice and eastern gray whale feeding ecology

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Framework to integrate sea ice & stock assessment

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Sea ice and eastern gray whale feeding ecology

Framework to integrate sea ice & stock assessment

Results

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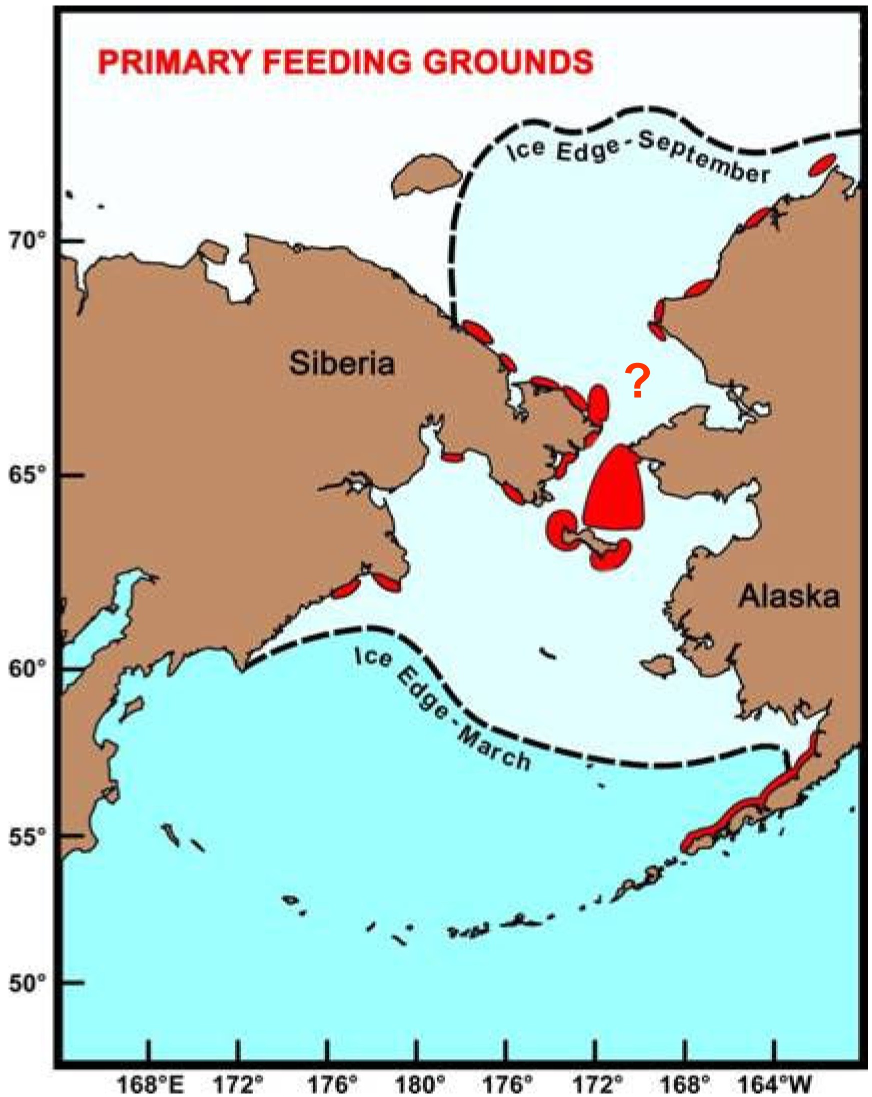
Summary and Future Directions

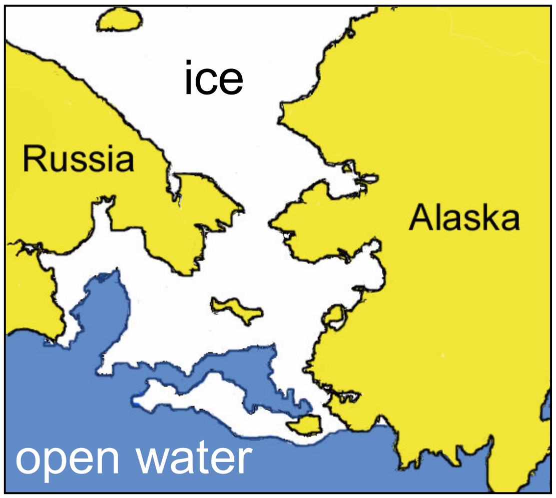
Eastern gray whale feeding ecology



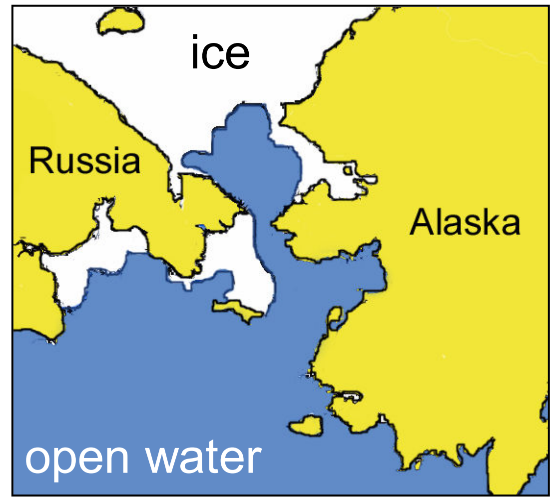
- Feed (May-Oct) where it's productive; calve (Dec-Feb) where it's warm
- Benthic feeders with minimal feeding during migration and in calving grounds
  - constrains foraging area
  - establishes "vulnerability" to varying ice conditions

