Large zooplankton and their predators in a warming Bering Sea: ecosystem and life history modeling approaches

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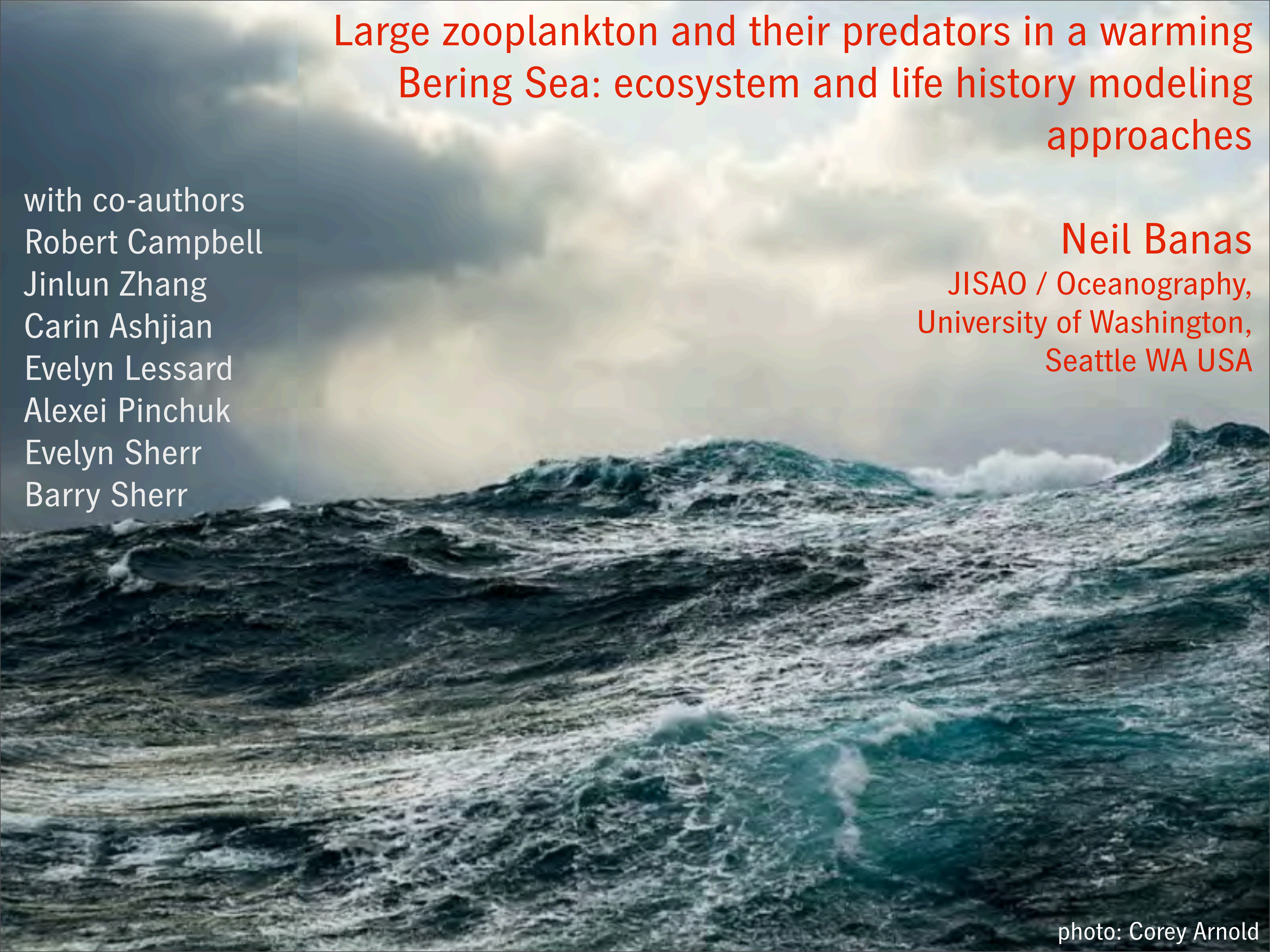
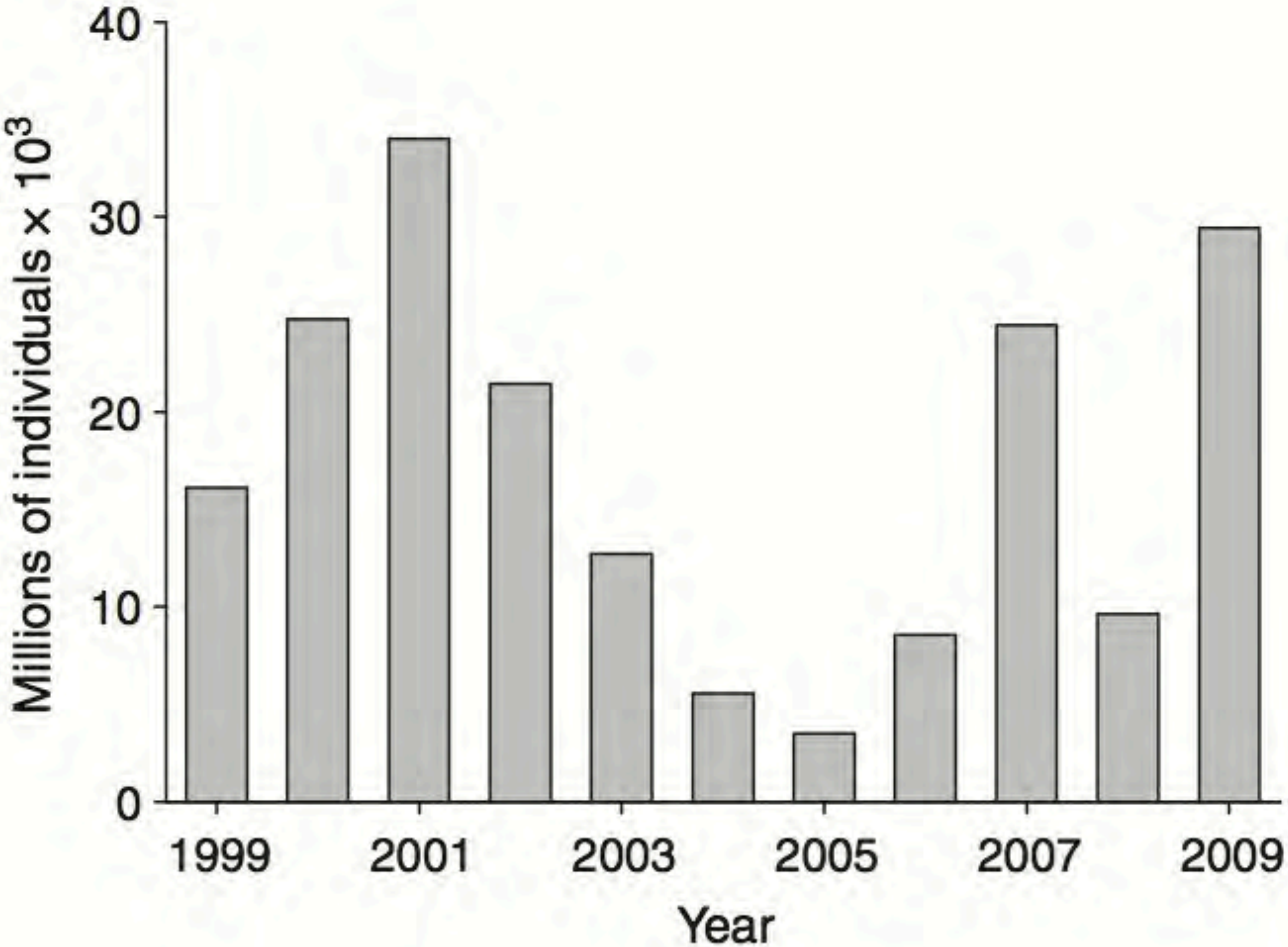


