Who or What is Regulating Zooplankton Production?

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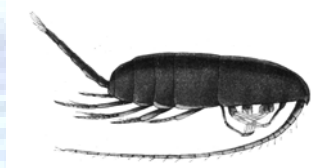
Why is it Important to Know?

- Depletion of prey by populations may limit their own recruitment (density-dependence)
- Availability of zooplankton prey may limit production at higher trophic levels
- Removal of major zooplankton predators may benefit other competitors and result in a restructuring of the food web



Point #1 Density-dependent affects on recruitment

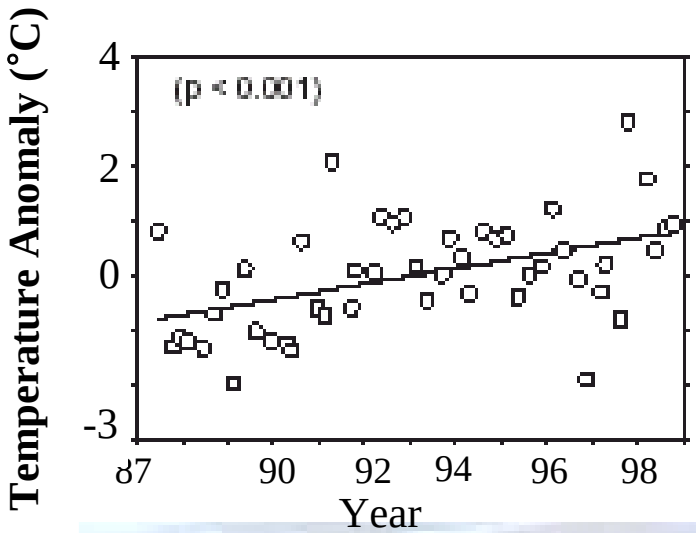
"Superabundance" of Gulf of Alaska Walleye Pollock in 1981

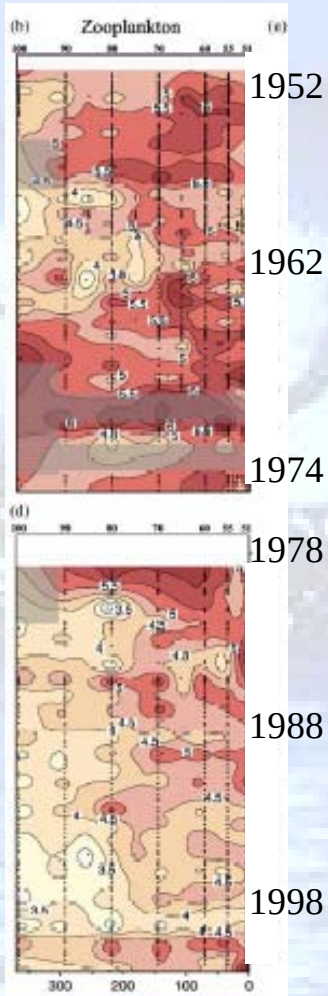
	1981		Other Years
	(in patch)	(out patch)	(in patch)
Larval Density (No. 10 m^{-2})	27,440	1,670	6,000
Nauplii as % Prey	10	80	
Mortality (d^{-1}) @ 20 days	0.138		0.027

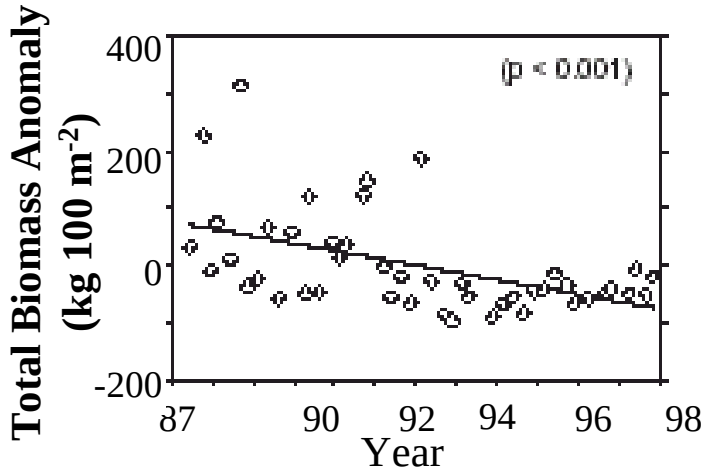
Duffy-Anderson *et al.* (2002)