Seasonal Ice

June 1999



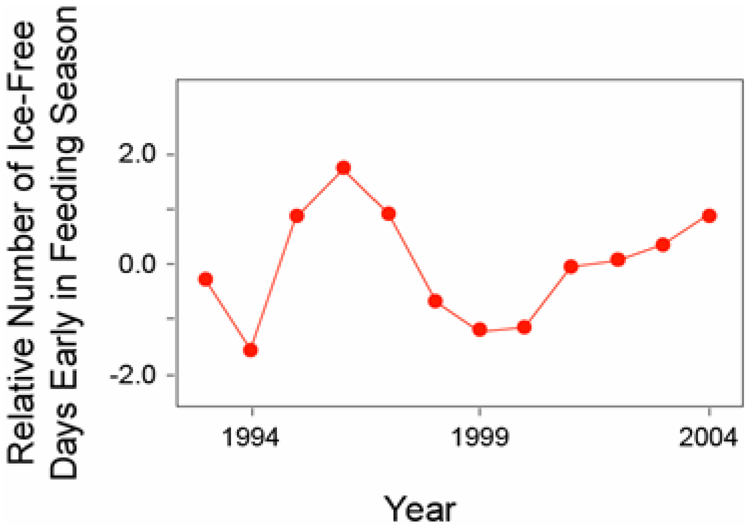
June 2003

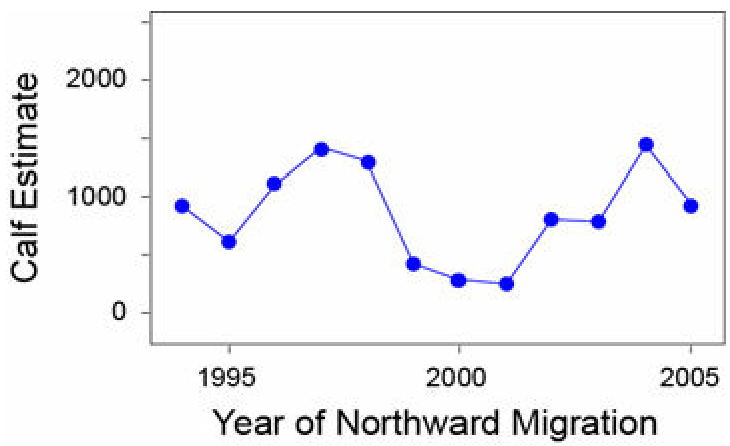


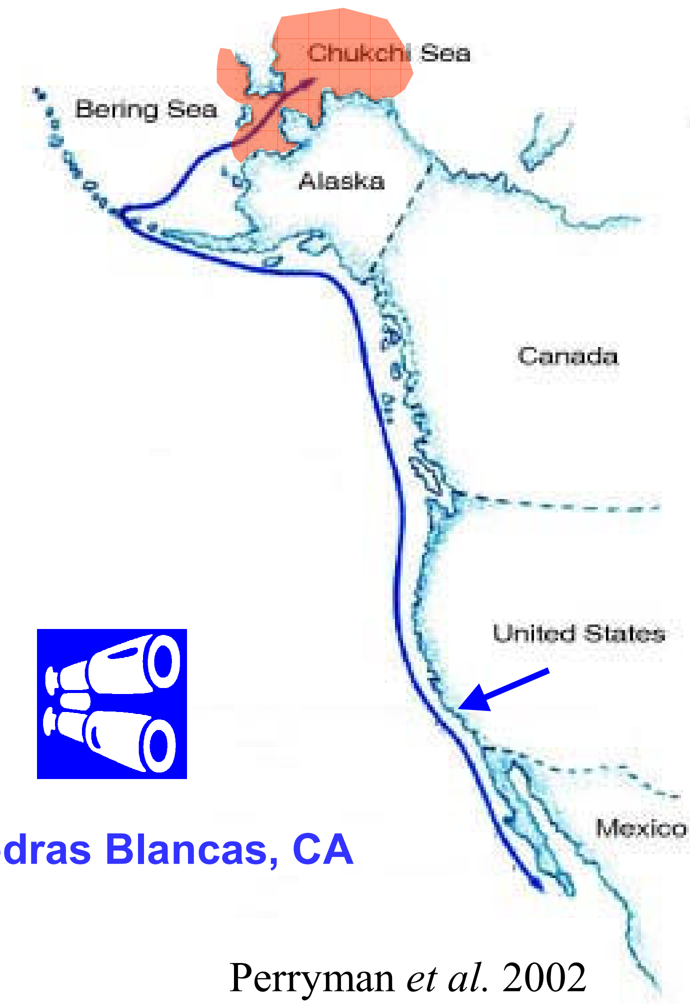
- Substantial, interannual variation in the timing of ice melt over the feeding grounds (May – July)
- Pregnant females have early and narrow window of arrival times (April – May)