photo: Corey Arnold

Figure 12. Age-1 pollock (*Theragra chalcogramma*) recruitment on the eastern Bering Sea shelf during the study period (Table 1.22 in Ianelli *et al.*, 2009).



Coyle et al. 2011

ice cover, Apr 1, from BESTMAS

Bering Ecosystem Study Ice-ocean Modeling and Assimilation System: Zhang et al. 2010, 2012)

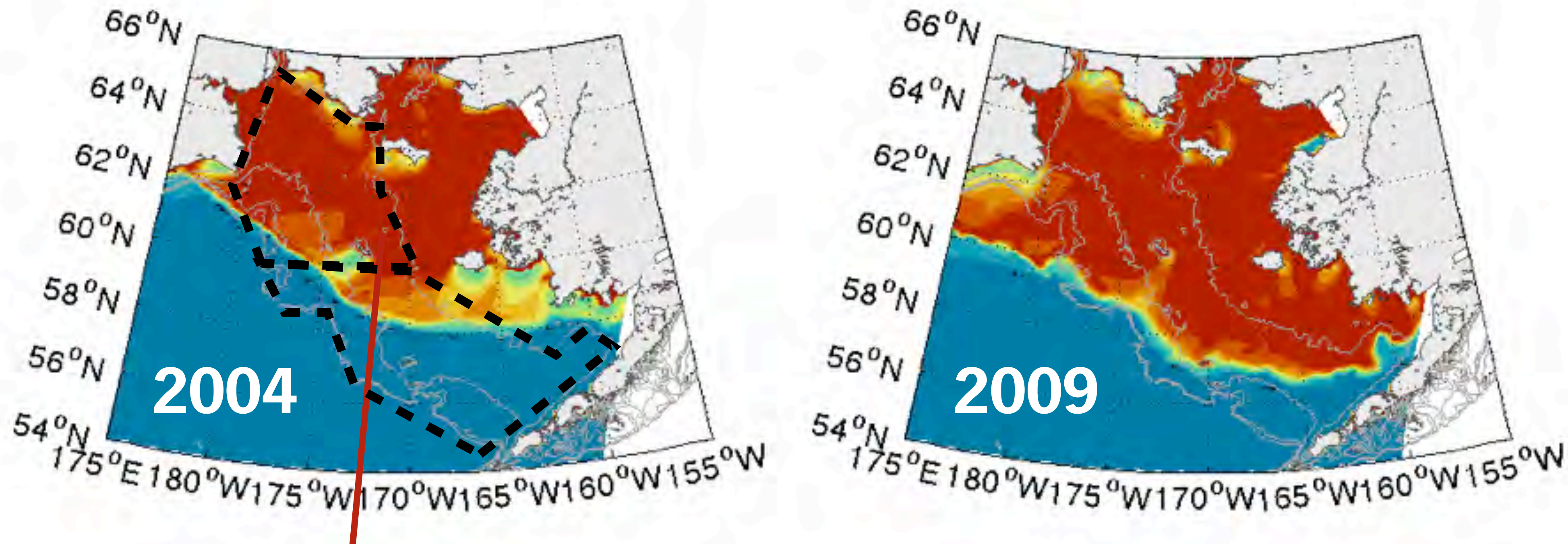
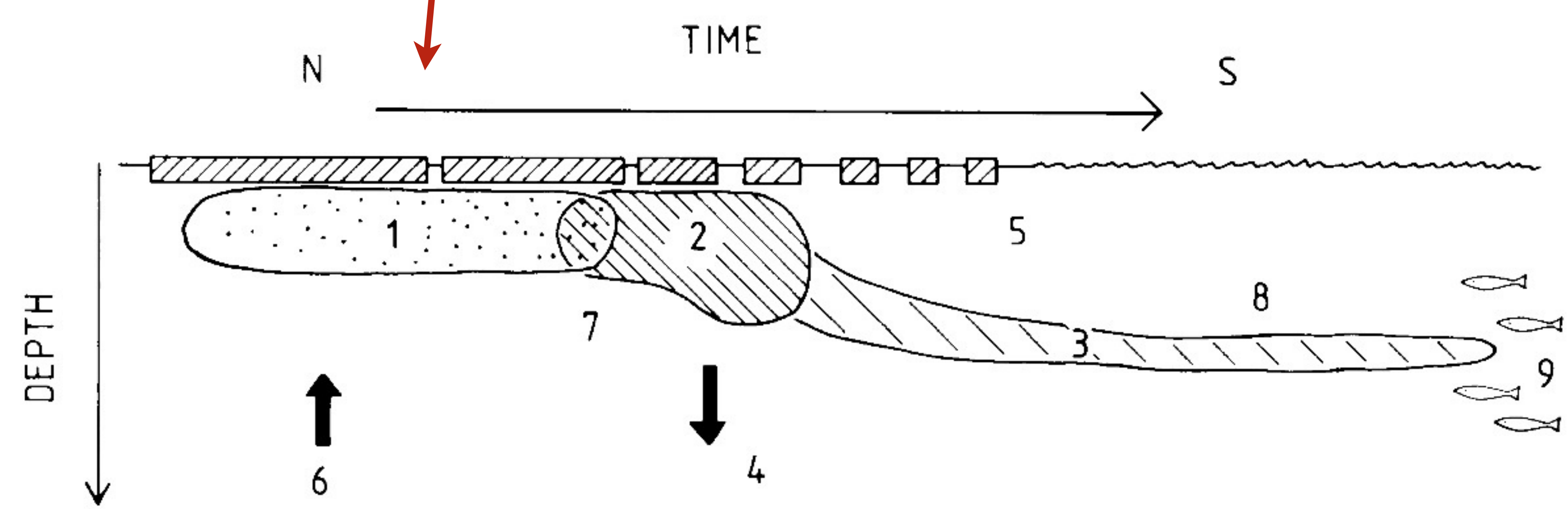