Point #2 Limitation of production at higher trophic levels

California Current Ecosystem







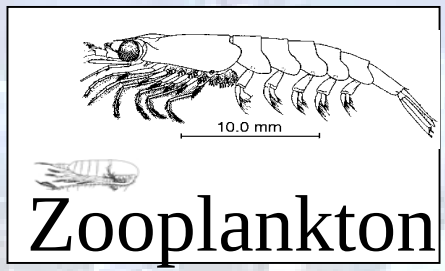
Hyrenbach & Veit (2003)
McGowan *et al.* (2003)

Point #3 Restructuring of food webs

Trophic Cascade Hypothesis

Predator Release
Regime Shift
Fishing

+



Zooplankton

+

Adult Pollock

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Juvenile Pollock
Forage Fish

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Apex Predators

Merrick (1997)

Production = Biomass x Growth

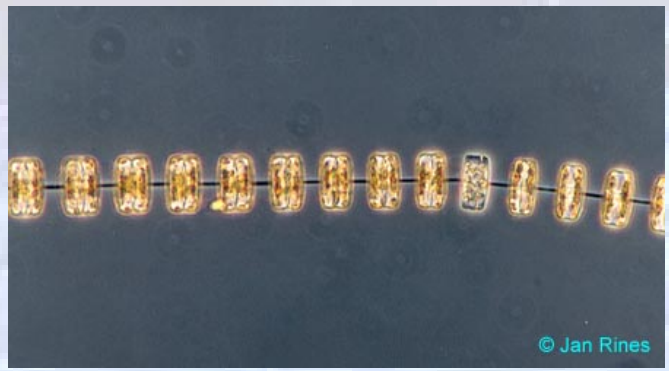
$$P = \sum_{i=1}^{j} N_i W_i g_i$$

Control From Below – Does It Occur?

zooplankton

Phytoplankton
+
µ-zooplankton

Physics



Example #1

Food Limitation:

