GLOBEC: Temporal Trends in Ecosystem Variability

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GLOBEC PIs
GOALS:

• To understand the effects of climate variability on the distribution, abundance, and production of marine animals, including commercially important living marine resources.

• To embody this understanding in diagnostic and prognostic ecosystem models, capable of capturing the ecosystem response to major climatic fluctuations.
One of the primary challenges is to understand the cumulative effects of large scale and regional scale physics on ecosystem dynamics and variability.
Three Regional Programs


Climate variability examined through
• Retrospective data analyses
• Field process studies
• Synthesis & modeling
Georges Bank Program
US GLOBEC Northwest Atlantic Program: Georges Bank Study Area

Physical processes: circulation, stratification, exchange of water over the bank

A: eggs, B: larvae, C: pelagic juveniles

Lough and Manning (2001)

Calanoid copepods

Cod & hake eggs & larvae
Oxygen isotope ratios (O18/O16) traced low salinity water to the Labrador Sea

(Houghton et al. 2002)
Climate: Georges Bank Freshening During 1990s


Freshwater in early 1990s traced to Arctic

- Arctic Oscillation: positive phase - winds strengthen in Beaufort Gyre, meltwater accumulates locally
- Arctic Oscillation: negative phase - winds reverse, freshwater released from gyre

Oxygen isotope ratios (O18/O16) traced low salinity water to the Labrador Sea (Houghton et al. 2002)
Present Work, Synthesis: Models

Regional-Scale Model

Goal: To understand the underlying mechanisms influencing biological communities over Georges Bank.

Basin-Scale Model
Coupling circulation models (FVCOM and ROMS) with lower food web (NPZD) and copepod population dynamics models to study how climate and local forcing impacts system productivity and species composition.
End to End Food Web Model for Georges Bank (Steele et al. 2007)
Northeast Pacific GLOBEC Program
Northeast Pacific Field Program: 1997-2005

Productive eastern boundary current

Coastal downwelling
Coastal upwelling

SST plotted in shade relief format

D. Haidvogel (Rutgers) & Y. Chao (JPL)
Basin-Scale and Regional Events During NEP GLOBEC

- 1997-1998 El Niño (SST, SSH, transport, biological communities)
- 1999 Regime shift of physical properties & biological communities
- 2002 Anomalous cold/fresh water mass in Gulf of Alaska and off coast of Oregon
- 2002-2006 Hypoxia events off coastal Oregon & Washington
During a warm Pacific Decadal Oscillation (PDO), zooplankton and salmon stocks decrease off of Washington and Oregon.
Pacific Decadal Oscillation vs Northern & Southern Copepod Anomalies Along Oregon Coast

PDO “negative” or cool phase

- Northern copepods have high biomass
  - Large individuals with lipids

Southern copepods low biomass

- Smaller, less lipid

PDO “positive” or warm phase is opposite

Biomass changes are rapid and orders of magnitude differences among years.

B. Peterson (NOAA)
High Coho Salmon Survival Related to Increased Biomass of Northern Copepods

OPI = Oregon Production Index

B. Peterson (NOAA)
Effects of Large-Scale Processes on Coastal Properties

2nd mode in SSH tracks salinity, NO$_3$, and chlorophyll concentrations in nearshore region of NEP over decades.

DiLorenzo et al. 2008
Multi-Scale Modeling of the North Pacific Ocean (Curchitser et al. 2005)

Nested Grids - Regional Ocean Modeling System (ROMS)

0.4 degrees, 10 km, 2-3 km resolution
2002 Cold Anomaly Field Observations and Model Results

• Model suggests the origin of the cold water mass was due to enhanced winter mixing in Alaska Gyre during the previous winter; change in density allowed southward transport of water mass

• Off Oregon, California Current cooled (1 degree cooler & 0.4 psu fresher than 2001), thermocline deepened, decreased stratification

• Upwelling led to increased nutrient supply & biological production on shelf

• Decay of sinking phytoplankton led to hypoxia, killing many bottom fish and invertebrates, such as crabs.

Bottom dwelling fish off of Oregon

Normal year

2005
US Southern Ocean GLOBEC Program

US
Great Britain
Germany
Australia
Korea

- Investigated the physical and biological factors that influence the growth, recruitment, and overwintering survival of Antarctic krill and their predators in the vicinity of Marguerite Bay, west of the Antarctic Peninsula.

- Extensive field program during austral fall and winter 2001 & 2002

*Euphausia superba*
Larval krill survival is attributed to the annual presence of an early forming and long-lasting ice cover, which provides a dependable food source and protection for larval krill.
Western Antarctic Peninsula & Bellingshausen Sea

Winter temperatures warming faster than any other area on the planet: 5.8ºC between 1950-2005.