Figure 2. Schematic picture of the seasonal plankton development in the Barents Sea. The receding ice edge acts as a biological time-setter, and various stages of the seasonal plankton development can be found along a North–South gradient. (48).



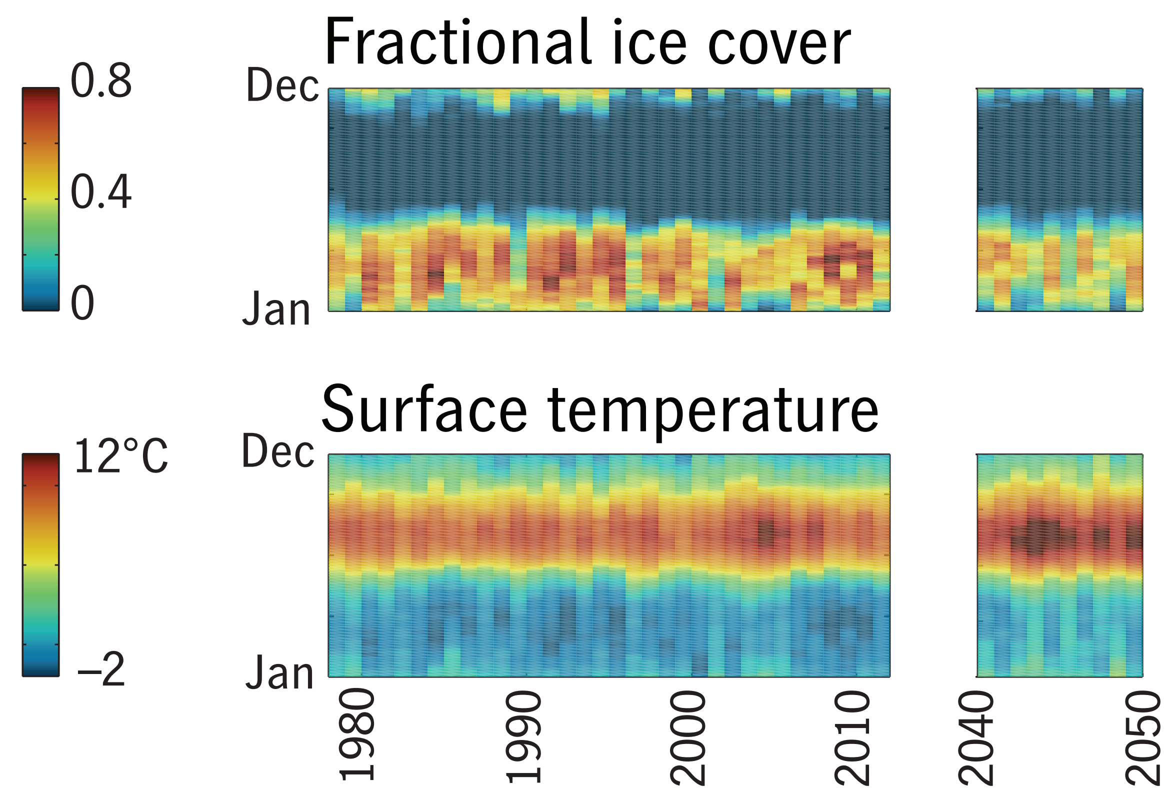
1 – prebloom phytoplankton growth
2 – ice-edge phytoplankton bloom
3 – post bloom deep-chlorophyll maximum
4 – sedimentation of phytoplankton
5 – oligotrophic post-bloom surface layer
6 – upward migration of overwintering zooplankton
7 – spawning of zooplankton
8 – growth and development of a new generation of zooplankton
9 – capelin feeding migration

Sakshaug and Skjodal, *Ambio*, 1989

Climate projection from BESTMAS (Zhang et al. 2010, 2012)

Assimilative ice-ocean hindcast + linear trend of +8°C by 2100 (near mean of CMIP3 ensemble)

Mean over middle–outer shelf (50–200 m depth)



