The rise and fall of large medusae in the Bering Sea in relation to regime shifts

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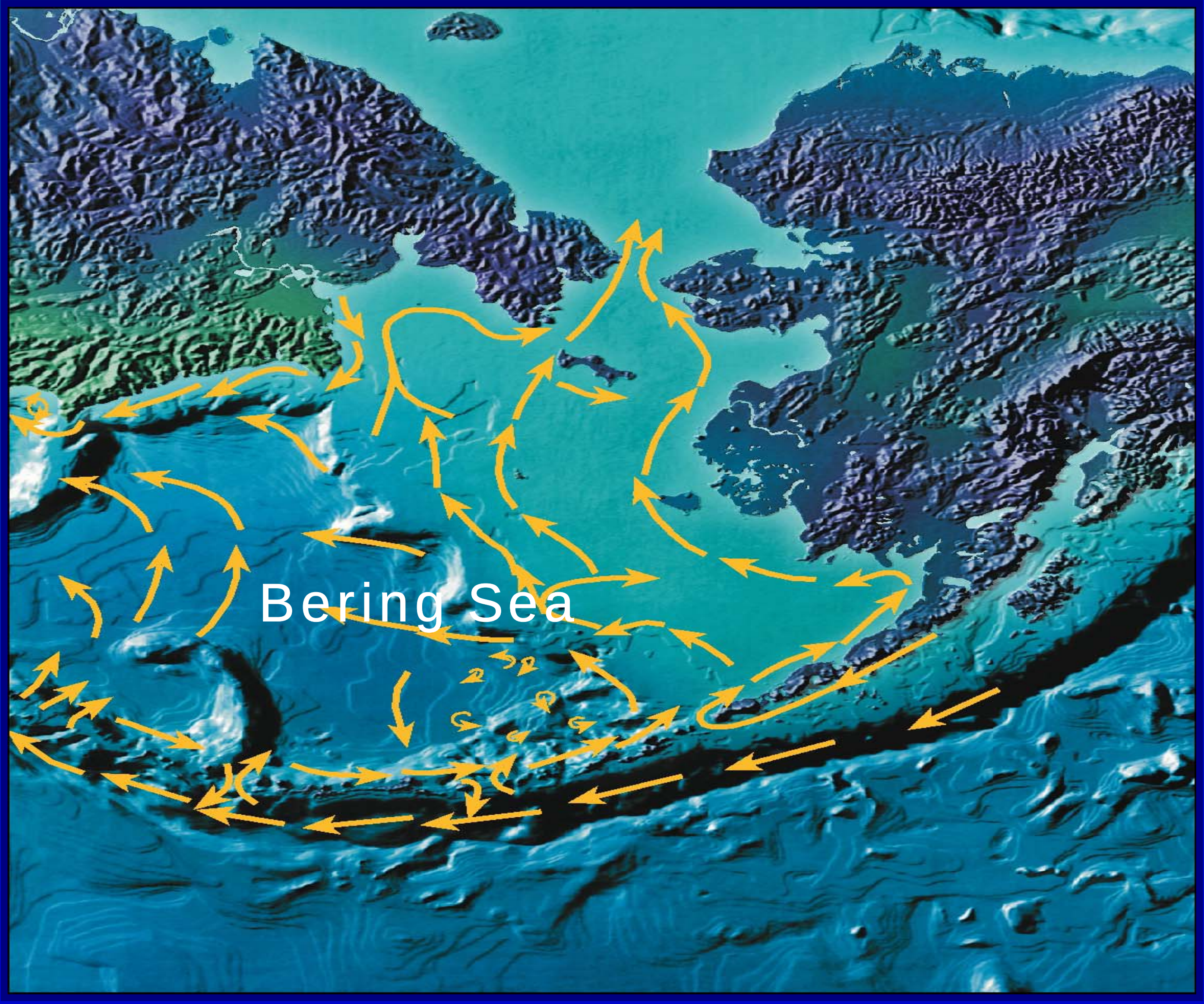
Study Area



P. Stabeno, PMEL

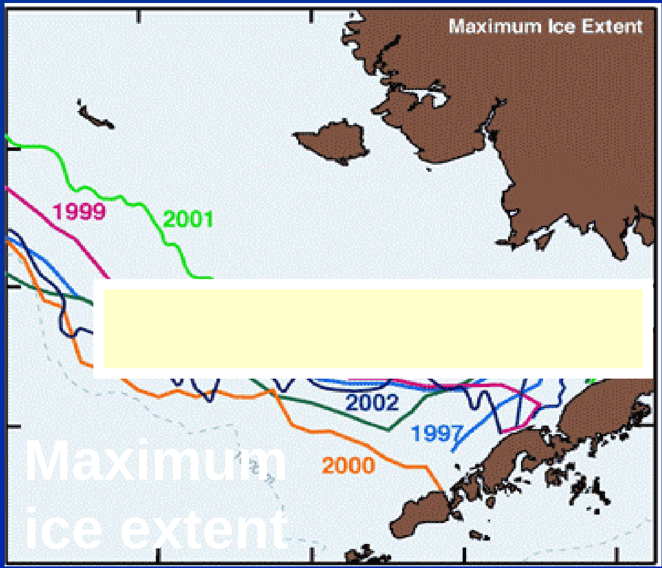
Highly Productive Ecosystem

Photo: Mike Brittain
North Gulf Oceanic Society

Recent Changes in the Eastern Bering Sea

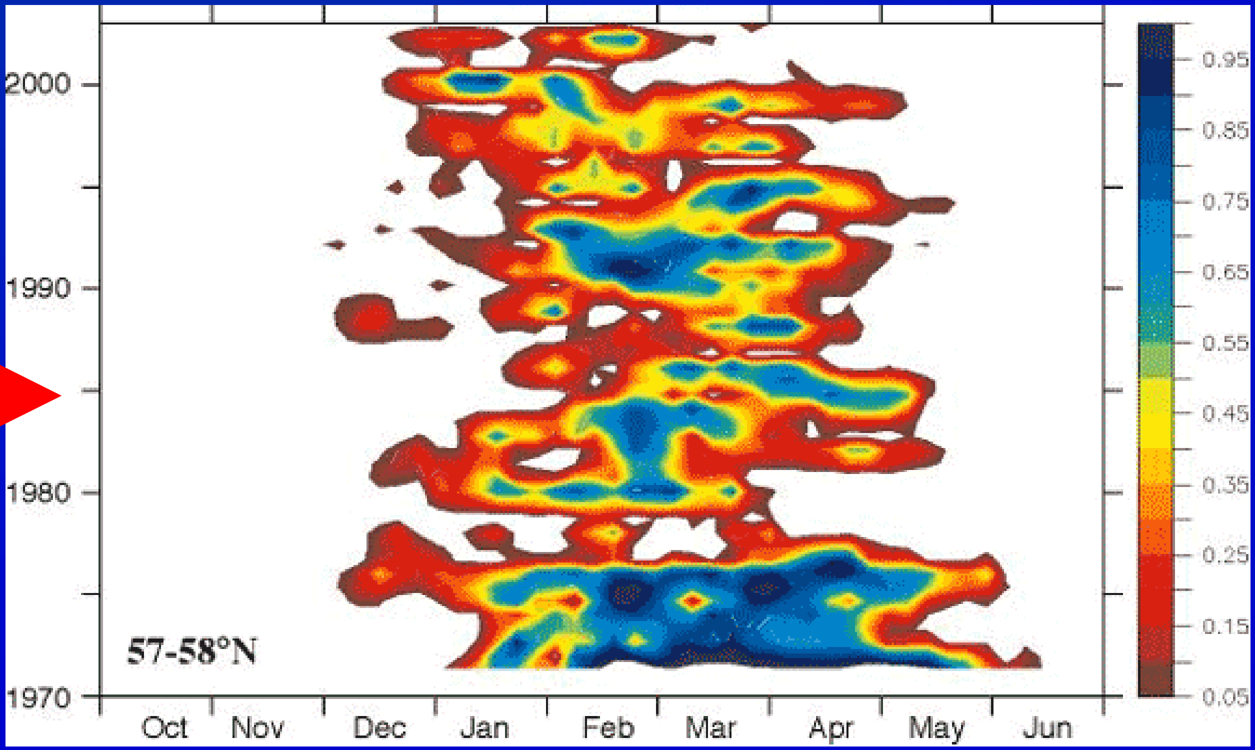
- Seasonal Sea Ice Cover Diminishing
- Warming Sea Water Temperatures
- Changing Timing and Fate of Spring Primary Production
- Increasing Occurrence of Phytoplankton Blooms
- Diminishing Summer Zooplankton Biomass
- Decreasing Seabird and Pinniped Populations

Changing Climate



Bering Sea ice has retreated over last two decades (1970 - 2003)