graphics thanks to C. Stinchcomb

Ice and calf estimates







Pt. Piedras Blancas, CA

Perryman *et al.* 2002

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Available data

1. Abundance estimates (1968-2002)

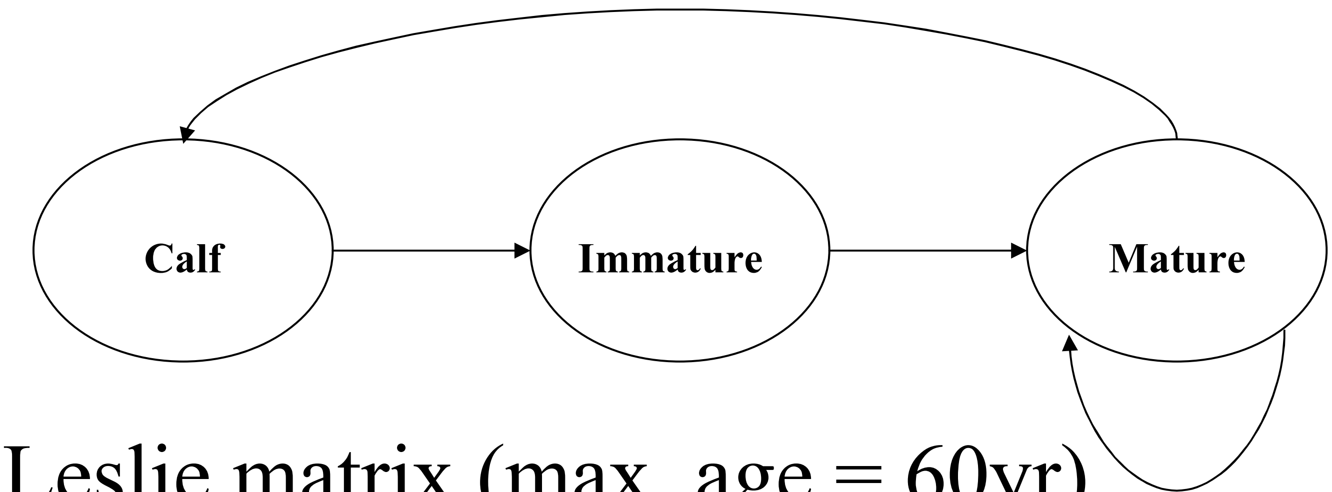
2. Calf estimates (1980-81 & 1994-2005)

3. Sea-ice estimates (1978-2005)

    *<u>Missing years: prior to ’78</u>

4. Catch history by sex

Model:



Simplified Leslie matrix (max. age = 60yr)

Parameters [Bayesian priors]:

S_0	calf survival
S_{1+}	age 1+ survival
f_{max}	fecundity (density dependent)
ASM	age at sexual maturity
λ_{max}	intrinsic population growth rate

Wade, 2002

Calf production

1. <u>Deterministic:</u>

   Calves = birth rate (density dependent) * mature females

2. <u>Stochastic:</u>

   Calves = deterministic calves * process error

   where:

   process error = $\exp[\varepsilon_t - (\sigma_\varepsilon^2 / 2)]$

   and, $\varepsilon_t \sim N(0; \sigma_\varepsilon)$ [priors on annual deviations]

Environment as data

Expected sea ice (I_t) proportional to process error in calf production:

$$I_t = \beta * \varepsilon_t$$

Model is then fit to the ice data (in addition to abundance and calf data):

$$-\ln(L_{ice}) = \sum_t \left[\ln(\sigma_I) + \frac{\left(I_t^{obs} - I_t\right)^2}{2\sigma_I^2} \right]$$

Harley and Maunder, 2004 IATTC, stock assess. report

Assumptions

During years without sea ice data, expectation of stochastic calf production = traditional deterministic model

Life history parameters are independent (e.g. low birth rates do not imply low survival rates)

Carrying capacity is constant over time period considered (1930 – present)

The number of receptive females is equal to the number of mature females

The relationship between sea ice and variability in birth rates is density independent