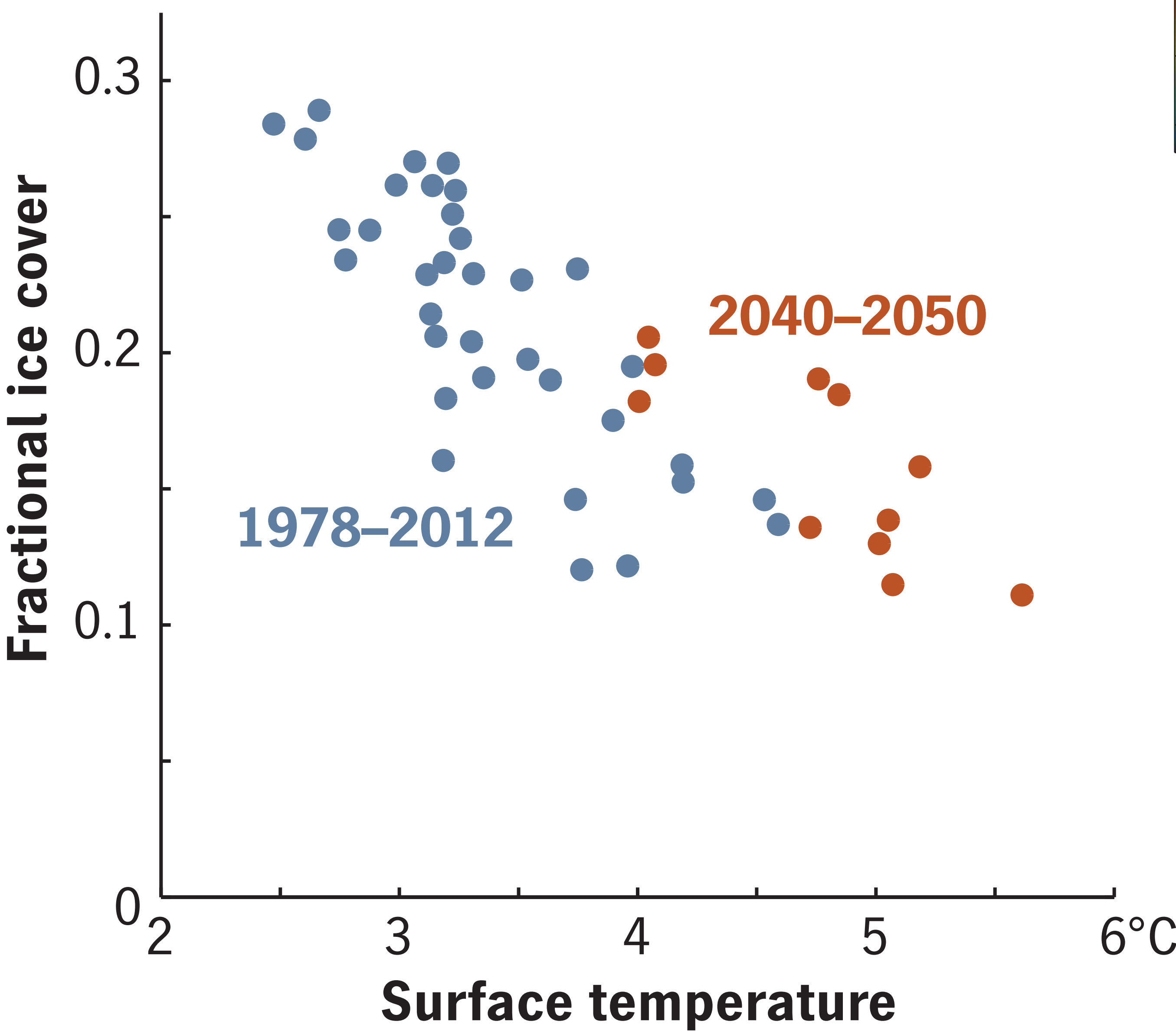
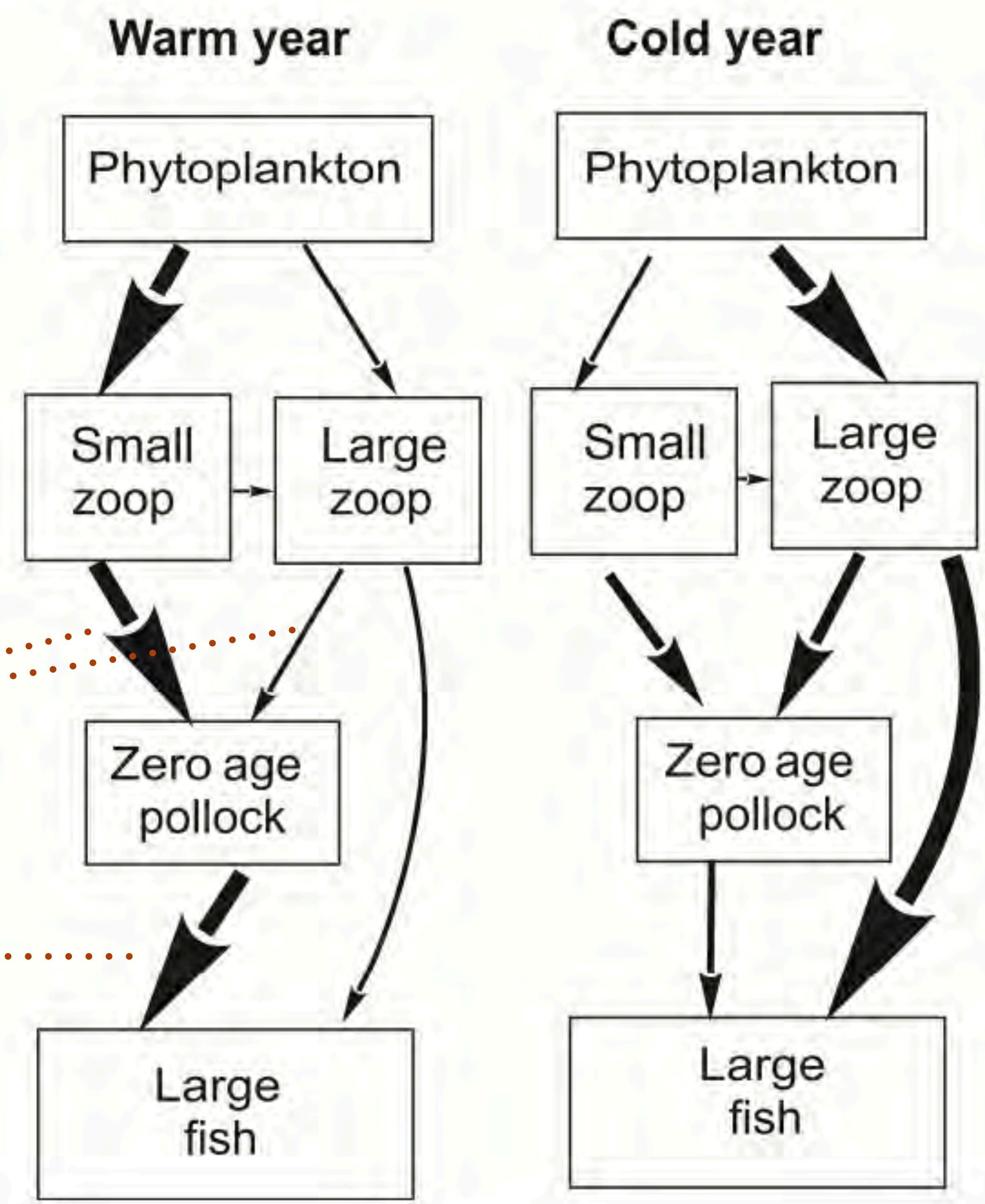


Figure 11. Conceptual model of energy flow through the ecosystem on the southeastern Bering Sea shelf during warm and cold conditions.