Percent ice cover within gray box on map above



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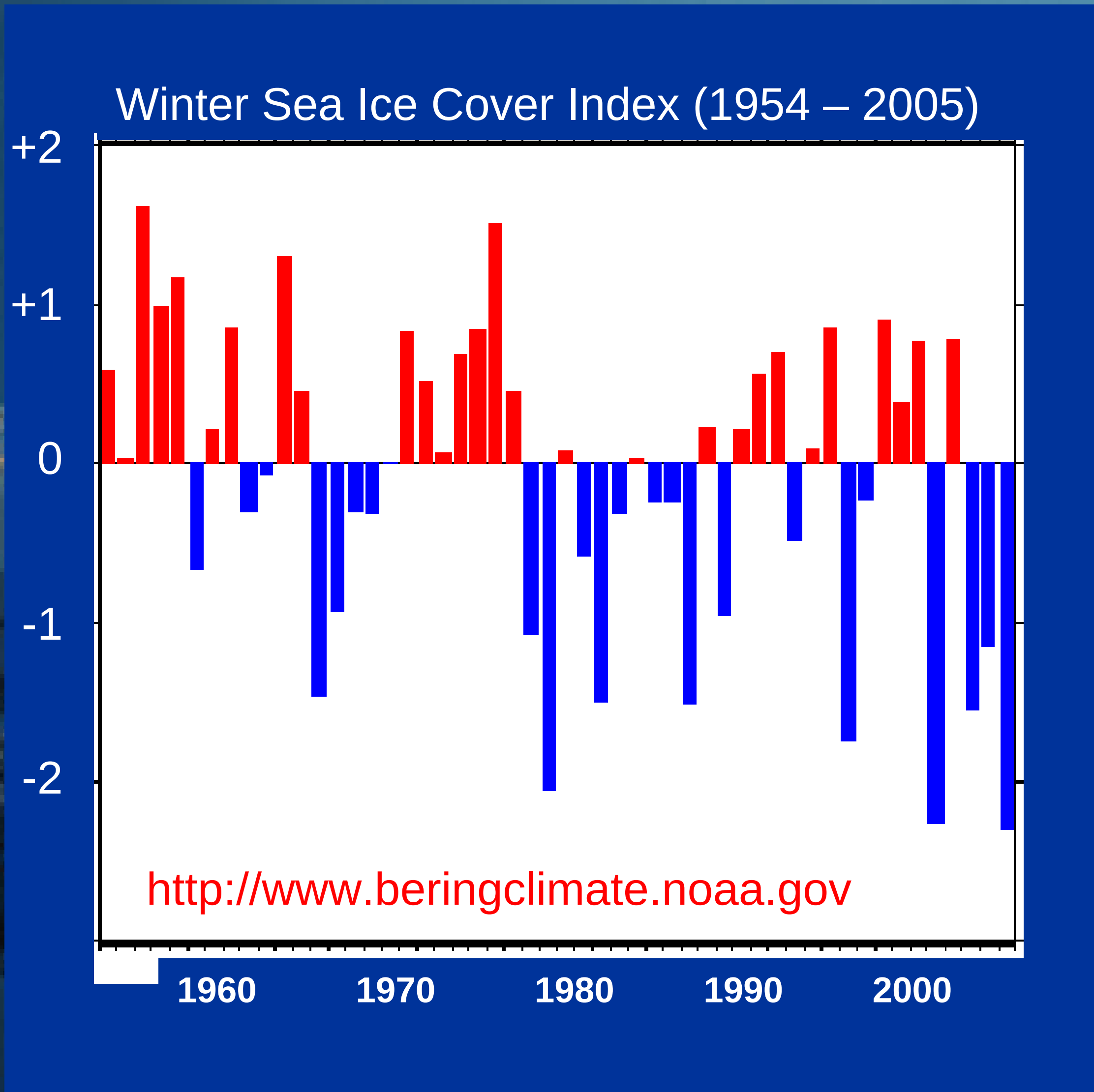
Loss of Winter Sea Ice

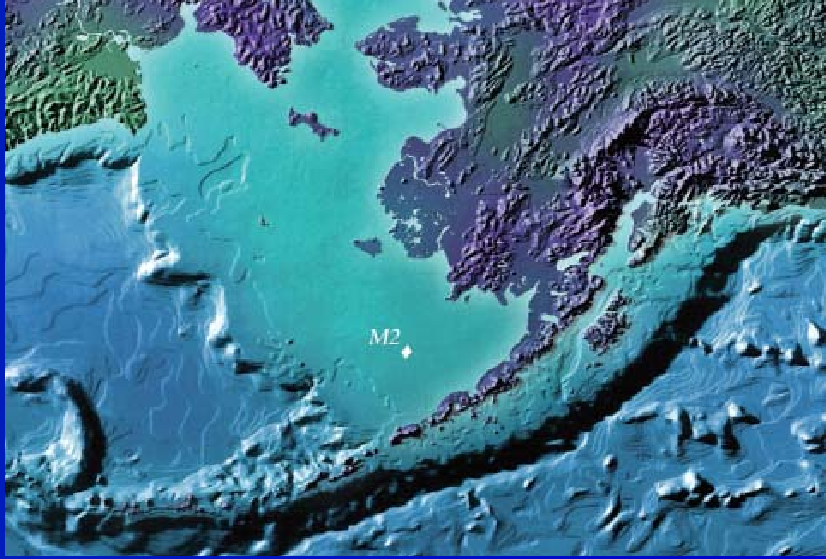


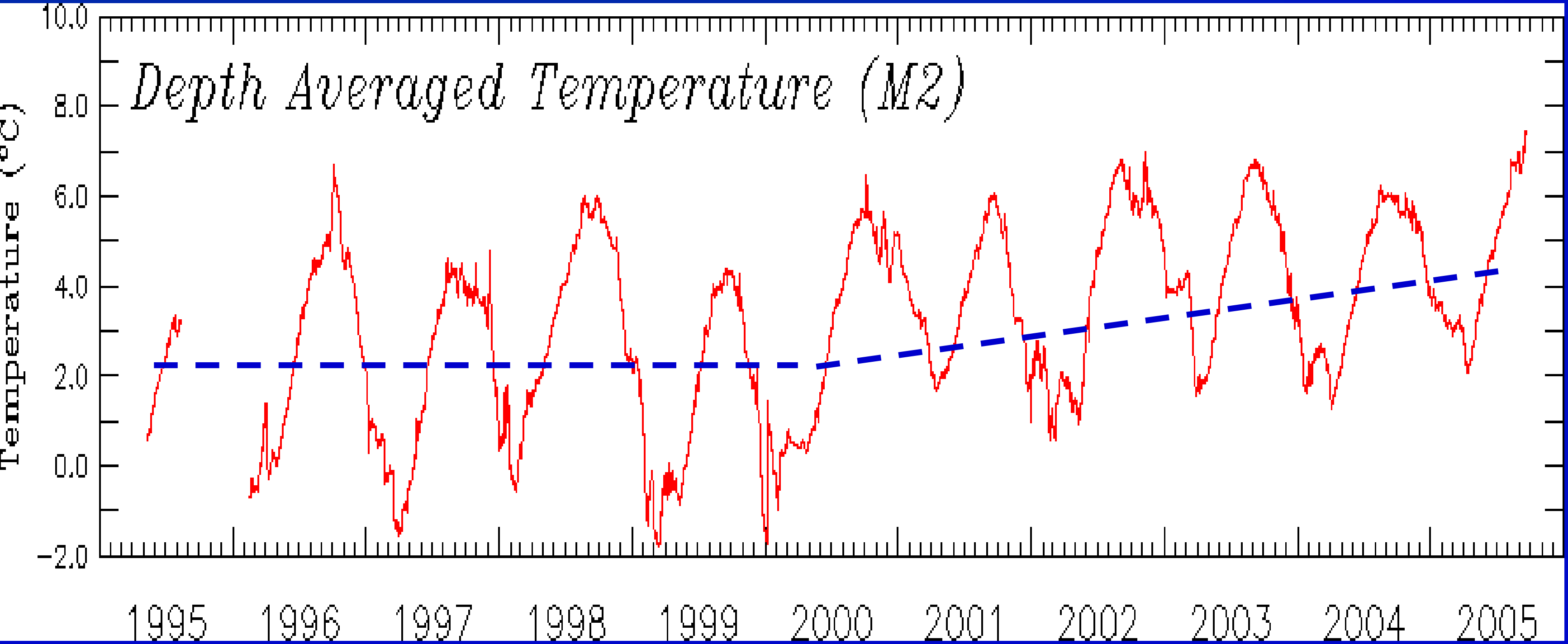
Winter-time (Dec - Jan - Feb) sea ice has vanished from the Bering Sea over the last five decades (1954 - 2005)