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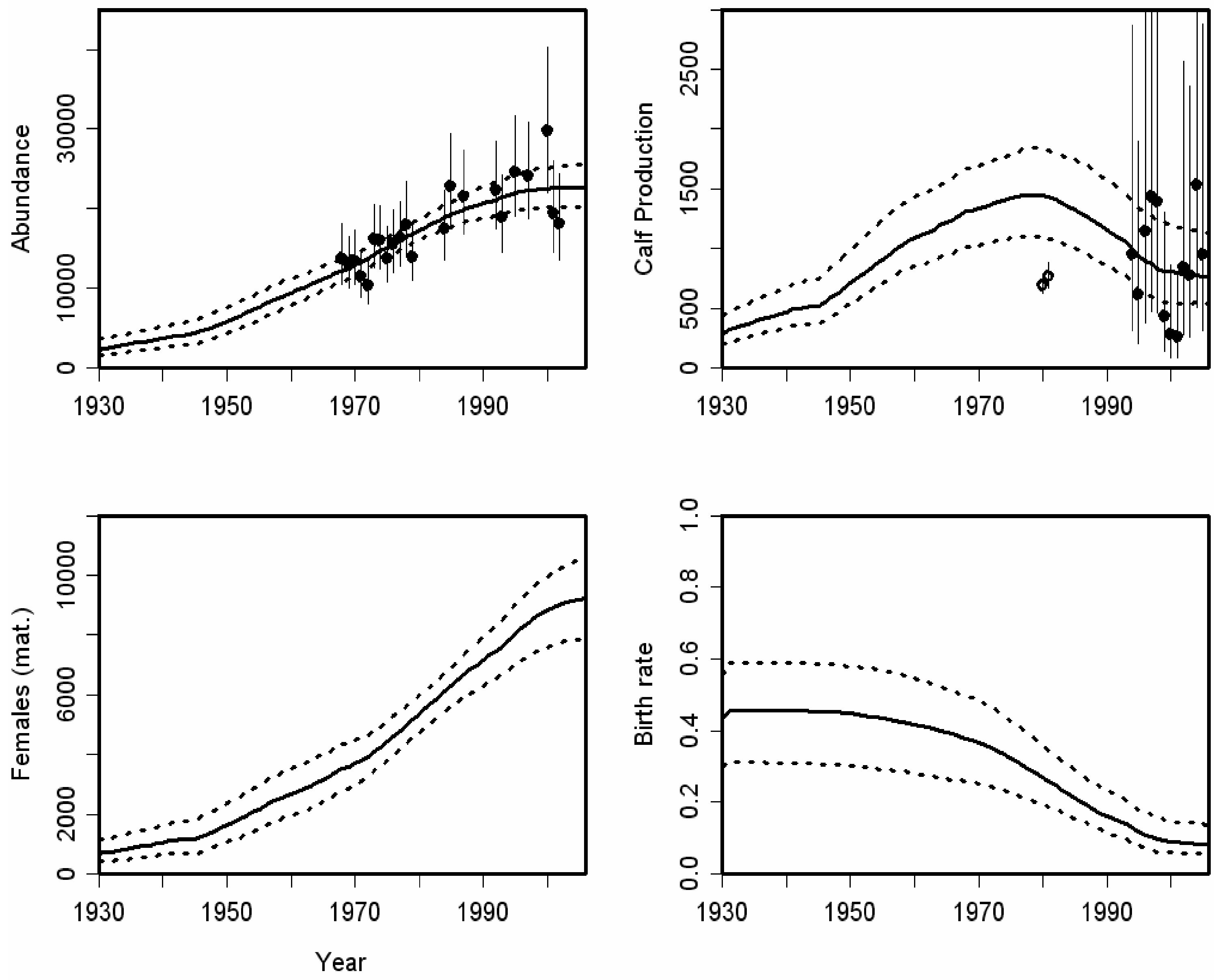