Southern California Bight

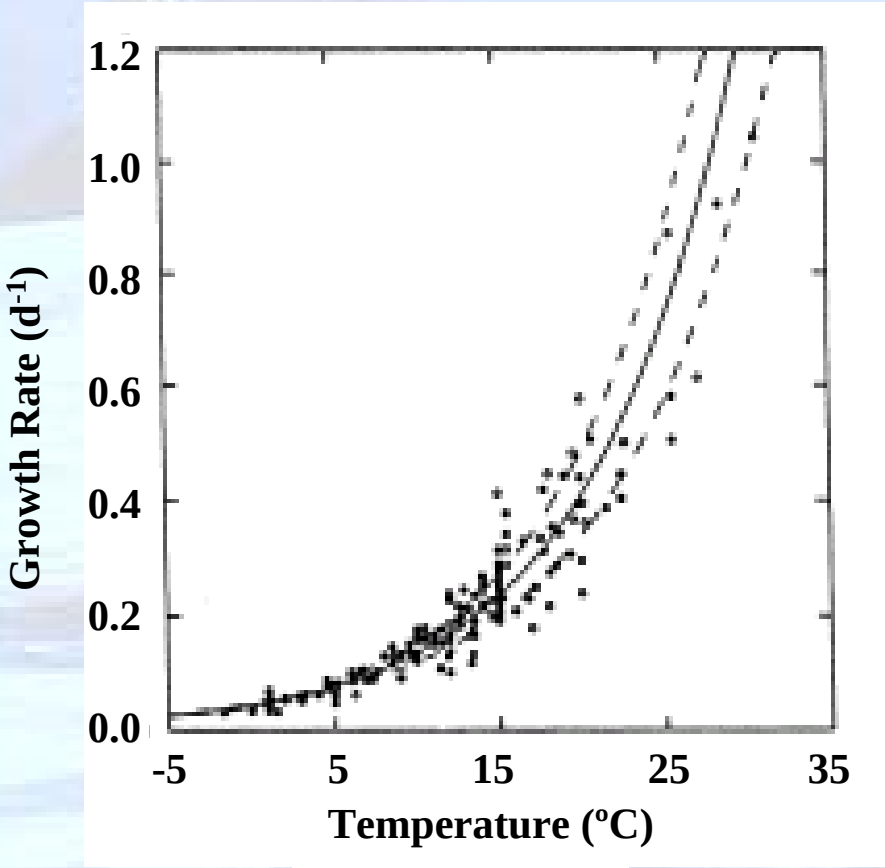
Calanus pacificus

	% of Population Biomass		
	Loss	Maintain	Gain
April	40	30	30
June	45	5	55

Mullin & Brooks (1976)