P. Stabeno & J. Overland, PMEL

Rising Temperatures

Vertically Averaged Temperature (°C) at Mooring M2





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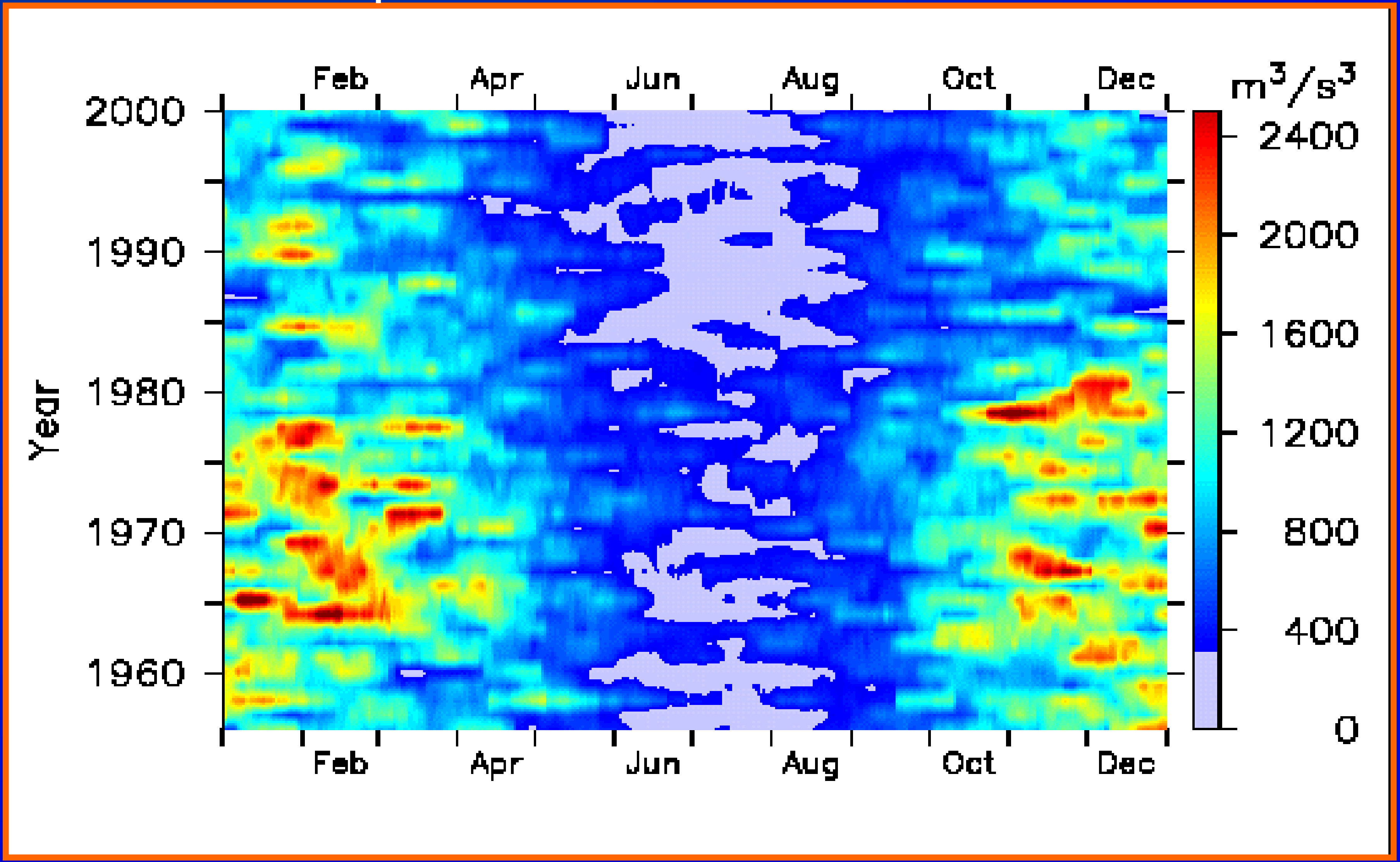
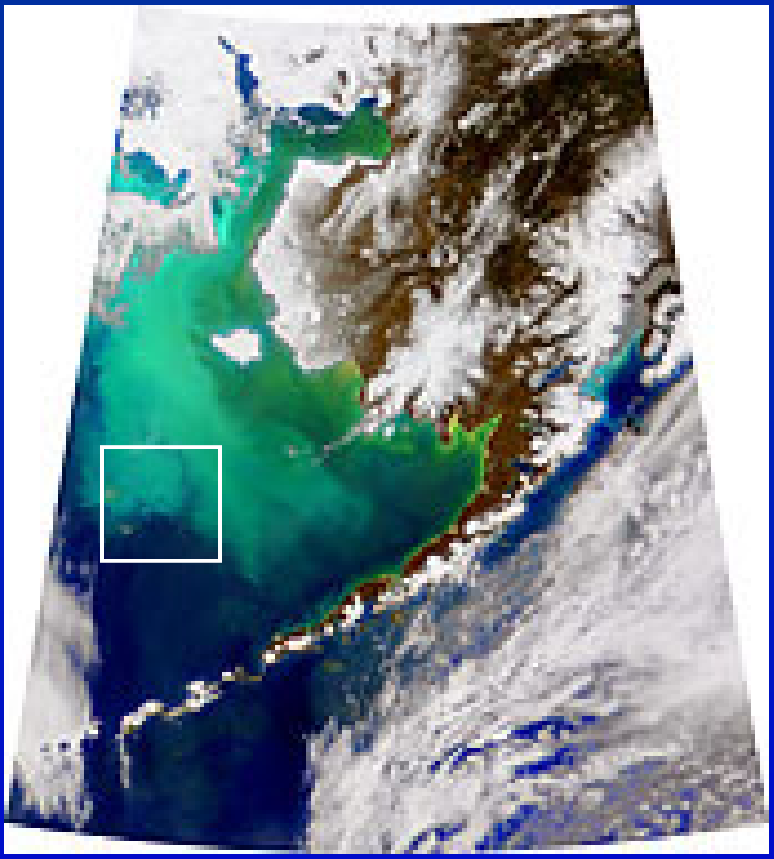
Less Wind Mixing