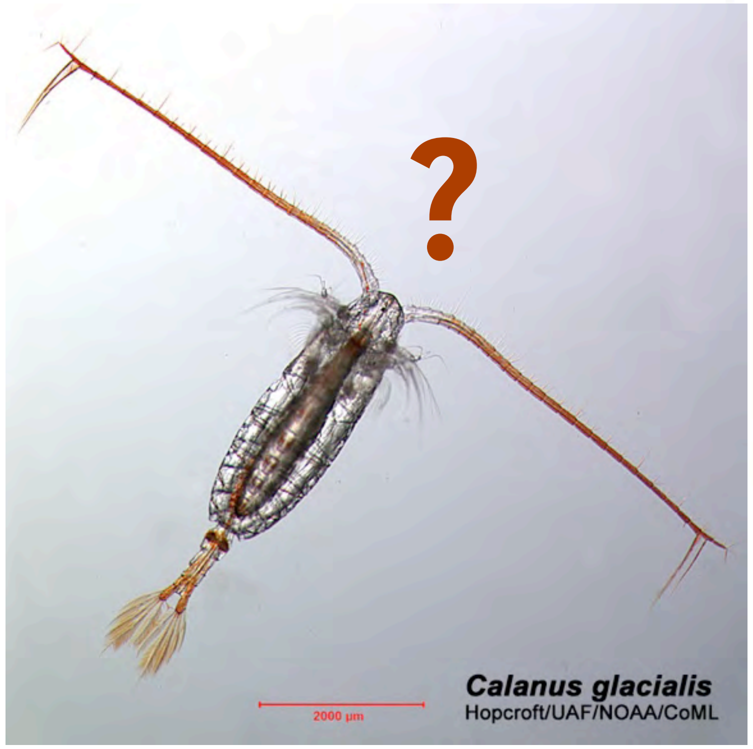
warm years =

high pollock abundance in first summer but poor prey quality;

low survival to age 1

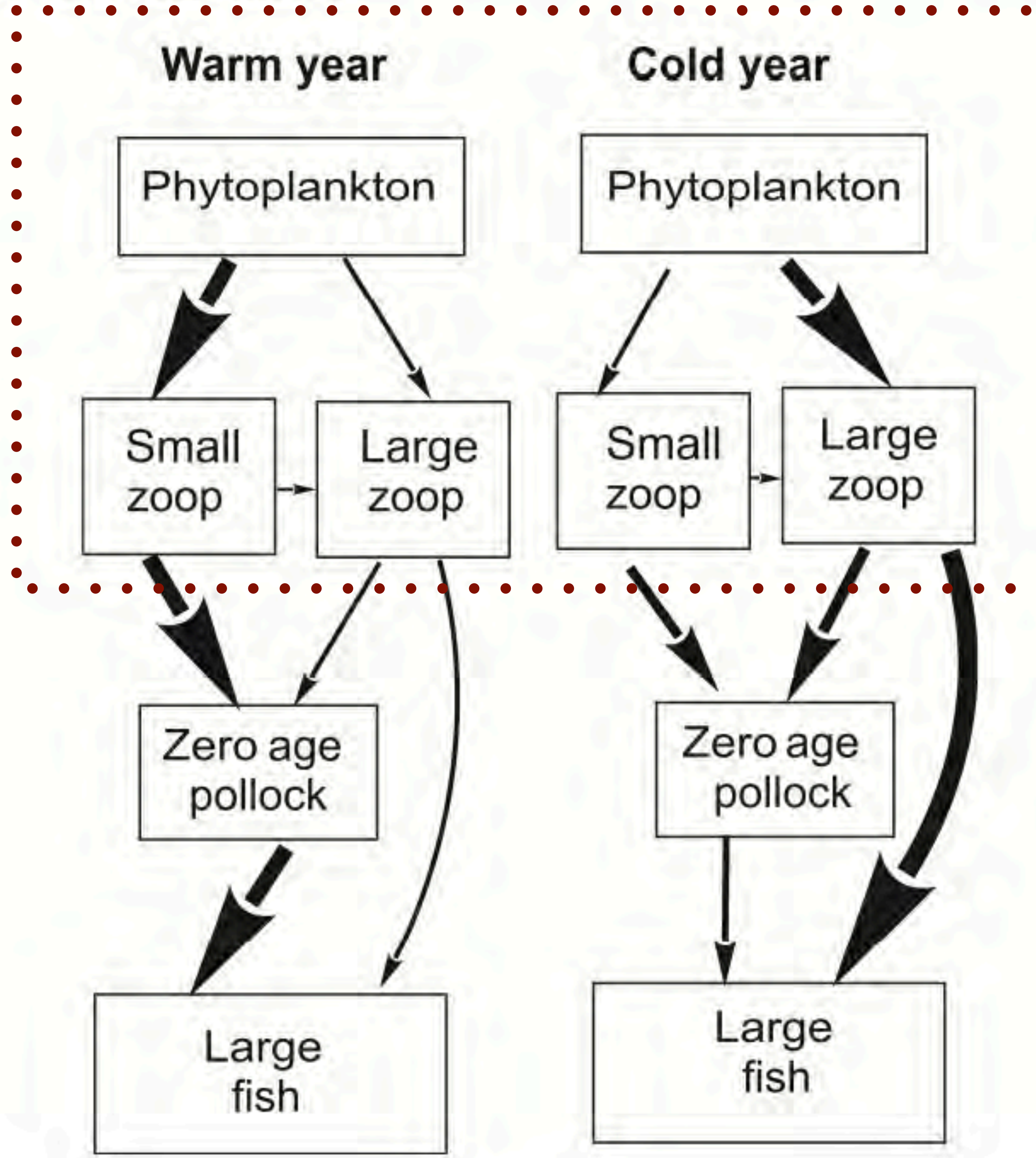
(Hunt et al. 2011)

Coyle et al. 2011



Calanus glacialis

Figure 11. Conceptual model of energy flow through the ecosystem on the southeastern Bering Sea shelf during warm and cold conditions.



why?