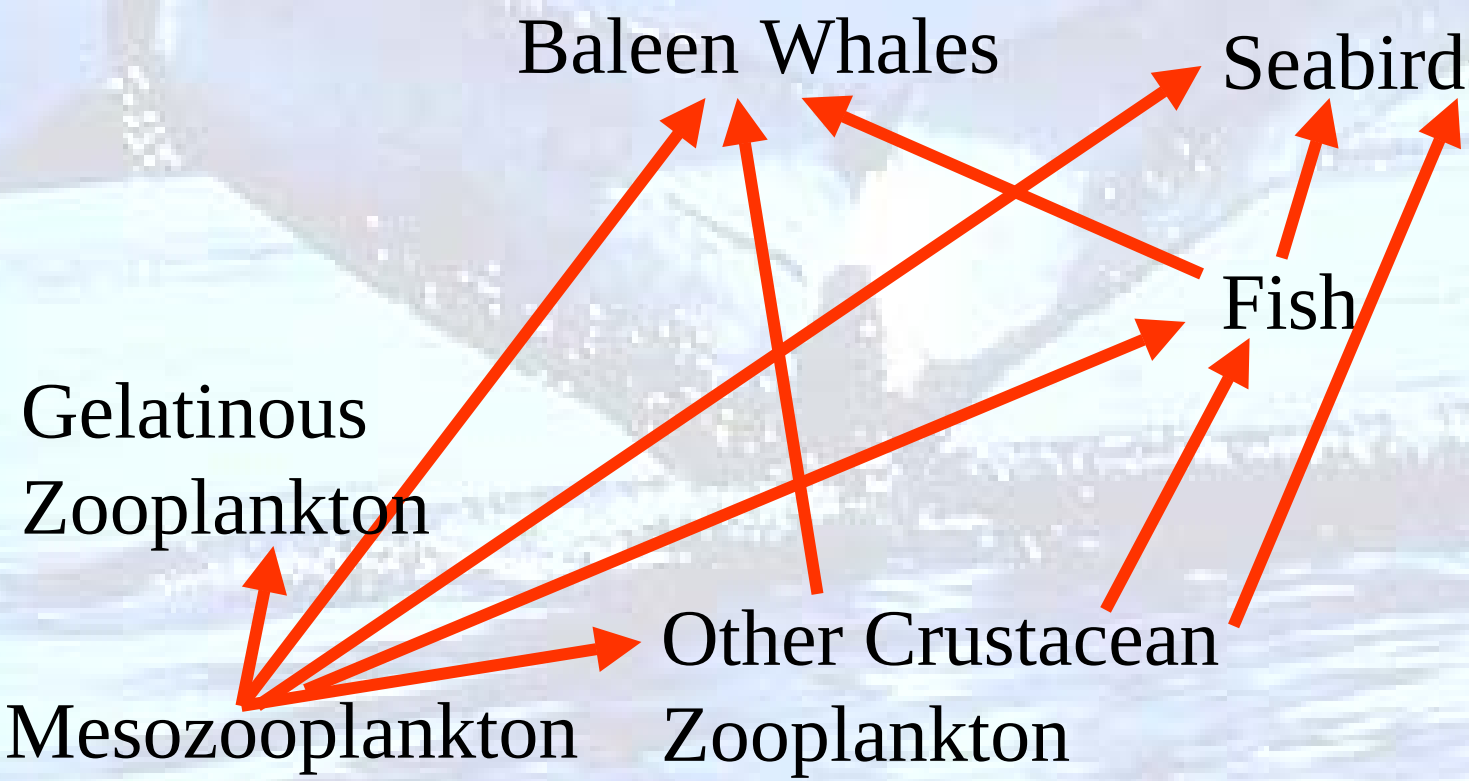
Examples #3 & #4

Temperature Limitation



- Huntley & Lopez (1992)
  - $R^2 = 0.91$
- Hirst & Lampitt (1998)
  - Broadcast
    - T & BW; $R^2 = 0.49$
  - Sac
    - T only; $R^2 = 0.52$

Control From Above – Does It Occur?

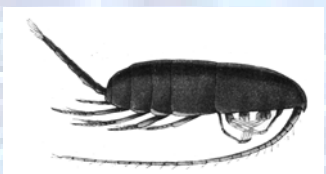


Examples #5 & #6

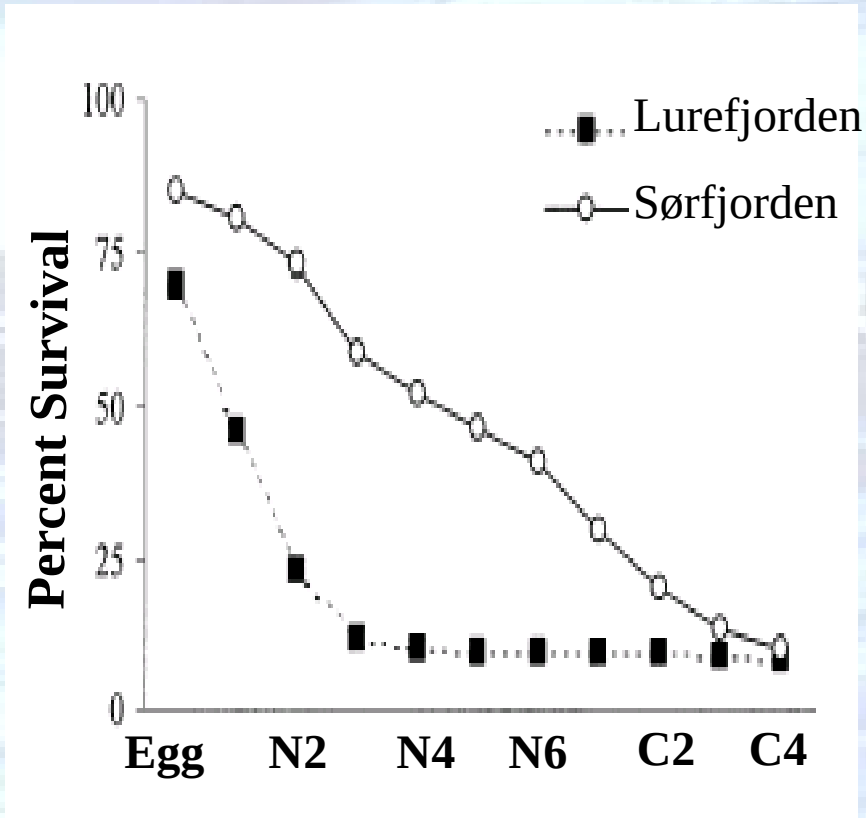
Control From Above

Ohman (1985)

- Examined *Pseudocalanus* population in a semi-enclosed bay deep inside a fjord
- 5 different indices of population control were examined – 4 which would indicate food limitation and one which examined “founder” effects.
- No indication of food limitation, therefore must be predation.