Wind Speed Cubed at St. Paul Island



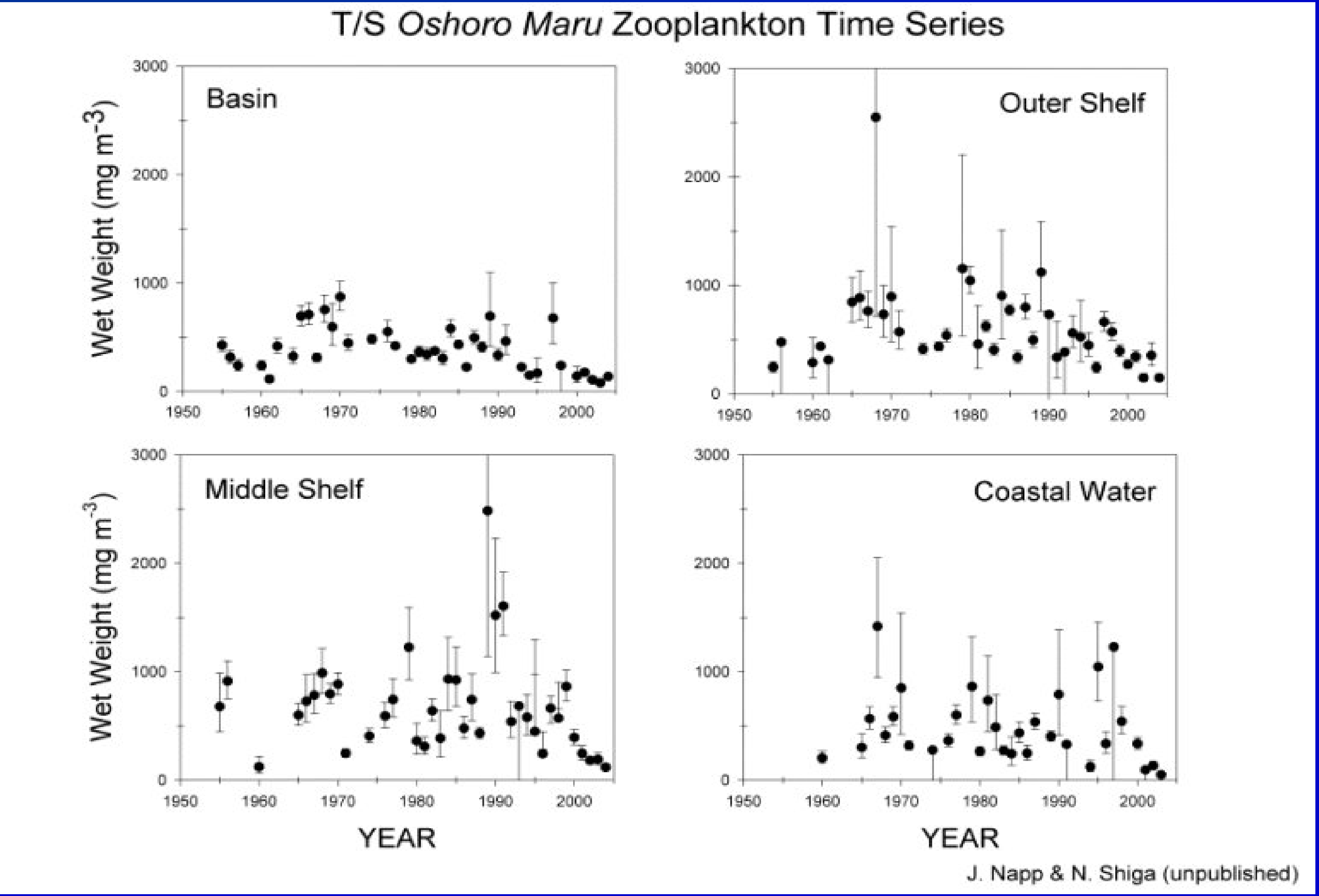
Unusual Plankton Blooms

Bering Sea Coccolithophore Bloom

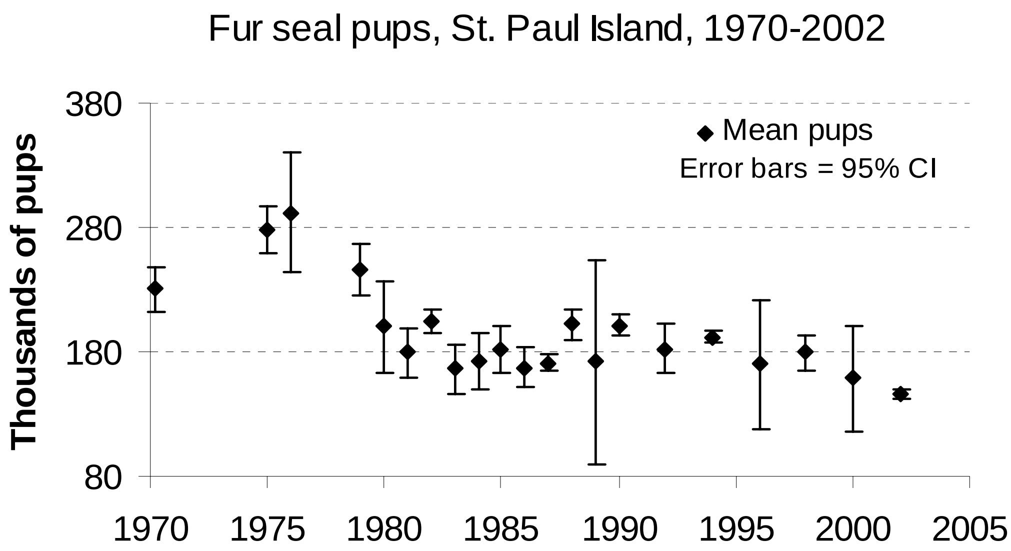


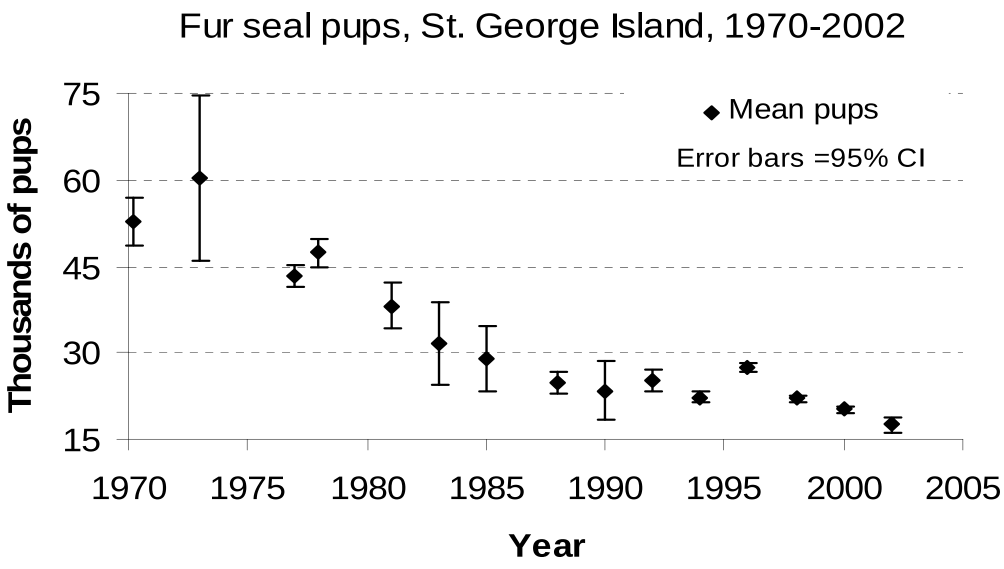
April 25, 1998 SeaWiFS

Decrease in Plankton Biomass



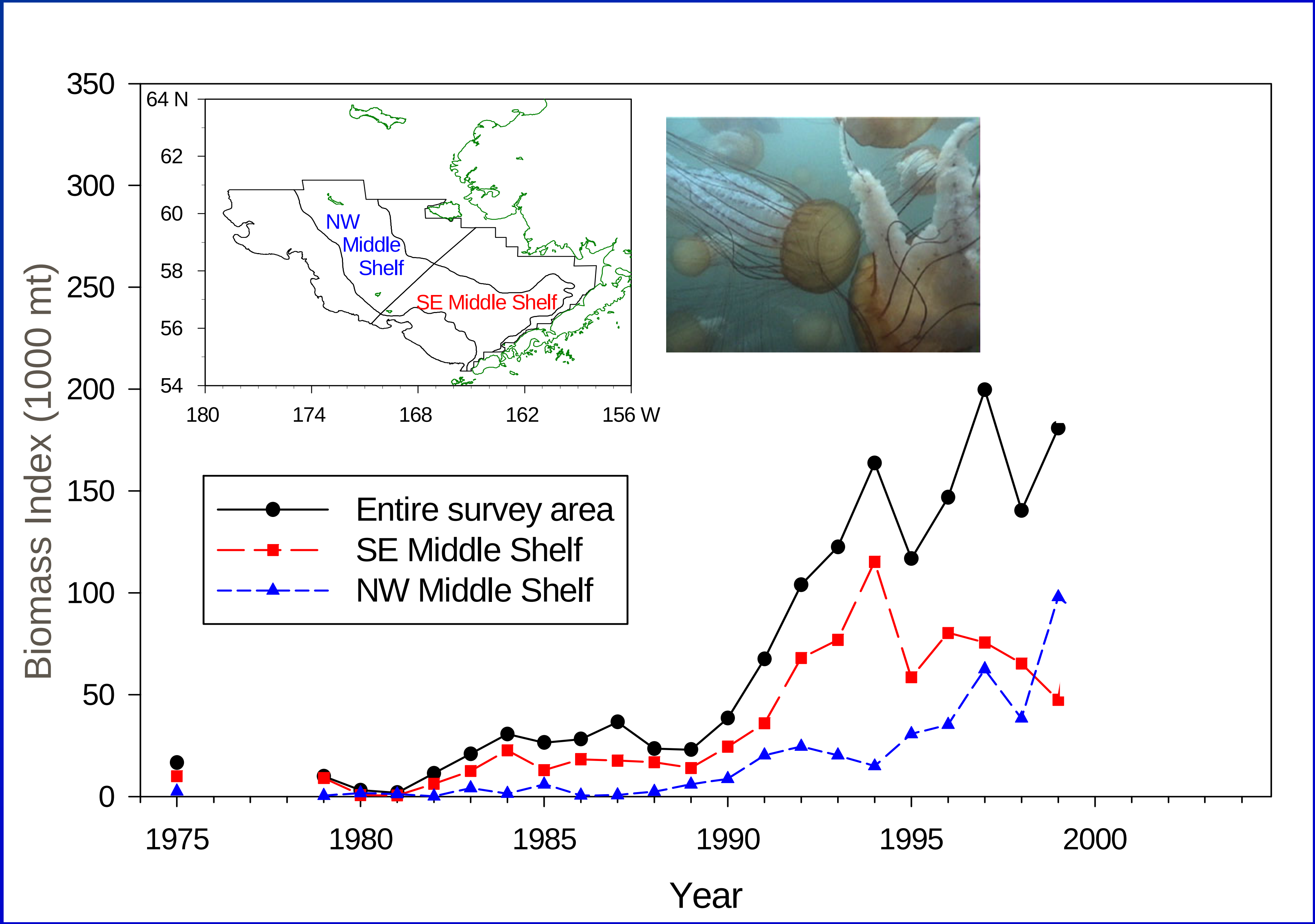
Changes in Top Trophics





Fur Seal Pups at the Pribilof Islands

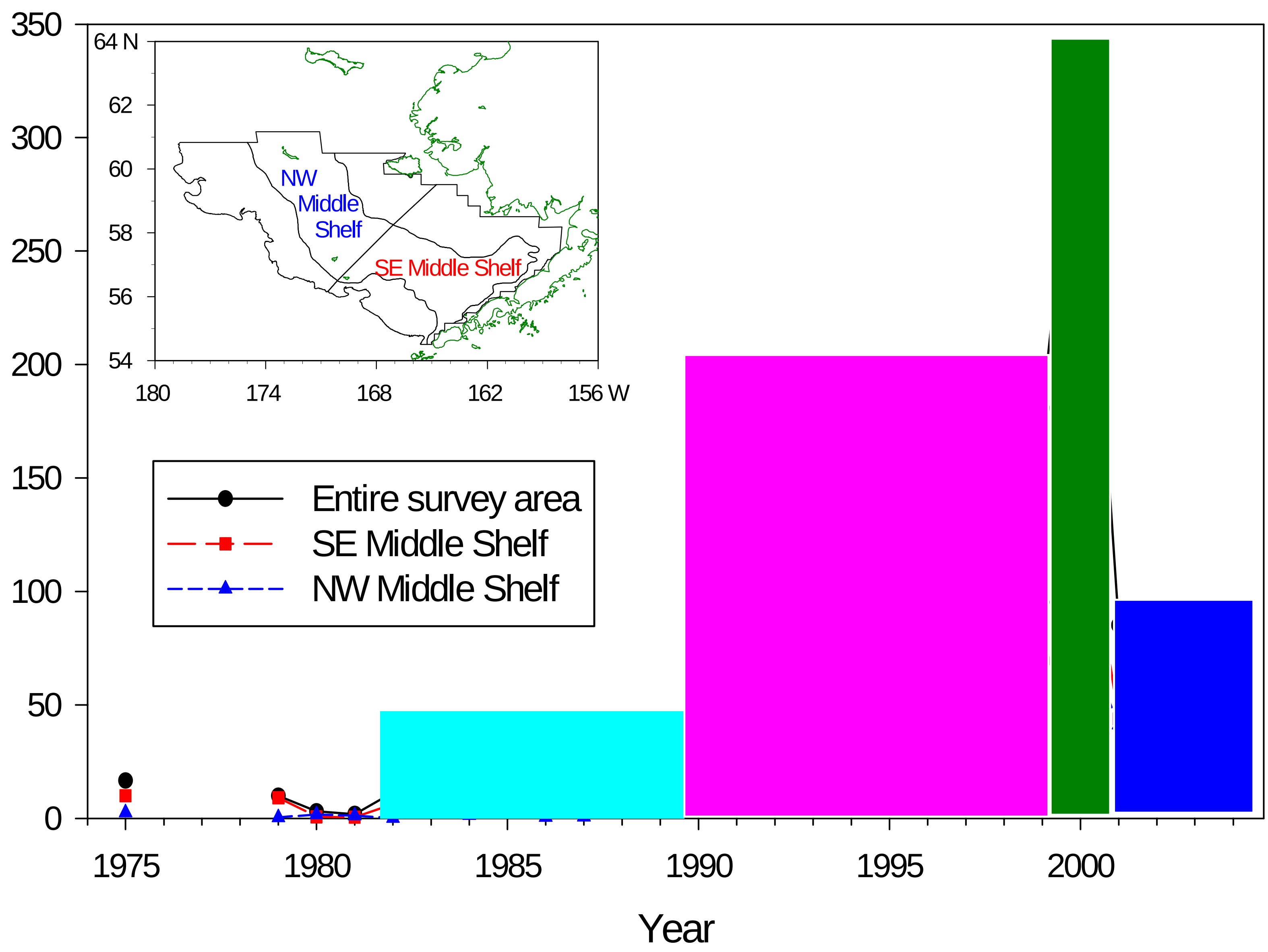