- Sea ice retreating 31 days earlier in spring
- Advancing 54 days later in fall
- Related to a shift towards positive values of the Southern Annual Mode since the 1990s (Stammerjohn et al. 2008)
Ice Concentration and Duration 1980 - 2005

Anvers Island 200km

Year
2005
2000
1995
1990
1985
1980

Date
May 1
Aug 1
Sept 1
Nov 1

Year
1980
1985
1990
1995
2000
2005

Date
May 1
Aug 1
Sept 1
Nov 1
Feb 15

Erik Chapman
High Larval Densities in 2001 and High Recruitment to Juvenile Stage in 2002

(Daly 2004)

- **2001**: larvae very abundant, up to 132 ind m$^{-3}$
- **2002**: fewer larvae, large recruitment of juvenile krill

![Graph showing krill abundance](image)

**Mean krill abundance (ind m$^{-3}$)**
- **2001**
- **2002**

![Map showing distribution](image)
Southern Ocean GLOBEC: Sea Ice Duration & Extent:

***Winter Sea Ice extent was similar in 2001 and 2002***

Fall 2001:

- Lower ice coverage during summer
- Sea ice formed later (June/July)

Fall 2002:

- South Marguerite Bay covered by ice throughout the year
- Sea ice formed earlier (May)

Winter Sea Ice extent was similar in 2001 and 2002.
Role of Phytoplankton

- Females require above-average chl to support reproduction (1-5 mg chl m$^{-3}$) (Ross & Quetin, 1986) and sustain multiple spawning (>0.5 mg chl m$^{-3}$) (Nicol et al., 1995).

- First-feeding larvae need food to survive.

- Enhanced food availability allows larvae to achieve faster growth rates, thereby obtaining a larger size and better condition to survive starvation overwinter (Daly, 2004).

- Thus, knowledge about differences in the timing, extent, and evolution of phytoplankton blooms is important for understanding interannual variability in krill recruitment.
1. First elevated chl concentrations in October in the Bellingshausen Sea, and along the shelf-break.

2. Blooms progress onshelf into Marguerite Bay and persist until April.

3. In the northern Peninsula blooms move to coastal areas, but concentrations were relatively lower during our study period.
CHLOROPHYLL DYNAMICS (Marrari et al. 2008)

• In order to investigate differences in the timing and evolution of blooms, study area divided in 13 sub-regions.

• Generated time series of mean chlorophyll in each sub-region from 1997 until 2004.
## 25 Years of *E. superba* Recruitment Data

<table>
<thead>
<tr>
<th>Year Spawned</th>
<th>$R_1$</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979-1980</td>
<td>0.559</td>
<td>Elephant Island*</td>
</tr>
<tr>
<td>1980-1981</td>
<td>0.757</td>
<td>Elephant Island*</td>
</tr>
<tr>
<td>1981-1982</td>
<td>0.470</td>
<td>Elephant Island*</td>
</tr>
<tr>
<td>1987-1988</td>
<td>0.651</td>
<td>Elephant Island*</td>
</tr>
<tr>
<td>1994-1995</td>
<td>0.639</td>
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<td>1999-2000</td>
<td>0.573</td>
<td>Elephant Island*</td>
</tr>
<tr>
<td>2000-2001</td>
<td>0.748</td>
<td>LTER/Marguerite Bay*</td>
</tr>
<tr>
<td>2000-2001</td>
<td>0.000</td>
<td>Elephant Island*</td>
</tr>
</tbody>
</table>

*Siegel et al. 2002, †Siegel et al. 2003

- $R_1$ is percent of recruited juveniles (year 1) relative to total number of krill > 20 mm
- Since 1977, only five high recruitment ($R_1 > 0.5$) events
- 1980/81 and 2000/01 had largest recruitment events
- Since 1982, about 5-7 years between successful recruitments
- Krill live about 6-7 years
Chlorophyll vs. Krill Recruitment

Grey bars: Chl, black circles: $R_1$

$\text{Chl}^{SWF}$ in the Bellingshausen Sea during Nov vs. $R_1$ of $E.\ superba$ in the WAP

$R = 0.81; p < 0.05; n = 6$
Oceanic Niño Indices (NOAA) vs Krill Recruitment

EI: $R^2 = 0.017$
$P = 0.854$

LTER: $R^2 = 0.002$
$P = 0.858$

Graph showing the relationship between Austral Spring: OND ENSO Index and Krill Recruitment. The graph includes data points for the years 1980, 1981, 1982, 1988, 1995, 2000, 2001, and 2002. The regression lines for Elephant Island (EI) and Long-Term Ecological Research (LTER) are shown with $R^2$ values and $P$ values.
Spring Southern Annular Mode Indices vs Recruitment

Recruitment Elephant Island
Recruitment LTER

Elephant Is: $R^2 = 0.253$

***$P = 0.017$

LTER: $R^2 = 0.001$

$P = 0.899$

SAM indices: Byrd Meteorology Polar Group
Summer Mean Density of Krill and Chlorophyll Correlated at Circumpolar Scale

SeaWiFS Chlorophyll

\[ R^2 = 0.051 \quad p = 0.017 \]

Krill Abundance

Atkinson et al. (2004)
Decrease in Krill Abundance: 1976 to 2003

Krill data spanning back to 1926.

Atkinson et al. 2004
GLOBEC Synthesis & Modeling Phase: End-to-End Food Web Models for Georges Bank, NE Pacific, and Southern Ocean

Goals
• Comparative analysis of physical and biological processes between regions
• Develop diagnostic measures to evaluate affects of climate variability and fishing pressure

Potential outcomes
• Transition results for ecosystem-based fisheries management
• Food web budgets for global carbon models