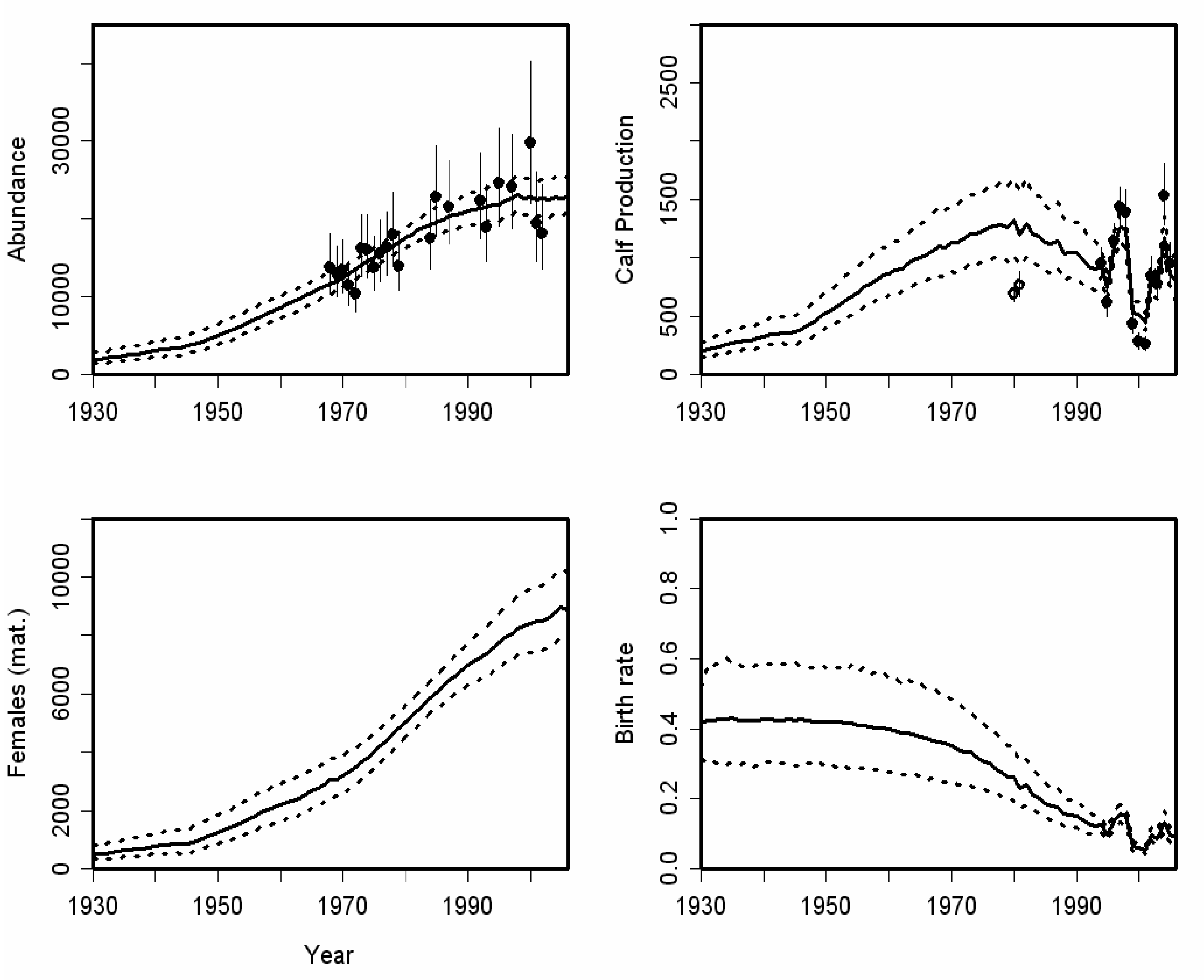
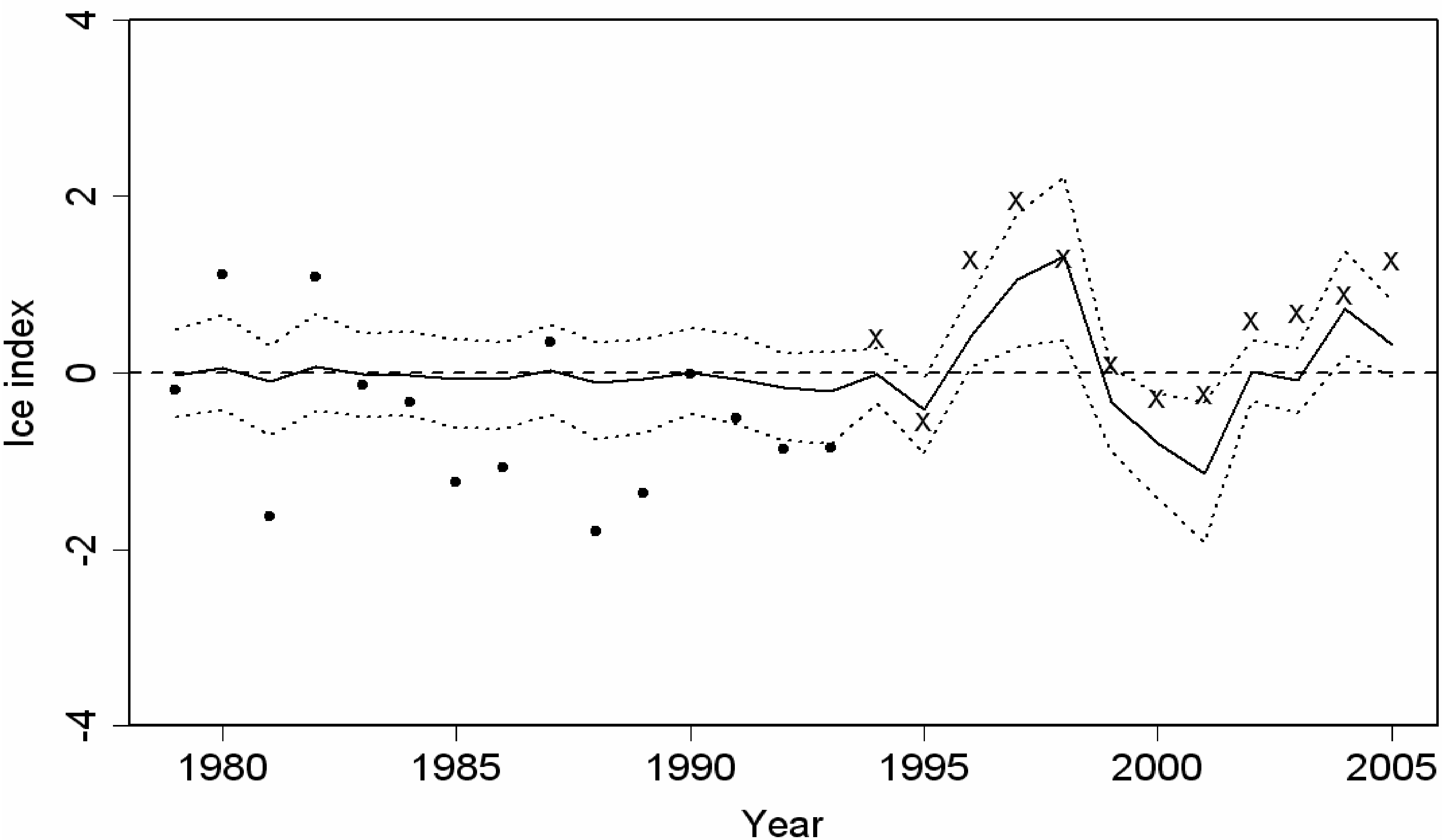
Deterministic calves (no ice)