NMML, NOAA



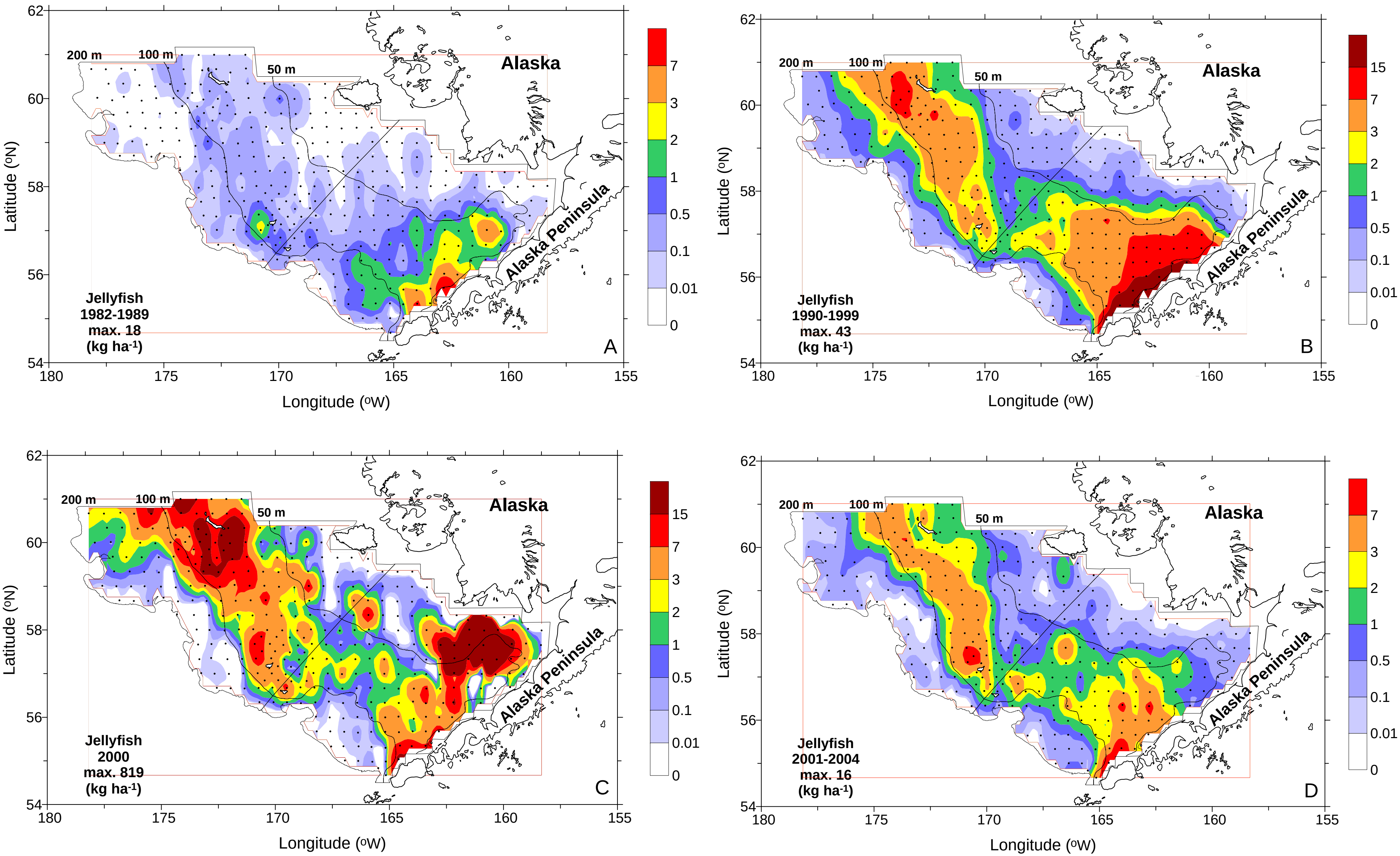
Brodeur et al. (2002)

Objectives

- Examine changes in distribution with time
- Examine abiotic and biotic correlates of jellyfish production
- Construct GAM model for best fitting variables
- Use GAM model to predict yearly biomass for two regions of EBS
- Propose conceptual model of effects of climate change on jellyfish production