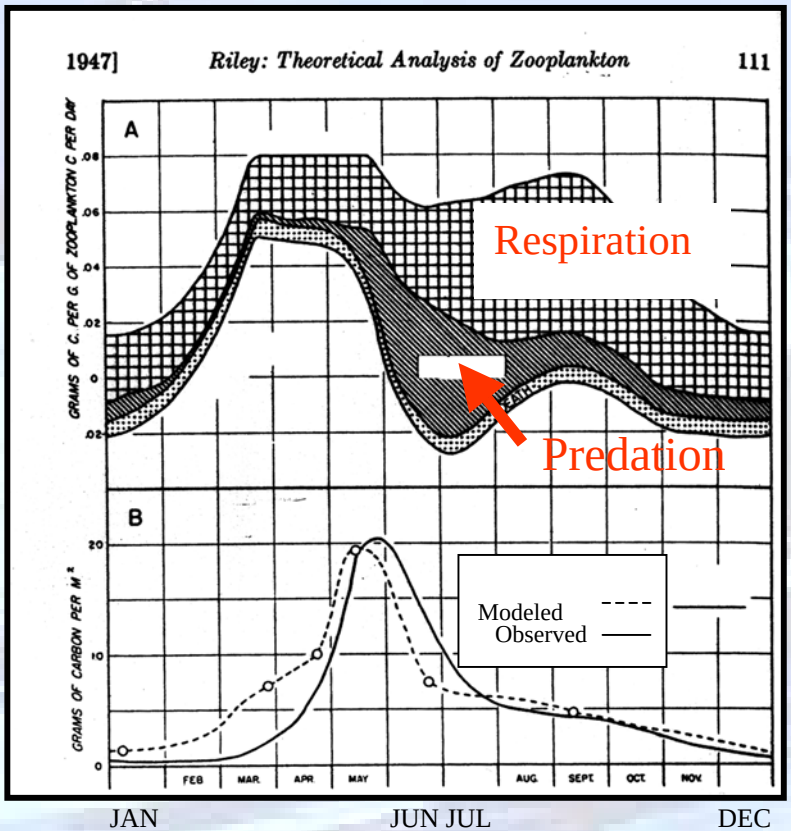
Stage-specific mortality of *Calanus* spp.



Eiane *et al*. (2002)