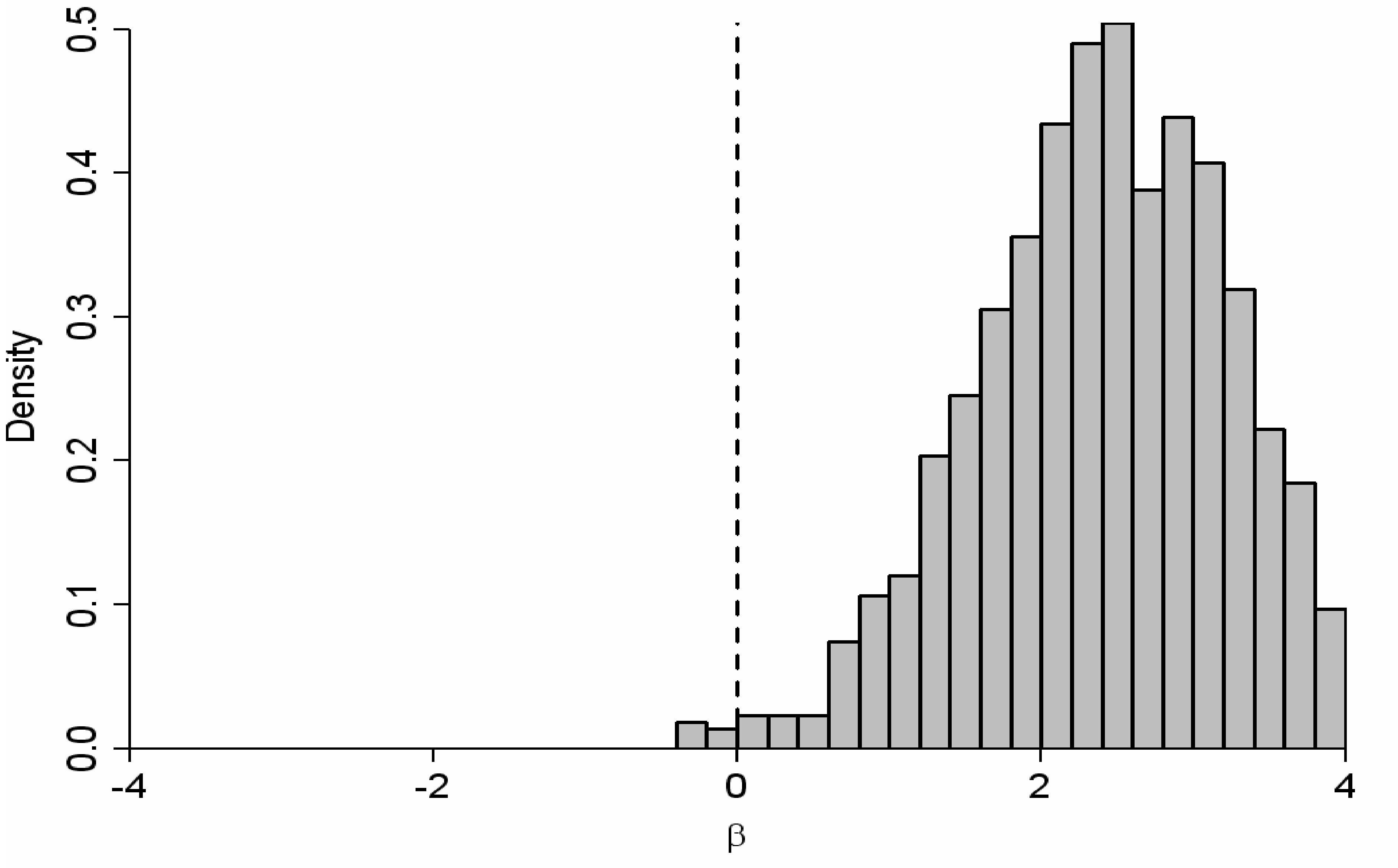
Stochastic calves (ice)