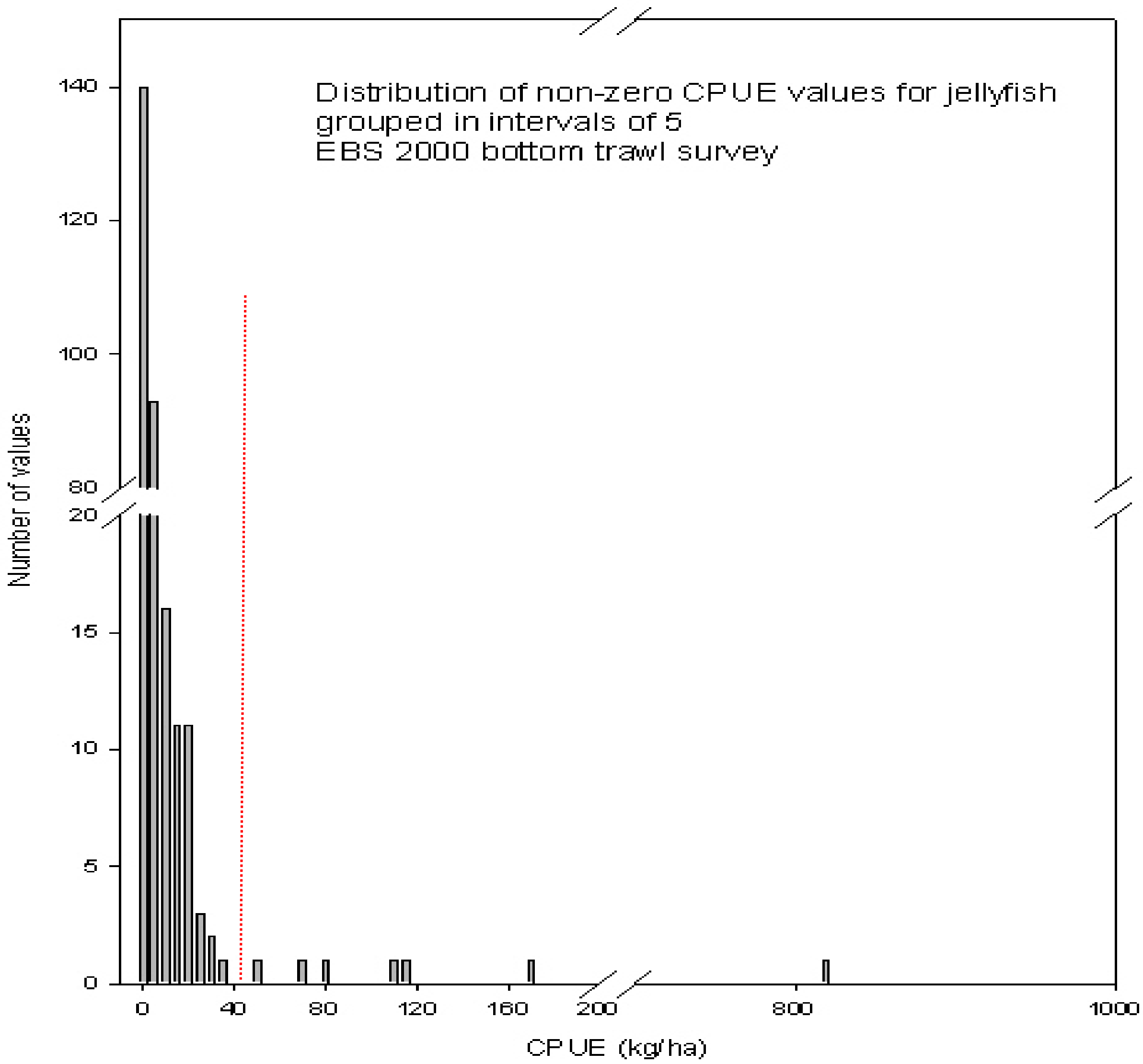


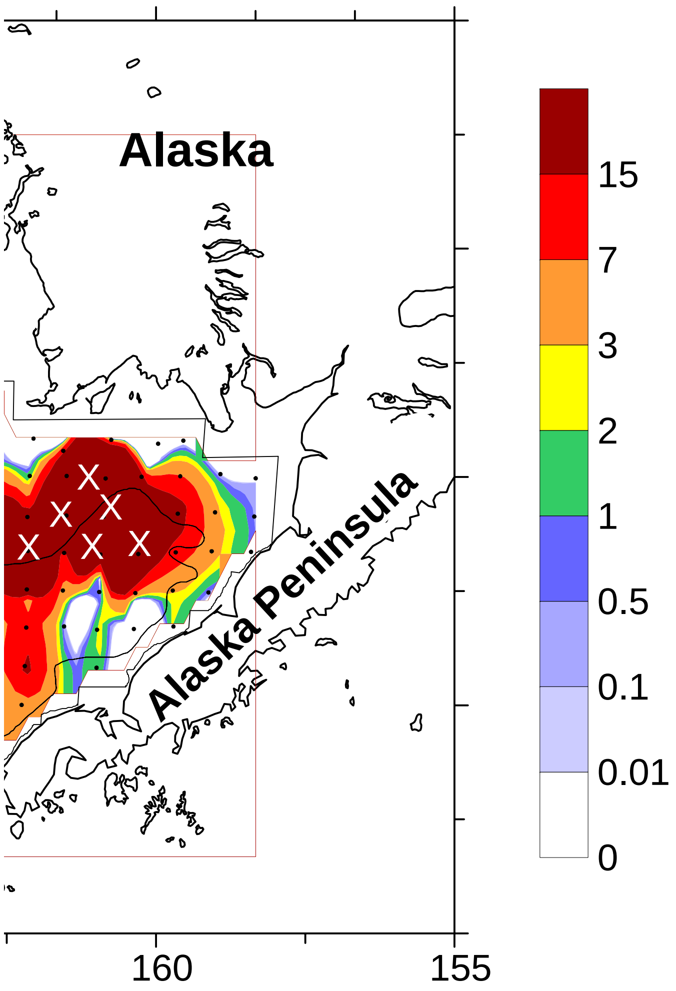
350
300
250
200
150
100
50
0
64 N
62
60
58
56
54
180
174
168
162
156 W
NW
Middle
Shelf
SE Middle Shelf
Entire survey area
SE Middle Shelf
NW Middle Shelf
1975
1980
1985
1990
1995
2000
Year



Alaska
Alaska Peninsula
200 m
100 m
50 m
Jellyfish
1982-1989
max. 18
(kg ha-1)
A
Jellyfish
1990-1999
max. 43
(kg ha-1)
B
Jellyfish
2000
max. 819
(kg ha-1)
C
Jellyfish
2001-2004
max. 16
(kg ha-1)
D
Latitude (oN)
Longitude (oW)
0
0.01
0.1
0.5
1
2
3
7
15

What happened in 2000?





How are changes in Gelatinous Zooplankton biomass related to ocean conditions?

Environmental Conditions and Medusan Populations

Adapted from Purcell (2005)

	rain	temp	sal	radiation	climate
Aequorea victoria (Puget Sound)		+	+		
Aurelia sp. (Sea of Japan)		+			
Aurelia aurita (North Sea)					- NAO/cold
Chrysaora melanaster (Bering Sea)		+		+	+ AO
Chrysaora quinquecirrha (Chesapeake Bay) 1960-1986 1987-2000	-	+	+	+	- NAO/cold
Pelagia noctiluca (Mediterranean and Adriatic Seas)	-	+			

General Additive Modeling (GAM)

1) Constructed separate models for SE and NW using Log (CPUE) as dependent variable

2) Forward stepwise selection strategy limiting degrees of freedom to 4

3) Minimize Generalized Cross Validation (GCV)

4) Variables could be dropped if addition of subsequent variables decreased significance

Data Available

Variable name	Description and source
jellyfish CPUE	Catch per unit effort of jellyfish from quantitative bottom trawl surveys of the eastern Bering Sea conducted by the Alaska Fisheries Science Center (AFSC). Standardized jellyfish biomass (kg ha^{-1}) calculated for the southeast and northwest regions of the Middle Shelf Domain.
sesprtemp **nwsprtemp**	March-May sea-surface temperature at 57°N, 164°W (southeast region) and 59°N, 171°W (northwest region) derived from a National Centers for Environmental Prediction (NCEP) reanalysis. When ice is present, values represent the estimated temperature of the ice surface.
sesumtemp **nwsumtemp**	June-August sea-surface temperature at 57°N, 164°W (southeast region) and 59°N, 171°W (northwest region) derived from a NCEP reanalysis.
wstressna **wstressmj**	The along-peninsula component of the wind stress (N m^{-2}) at Unimak Pass (54°N, 165°W) for the periods Nov-Apr and May-Jun. From the Bering Sea Climate website http://www.beringclimate.noaa.gov/index.html.
wmixmay **wmixjj**	Wind mixing indices represents the average value of friction velocity u^3 for the period 1-31 May near St. Paul Island (57.1°N, 170.2°W) and for the period June-July at NOAA Mooring 2 (57°N, 164°W); from Bering Sea Climate website.

Data Available (cont.)

Variable name	Description and source
currentlag	Distance (km) that Ocean Surface CURrents Simulation (OSCURS) model drifters traveled from the center of the NW jellyfish aggregation (assumed to be 60°N, 172°W); lagged by one year. From: http://las.pfeg.noaa.gov/las_oscurs/main.pl.
icecover	Ice cover index from Bering Sea Climate website.
iceretreat	Ice retreat index represents the number of days with ice cover after March 15. From Bering Sea Climate website.
mszoop **oszoop**	Biomass (mg m^{-3}) of zooplankton on the Middle Shelf (mszoop) and the Outer Shelf (oszoop) based on summer sampling by Hokkaido University (HU) Research Vessel *Oshoro maru*. Provided by N. Shiga (HU) and J. Napp (AFSC).
pollock	Juvenile walleye pollock biomass CPUE (kg ha^{-1}) in both middle shelf regions.
forage	Forage fish complex (Pacific herring, eulachon, and capelin) biomass CPUE (kg ha^{-1}) in both middle shelf regions.

General Additive Modeling (GAM)

Best SE Model

$$\log(CPUE) = \beta_o + s(sebiomlag) + s(sesprtemp) + s(wmixmay) + s(sepollock) + s(icecover)$$