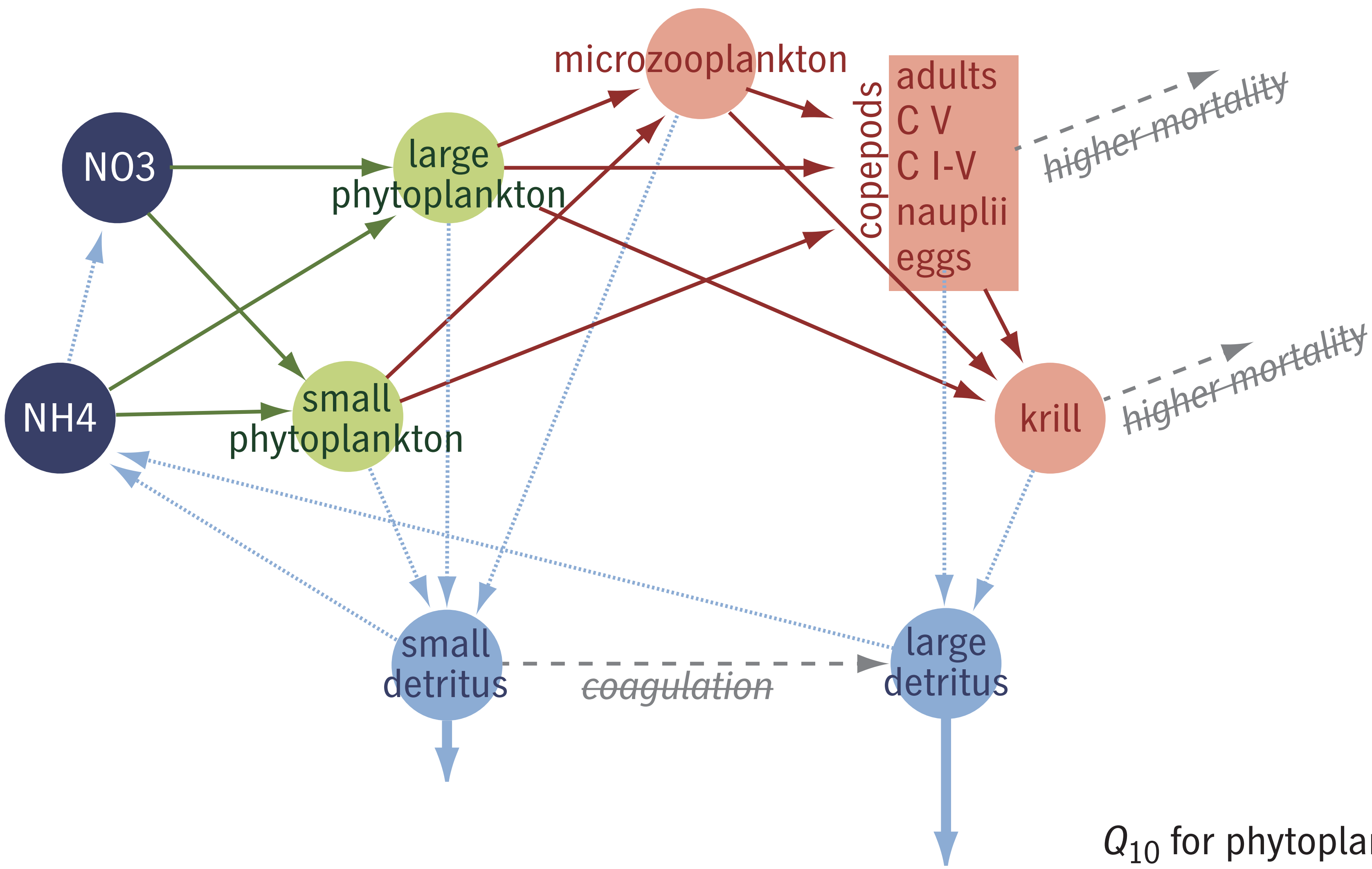
Coyle et al. 2011

Question 1

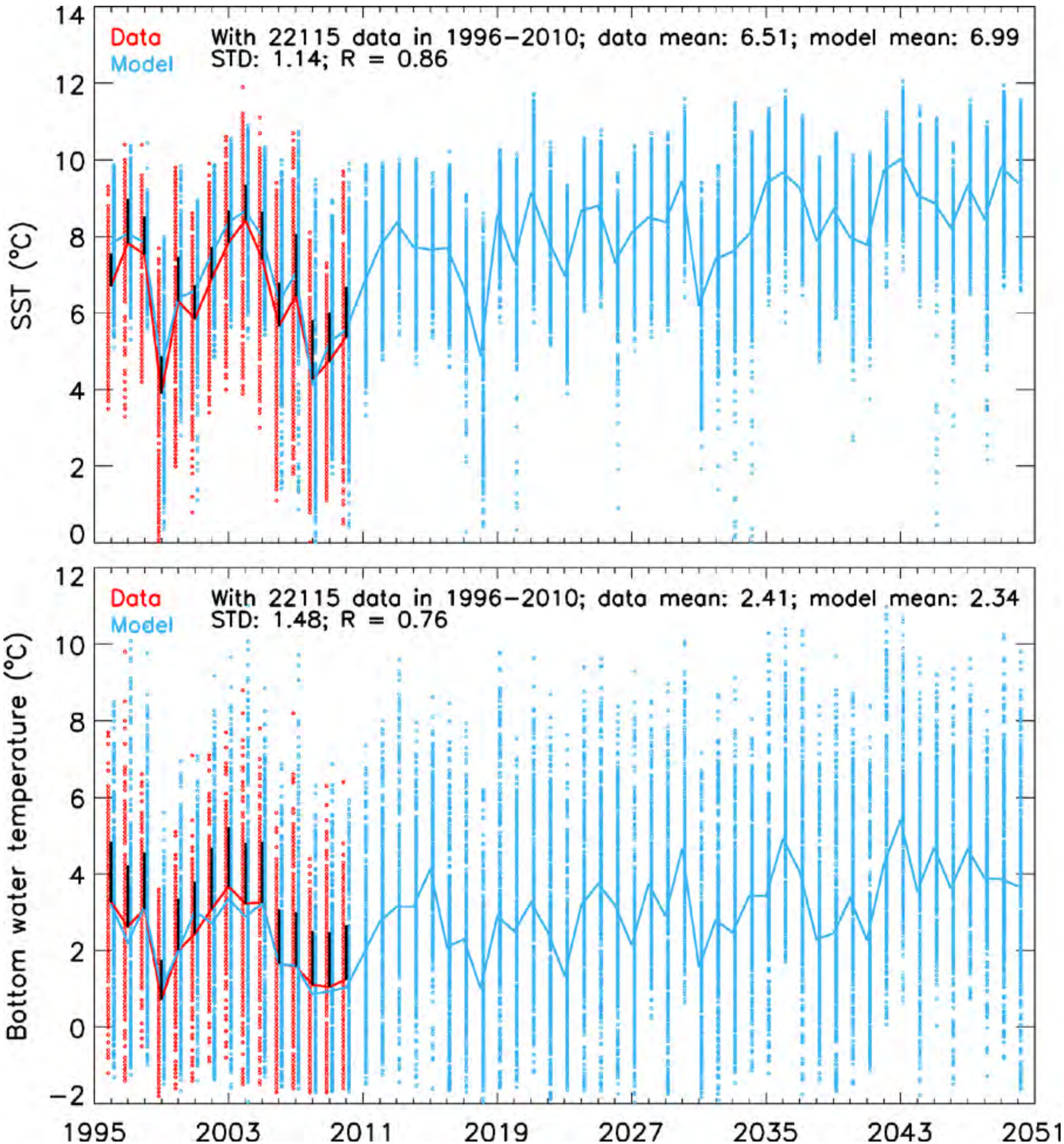
Do spring/summer phytoplankton dynamics (temperature, bloom timing, total production) explain why large crustacean zooplankton do better in cold years?