Example #7

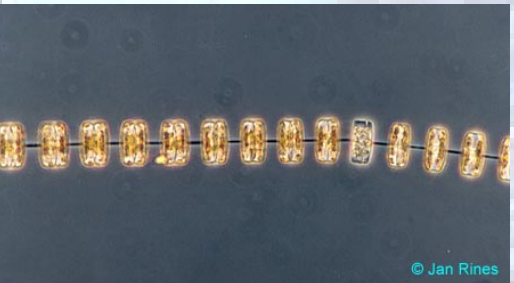
Control From Above & Below



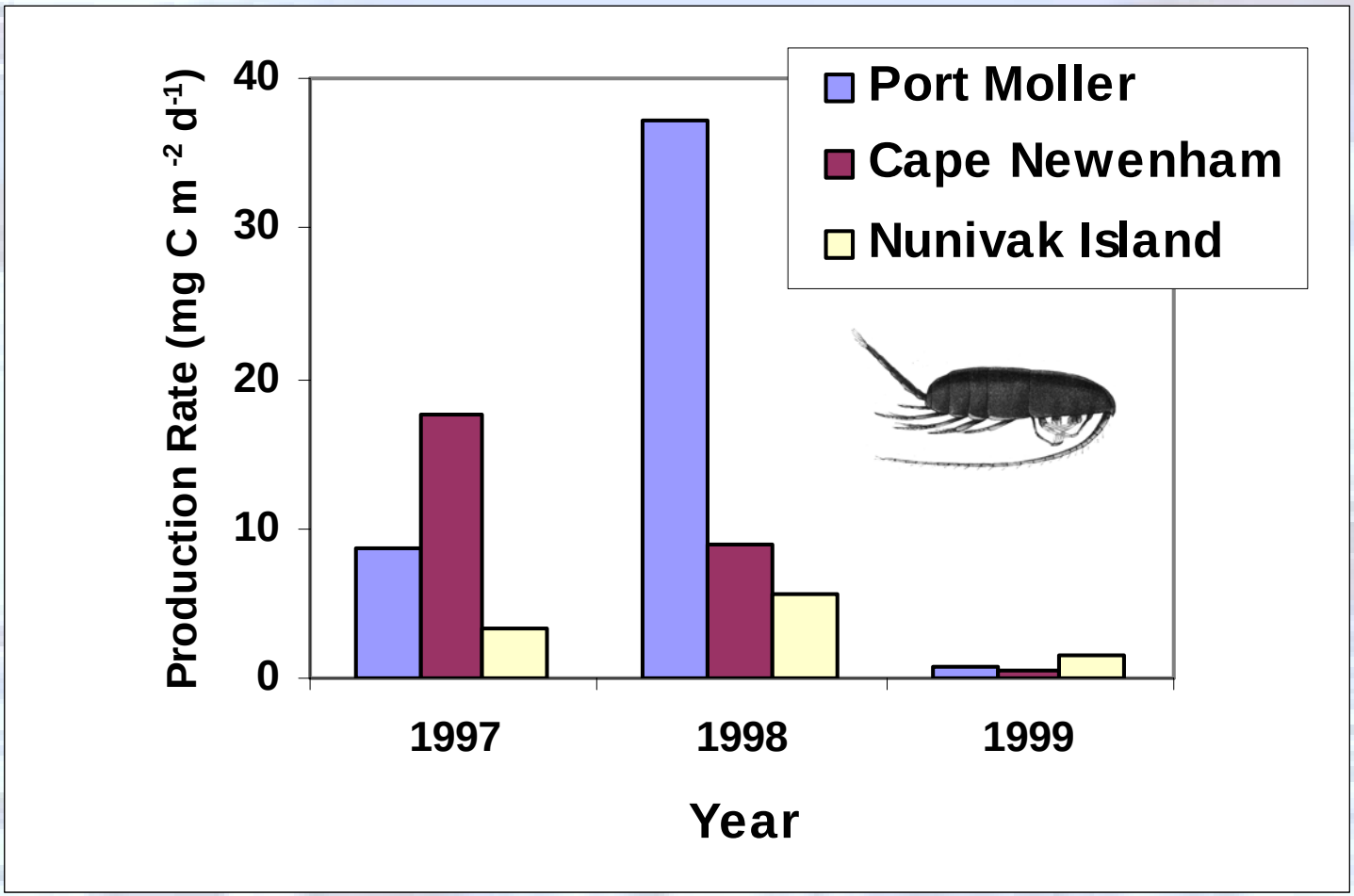
- Georges Bank
- Growth is Modeled
- Mortality is Closure
- Goal is for model to replicate time series of abundance/biomass observed in nature

Riley (1947)

What is Limiting Zooplankton Production in the Southeastern Bering Sea ?

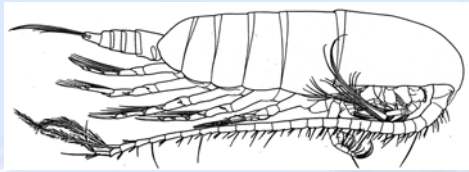


Temperature Limitation



Coyle and Pinchuk (2002)