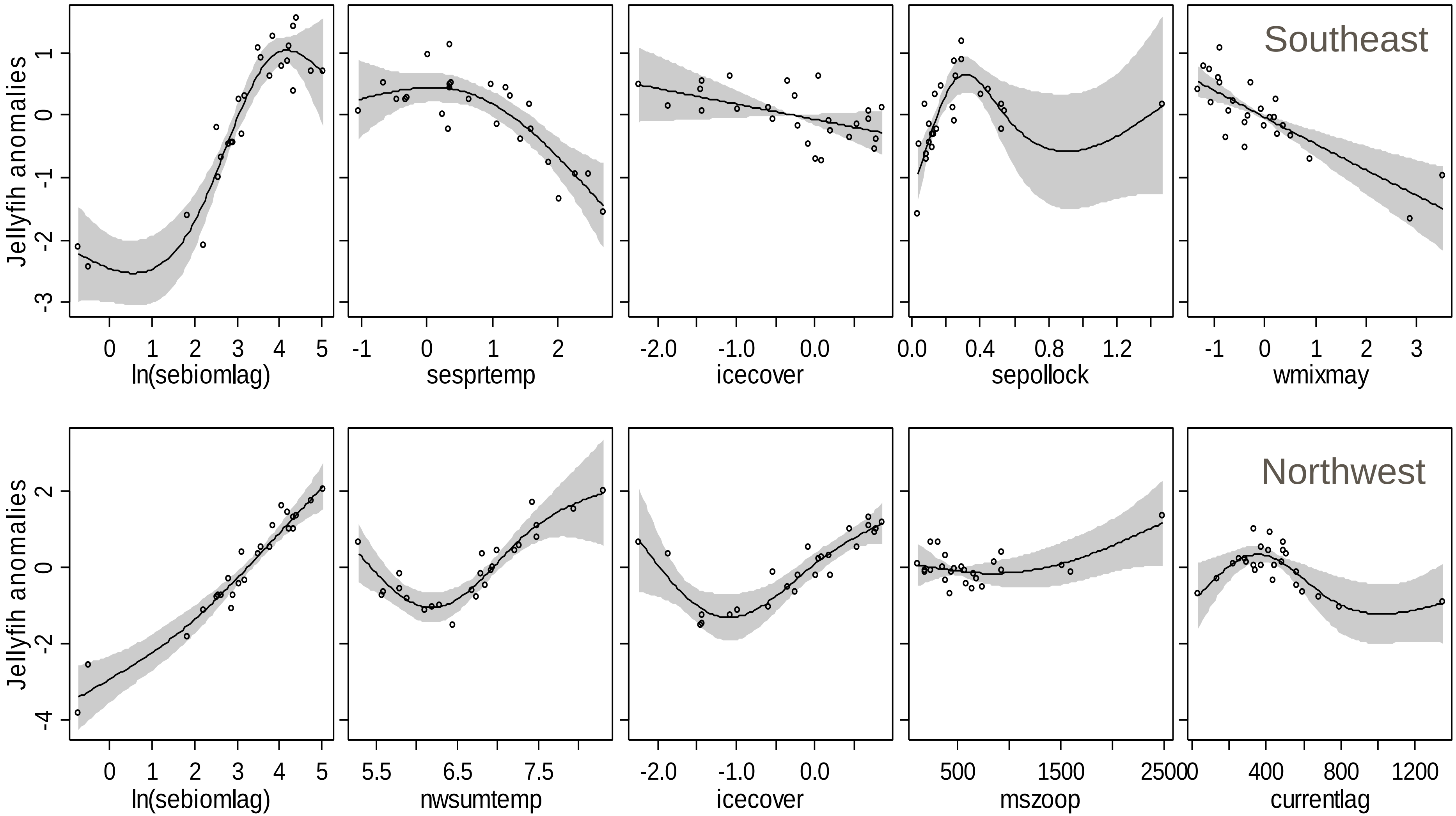
R^2 (%) = 89.6 GCV = 0.356

Best NW Model

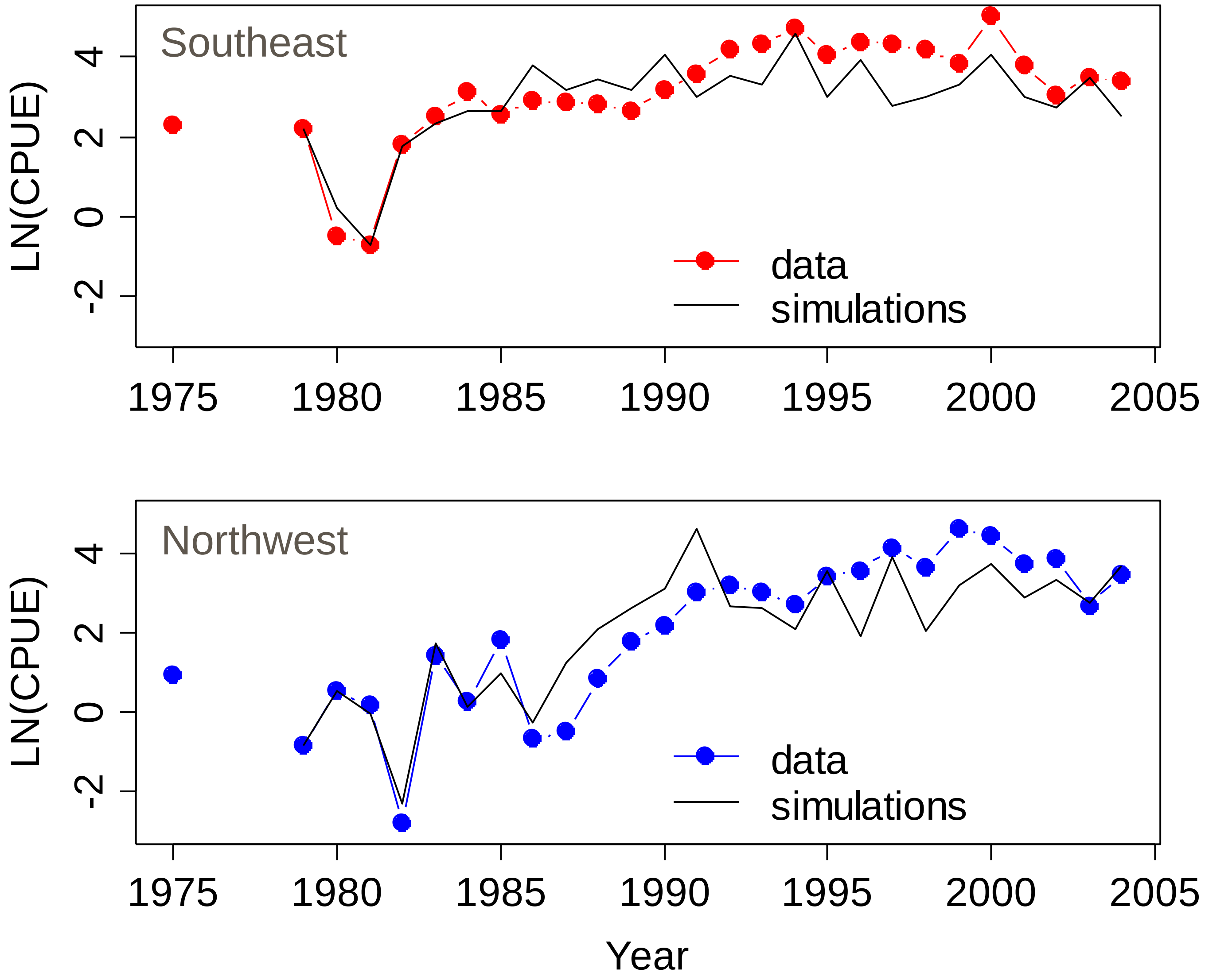
$$\log(CPUE) = \beta_o + s(sebiomlag) + s(nwsumtemp) + s(icecover) + s(mszoop) + s(currentlag)$$