Fits to sea ice data (generally poor)

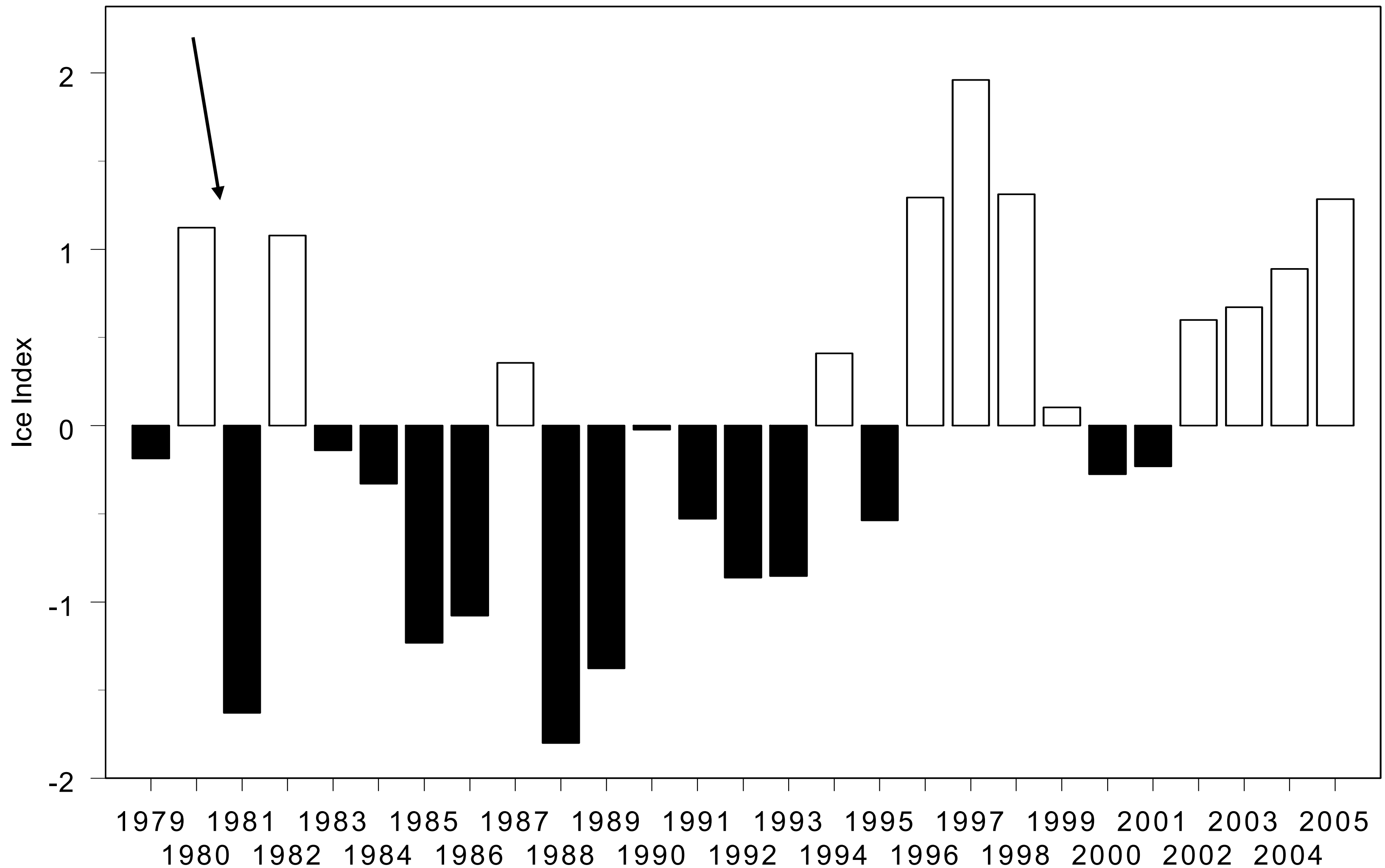


Sea ice affects recent calf production



Doh!

Huge contrast between sea ice in 1980 and ’81, but nearly equal calf production.



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Summary

First attempt to incorporate role of sea ice in gray whale stock assessment

Consistent with hypothesis that recent variation in birth rates is related to sea ice

However, it appears that relationship between sea-ice and calf production has not been constant through time

No evidence that current management quotas for aboriginal whaling need to be changed

Future directions

Compare alternative models for environmental process error which are density dependent
(Durant *et al*. 2005)

Improve realism of population dynamics model to keep track of receptive and calving females
(Reeves *et al*, 2005. ISRP)

Explore historic & future population dynamics and management scenarios given global climate model forecasts of regional sea-ice
(Overland and Wang, 2007)

Acknowledgements

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Those who collected the data used in these analyses