LowLaMB 1.0

(Lower-trophic Lagrangian Model for the Bering Sea)



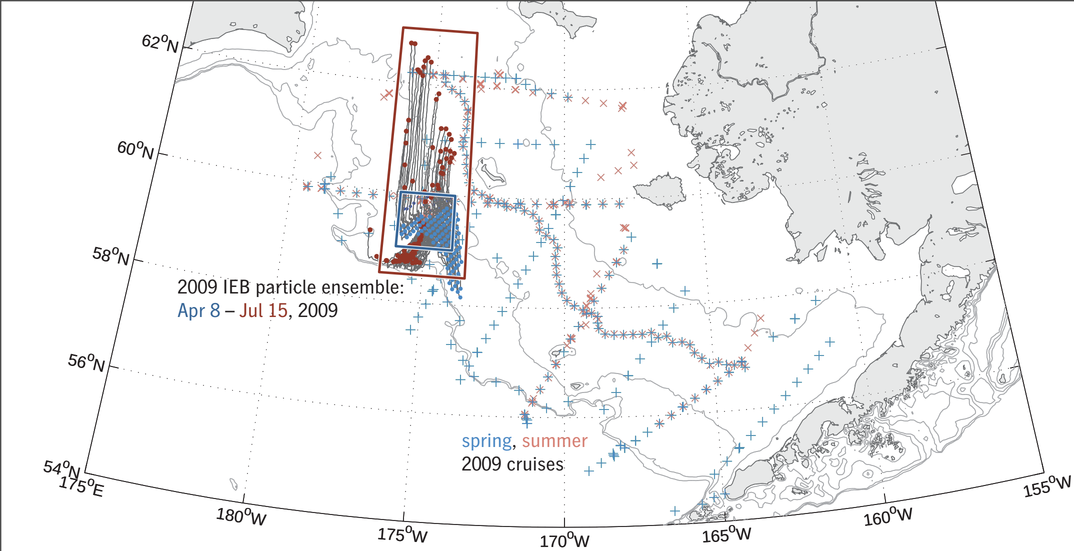
Q_{10} for phytoplankton growth = 2.0
Q_{10} for zooplankton growth = 2.8
Q_{10} for copepod development ~ 3.4