R^2 (%) = 93.8 GCV = 0.463

Best Fit GAM Variables

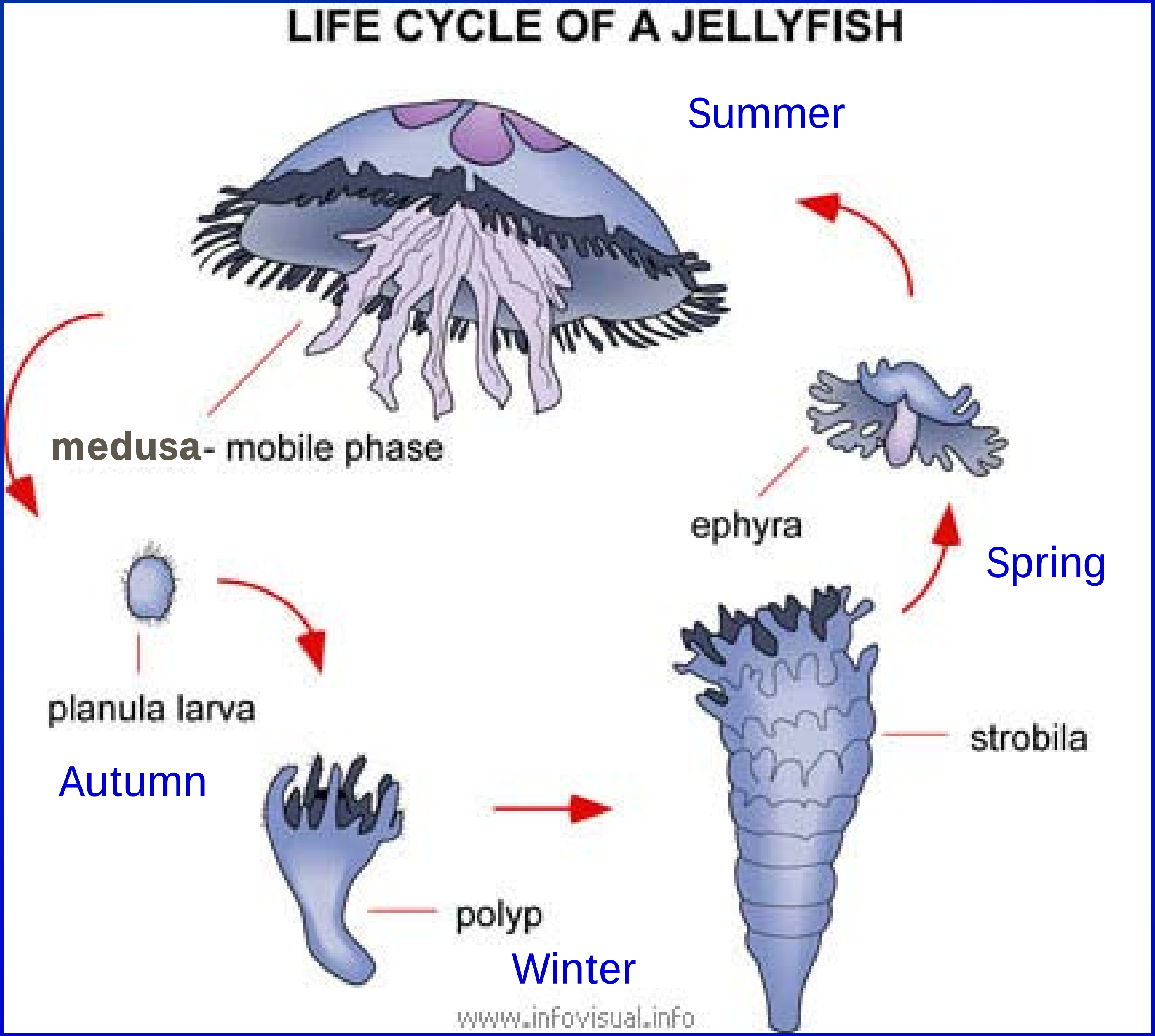


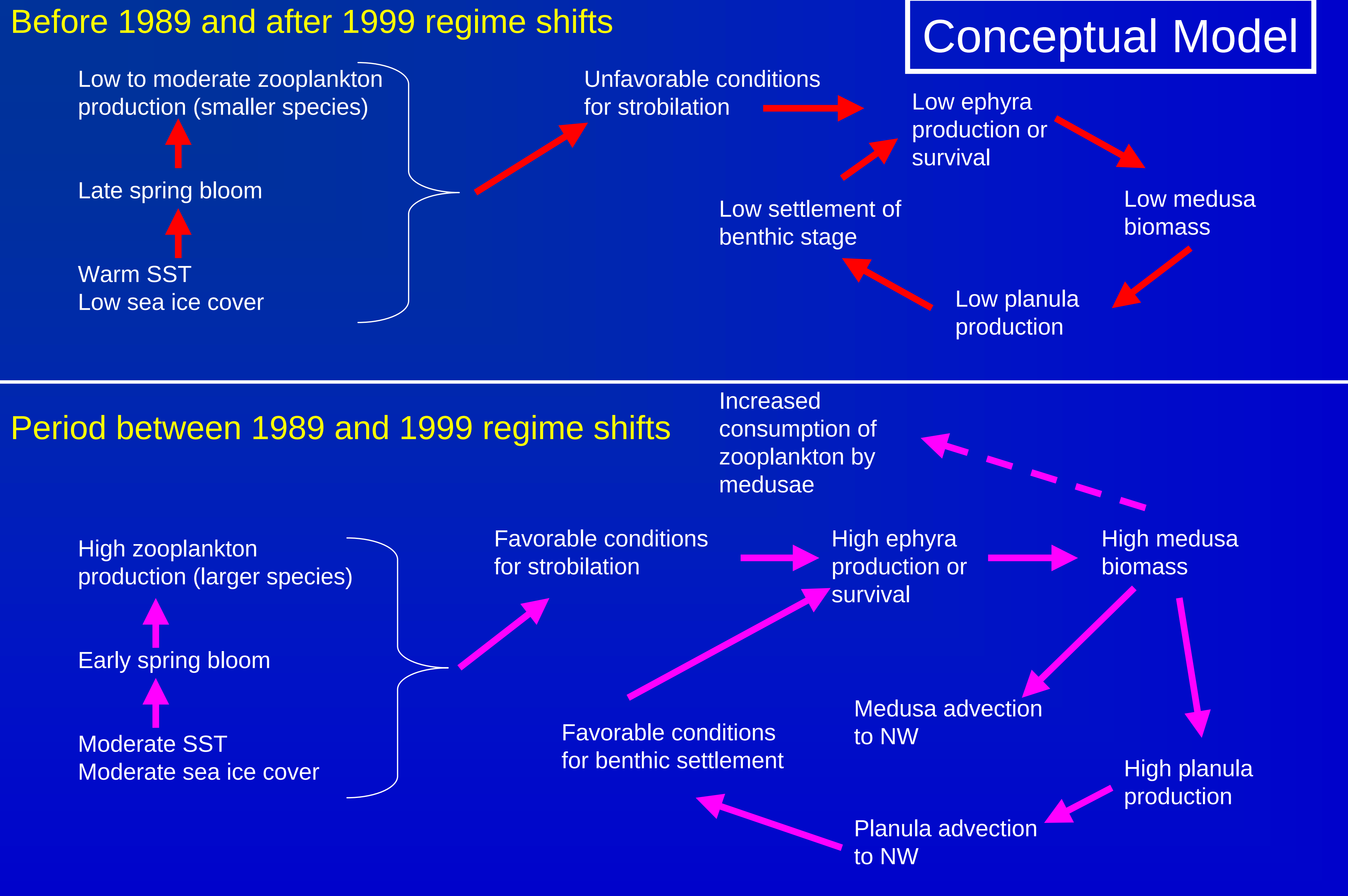
Predictive Models



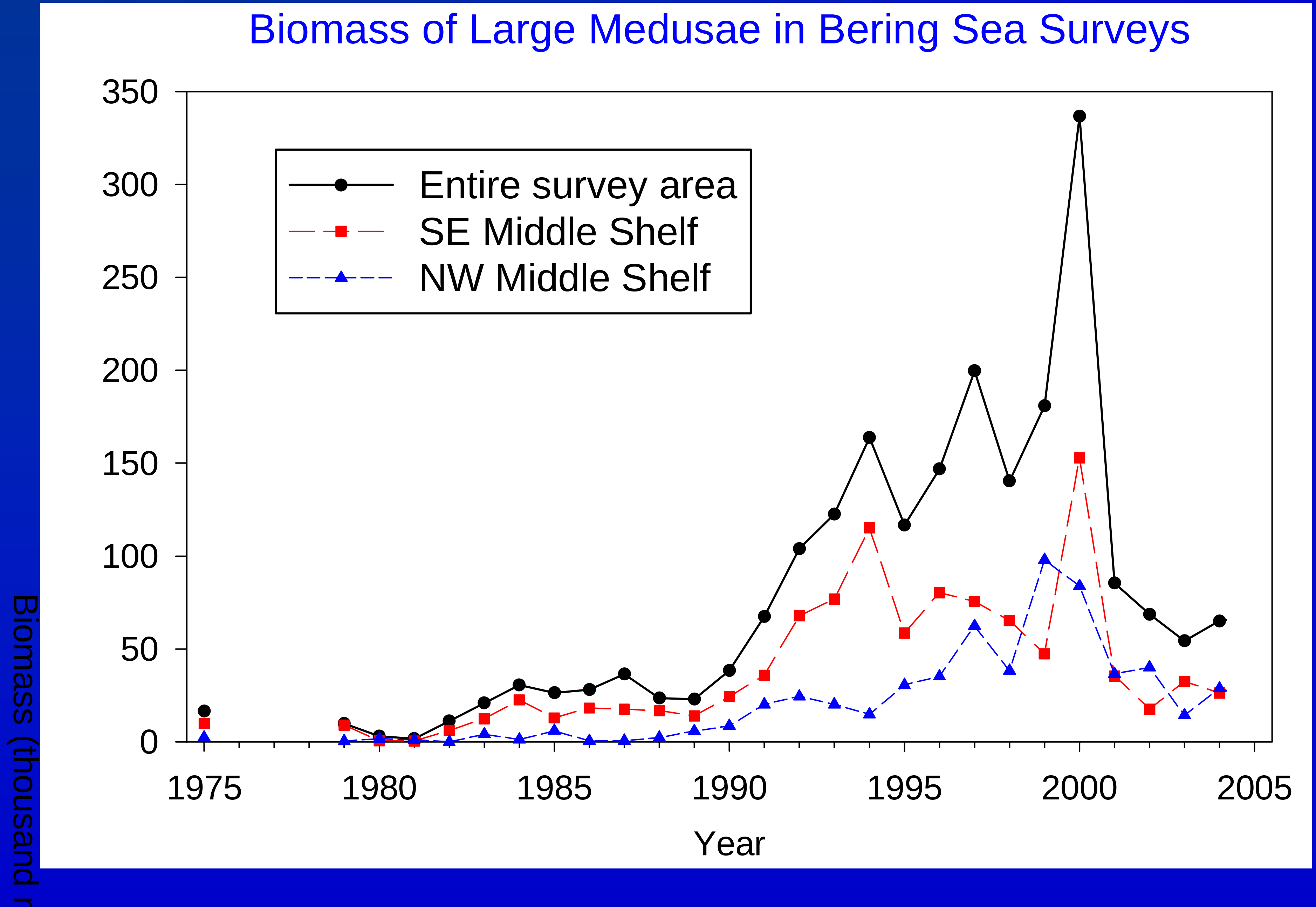
Summary of prevailing conditions in the Southeast (SE) and Northwest (NW) Bering Sea Middle Shelf (MS) regions in relation to jellyfish biomass fluctuations during 1975 to 2004.

Period	Jellyfish biomass	Location of maximum biomass	Sea-surface temperature	Sea ice cover	Zooplankton biomass	Age-0 pollock biomass
1975-1990	Low	SE MS	Cool, then warm	High, then low	Moderate to high	Moderate to high
1991-1999	Increasing	SE & NW MS	Moderate	Moderate	Moderate to high	Moderate
2000	Peak	SE & NW MS	Moderate	Moderate	Low	Very high
2001-2004	Low	SE & NW MS	Very warm	Low	Low	Low


LIFE CYCLE OF A JELLYFISH
Summer
medusa- mobile phase
ephyra
Spring
planula larva
strobila
Autumn
polyp
Winter
www.infovisual.info


Before 1989 and after 1999 regime shifts
Conceptual Model
Low to moderate zooplankton production (smaller species)
Late spring bloom
Warm SST
Low sea ice cover
Unfavorable conditions for strobilation
Low ephyra production or survival
Low medusa biomass
Low planula production
Low settlement of benthic stage
Period between 1989 and 1999 regime shifts
Increased consumption of zooplankton by medusae
High zooplankton production (larger species)
Early spring bloom
Moderate SST
Moderate sea ice cover
Favorable conditions for strobilation
High ephyra production or survival
High medusa biomass
Medusa advection to NW
High planula production
Planula advection to NW
Favorable conditions for benthic settlement

Future Work



Biomass of Large Medusae in Bering Sea Surveys
350
300
250
200
150
100
50
0
Entire survey area
SE Middle Shelf
NW Middle Shelf
1975
1980
1985
1990
1995
2000
2005
Year
Biomass (thousand m

Conclusions

- Jellyfish have shown an increase and decrease in biomass and several shifts in distribution over the last three decades
- SE jellyfish biomass most sensitive to springtime abiotic (temperature and ice cover) and biotic conditions (lagged jellyfish and pollock biomass)
- NW jellyfish biomass most related to summer physical variables (temperature, currents) and also zooplankton biomass and lagged SE jellyfish biomass
- Processes occurring the benthic (polyp) stage and pelagic young (ephyra) appear to greatly affect adult biomass
- Increasing ocean temperatures may not necessarily lead to higher jellyfish biomass and the response may be highly non-linear

Acknowledgments

- G. Walters and the RACE staff in the Alaska Fisheries Science Center for collecting survey data
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