Temperature Limitation

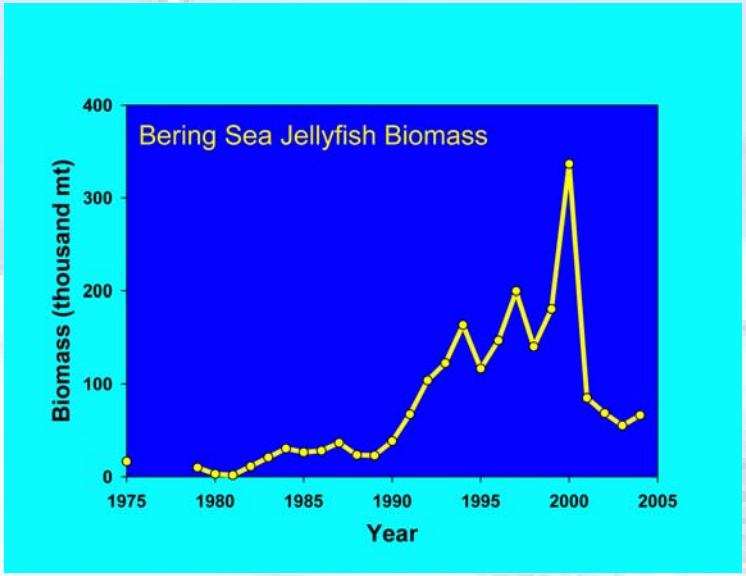


Calanus marshallae

	Bottom Temperature	Ice Extent	Bloom Onset
When C1 Appear	$P < 0.05$	$P < 0.05$	$P < 0.05$
May Concentration of Copepodites	NS	$P < 0.05$	NS

Baier and Napp (2003)

Predation By Soft-Bodied Zooplankton



- ***Chrysaora* Consumption**
  - **32 % standing stock**
  - **4.7% production**

Brodeur *et al*., (2002)

- ***Sagitta elegans* Consumption**
  - **12 - 75 % standing stock**
  - **44 - 78 % production**

Baier and Terizaki, unpublished

Predation By Fish

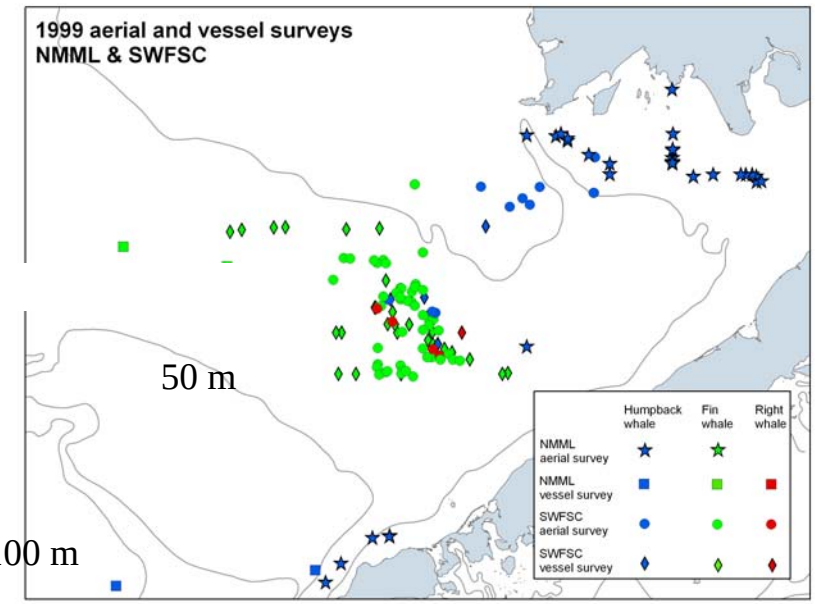
http://www.seafreez.com/Capelin.html

- ***Fish* Consumption**
  - **> 100 % standing stock**
  - **28 % production**
- **Bristol Bay Sockeye Salmon Consumption**
  - **8 – 21 % standing stock**
  - **5 % production**

Ciannelli *et al*. (2004)
Nishiyama (1982)

Whale Consumption

1999 Whale Surveys



- **Maximum Fin Whale Consumption**
  - **ca. 6 % of standing stock**
  - **ca. 0.6 % production**

Tynan (2004)
Moore *et al.*, (2002)

Seabird Consumption

- **PICES Subregion BSC**
  - **Consume 0.02 g C m^{-2}**
- **Pribilof Islands**
  - **Consume 0.03 g C m^{-2}**

Zooplankton Equivalents

ca. 1 % of standing stock

ca. 0.1 % production

Ciannelli *et al*. (2004)
PICES Scientific Report No. 14 (2000)

Control from Above

	Percent Removed						
	Plankton		Fish		Fin	Birds	**Total**
	Chaetognaths	Jellyfish	Ensemble	Salmon	Whales		
Standing Stock	12 - 75	32	> 100	8 - 21	6	1	**> 200**
Production	44 - 78	5	28	5	< 1	< 1	**> 100**