School of Aquatic and Fishery Sciences

University of Washington

Extra Slides Below

Caveats

1980 and 1981 calf estimates are inconsistent with respect to both: 1) expected (density dependent) fecundity and, 2) recent relationship between sea ice and variability in calf production

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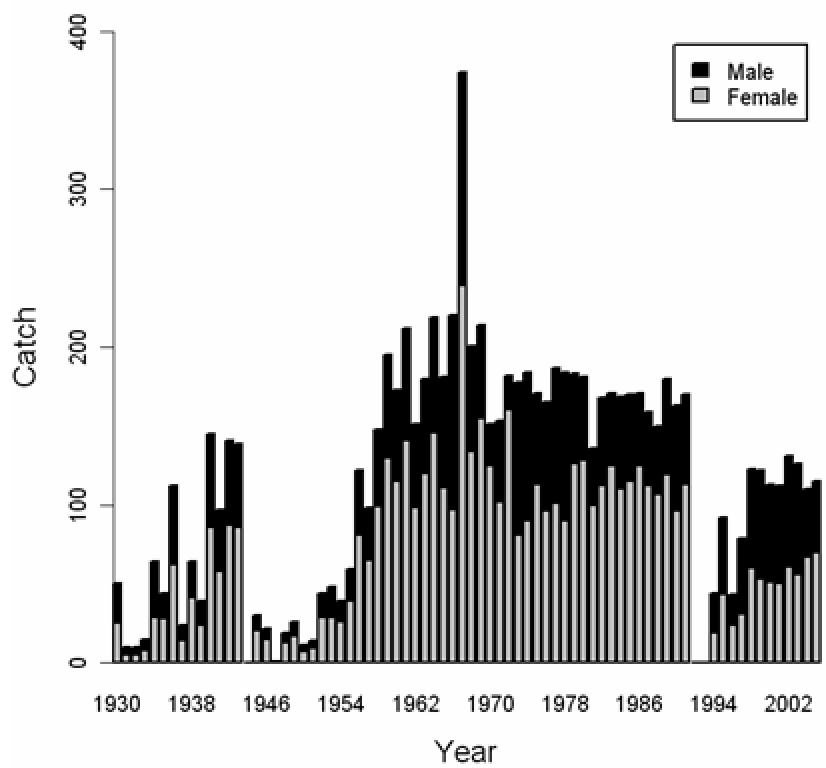
Summary, Caveats and Future Directions

Catches: 1930-2005



Likelihood (-log)

1. Abundance estimates (1968-2002)

$$L_1 = \sum_t 0.5 \left(\ln\left(\sigma_t^2 + CV_{\text{add}}^2\right) + \frac{\left(\ln N_t^{\text{obs}} - \ln N_t\right)^2}{\left(\sigma_t^2 + CV_{\text{add}}^2\right)} \right)$$

Likelihood (-log)

2. Calf estimates (1980, '81 & 1994-2005)

$$L_2 = \sum_t \left[\ln\left(\underset{\sim}{\sigma}_t\right) + \frac{\left(\ln C_t^{\text{obs}} - \ln C_t\right)^2}{2\underset{\sim}{\sigma}_t^2} \right]$$

Likelihood (-log)

2. Calf estimates (1981-82; 1994-2005)

$$L_2 = \sum_t \left[\ln\left(\underset{\sim}{\sigma}_t\right) + \frac{\left(\ln C_t^{\text{obs}} - \ln C_t\right)^2}{2\underset{\sim}{\sigma}_t^2} \right]$$

$$L_2 = \sum_t 0.5 \left[\ln\left(\underset{\sim}{\sigma}_t^2 + CV_{add2}^2\right) + \frac{\left(\ln C_t^{\text{obs}} - \ln C_t\right)^2}{\underset{\sim}{\sigma}_t^2 + CV_{add2}^2} \right]$$

Parameter	Value
Non-calf survival, S_{1+}	0.975
Age at sexual mat., *ASM*	7 yrs
Maximum birth rate, f_{max}	0.225 (calving intrvl. ~2yr)
MSYL	0.60 (z = 2.39)
Intrinsic growth rate, λ_{max}	1.07
Calf survival, S_0	0.796

Density dependence

Assumed to act on fecundity according to Pella-Tomlinson:

$$f_t = f_{eq} + (f_{max} - f_{eq}) \left[1 - (N_t / K)^{z} \right]$$

Where:

- f_t fecundity in year *t*
- f_{eq} equilibrium fecundity (solved for analytically)
- f_{max} max. fecundity
- N_t population size in year *t*
- K carrying capacity
- z shape parameter

History of depletion

Severely depleted by commercial whaling during 1850-1900

Endangered species protection 1970 (U.S.)

Remarkable recovery –> de-listed from endangered 1994

Currently subject to aboriginal subsistence hunt in Russia
(~ 120 whales/yr)

Quotas recommended by the IWC

Life history and status

1 calf ~ every 2 yrs

ASM ~ 7 yrs

Longevity ~ 60 years

Long annual migration between feeding and reproduction

Population hypothesized to be near carrying capacity (rebounded from severe depletion)