Conclusions

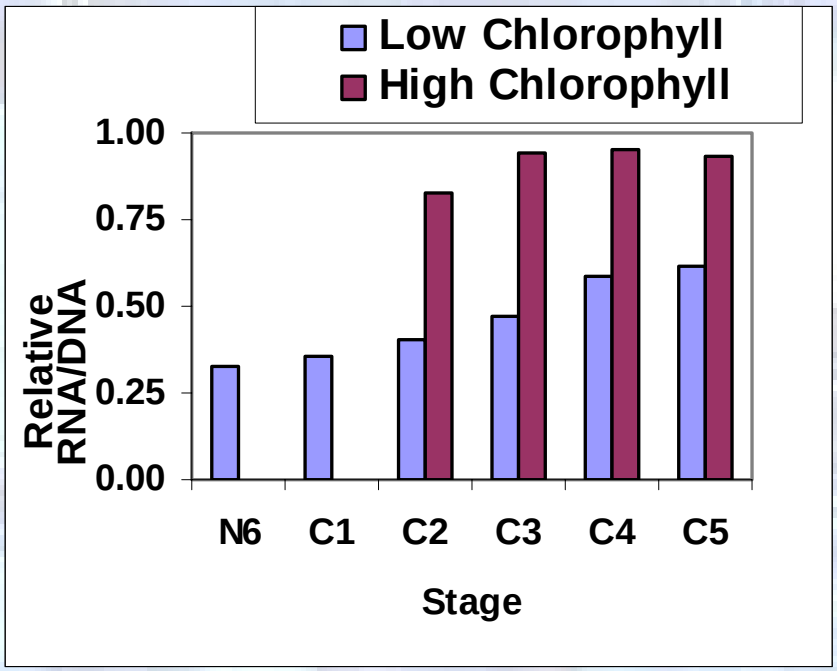
- **Both control mechanisms are operative; how do they interact?**
- **Need growth rate measurements at low temperatures.**
- **Species composition affects the result.**
- **Spatially-explicit rates, especially predation mortality.**
- **Simulations/models important to examine different mechanisms under different conditions.**

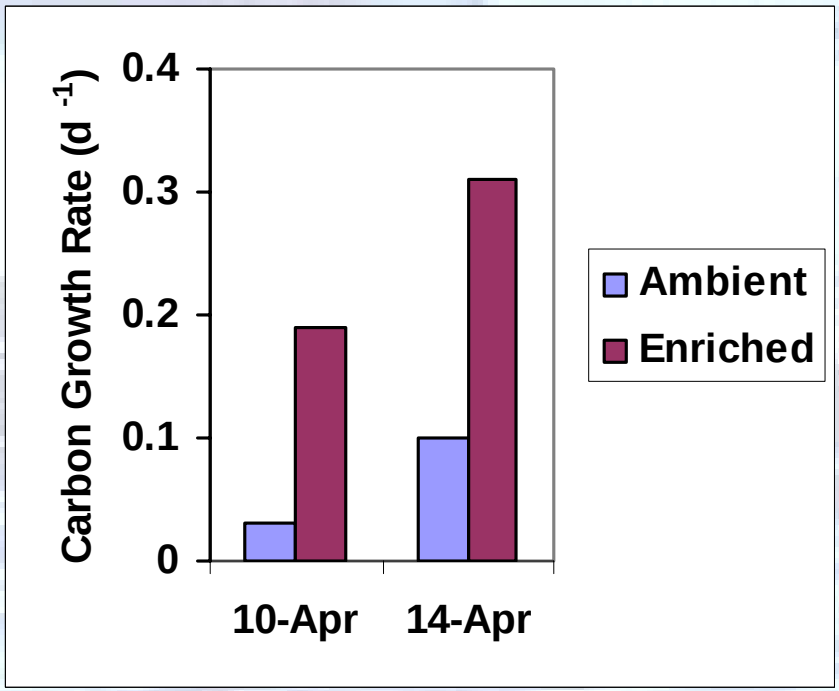
Example #2

Food Limitation:

Georges Bank

Calanus finmarchicus





Campbell *et al.* (2001)