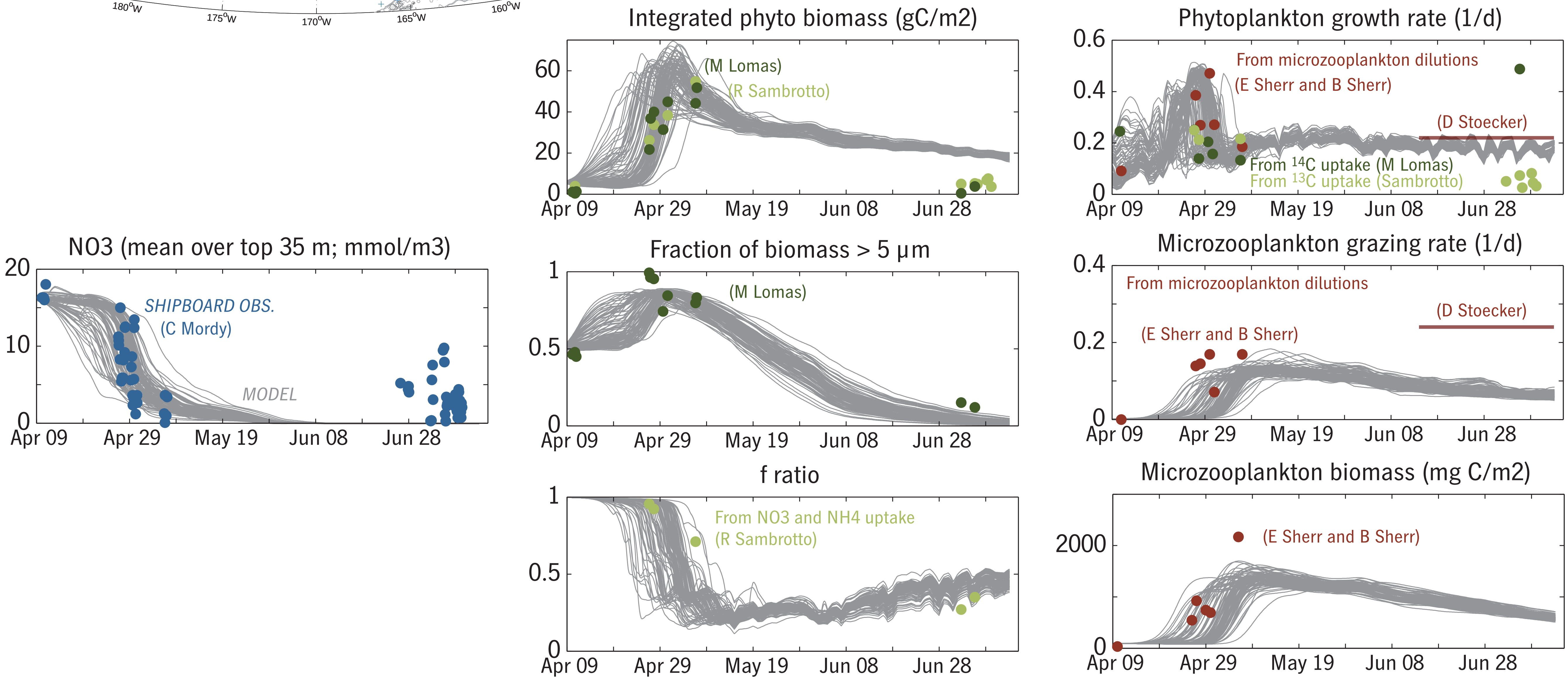


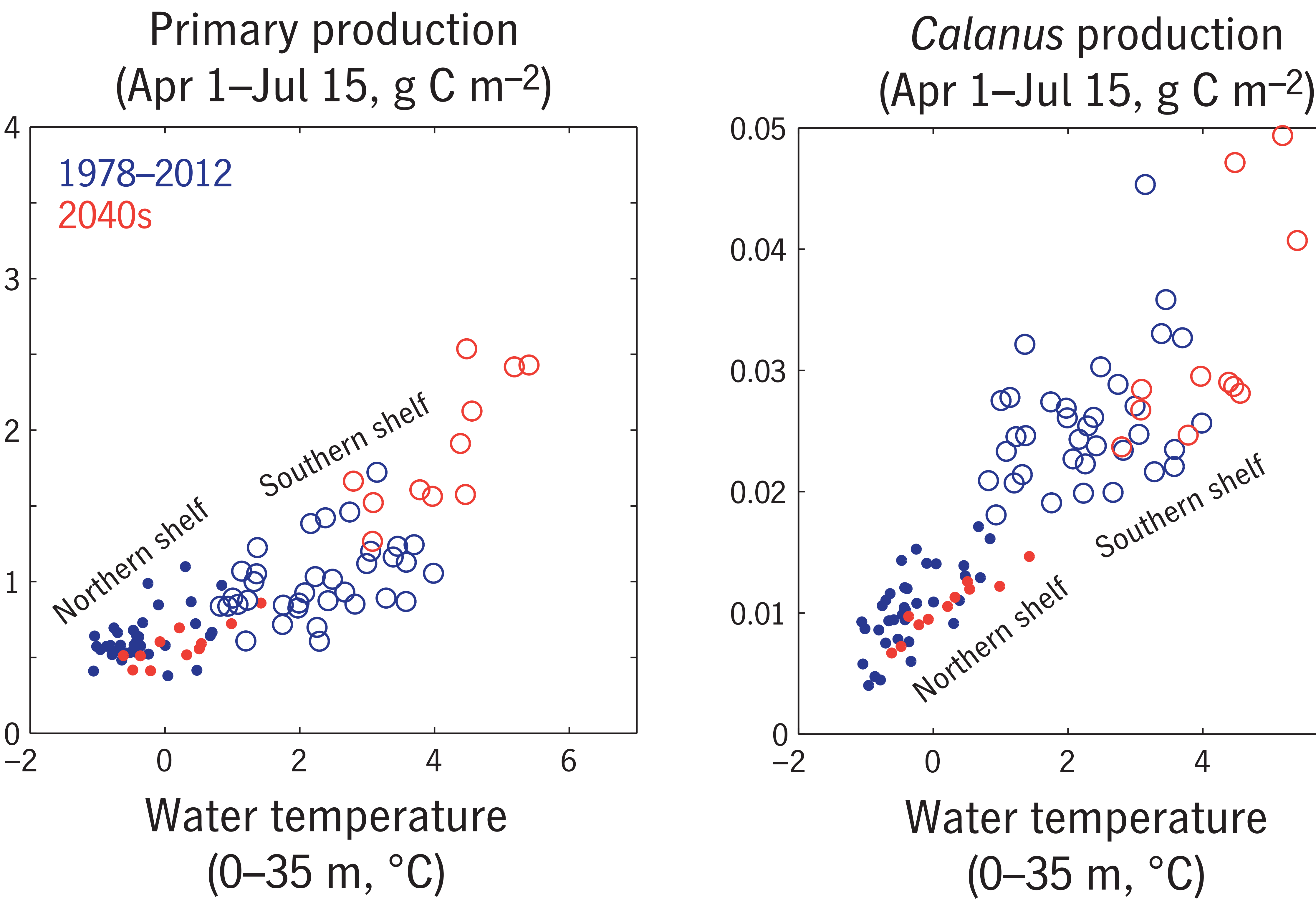
Surface and bottom temperature from AFSC groundfish surveys

BESTMAS hindcast + forecast (random resampling of hindcast + linear temperature trend, +8°C by 2100)

Validation: ice-edge bloom at 60N, spring 2009 (BEST program)







Primary production
(Apr 1–Jul 15, g C m−2)
1978–2012
2040s
Northern shelf
Southern shelf
4
3
2
1
0
−2
0
2
4
6
Water temperature
(0–35 m, °C)
Calanus production
(Apr 1–Jul 15, g C m−2)
0.05
0.04
0.03
0.02
0.01
0
Southern shelf
Northern shelf
−2
0
2
4
6
Water temperature
(0–35 m, °C)

Question 1

Do spring/summer phytoplankton dynamics (temperature, bloom timing, total production) explain why large crustacean zooplankton do better in cold years?

No! Both phytoplankton and zooplankton production are higher overall in warm years.

Question 2

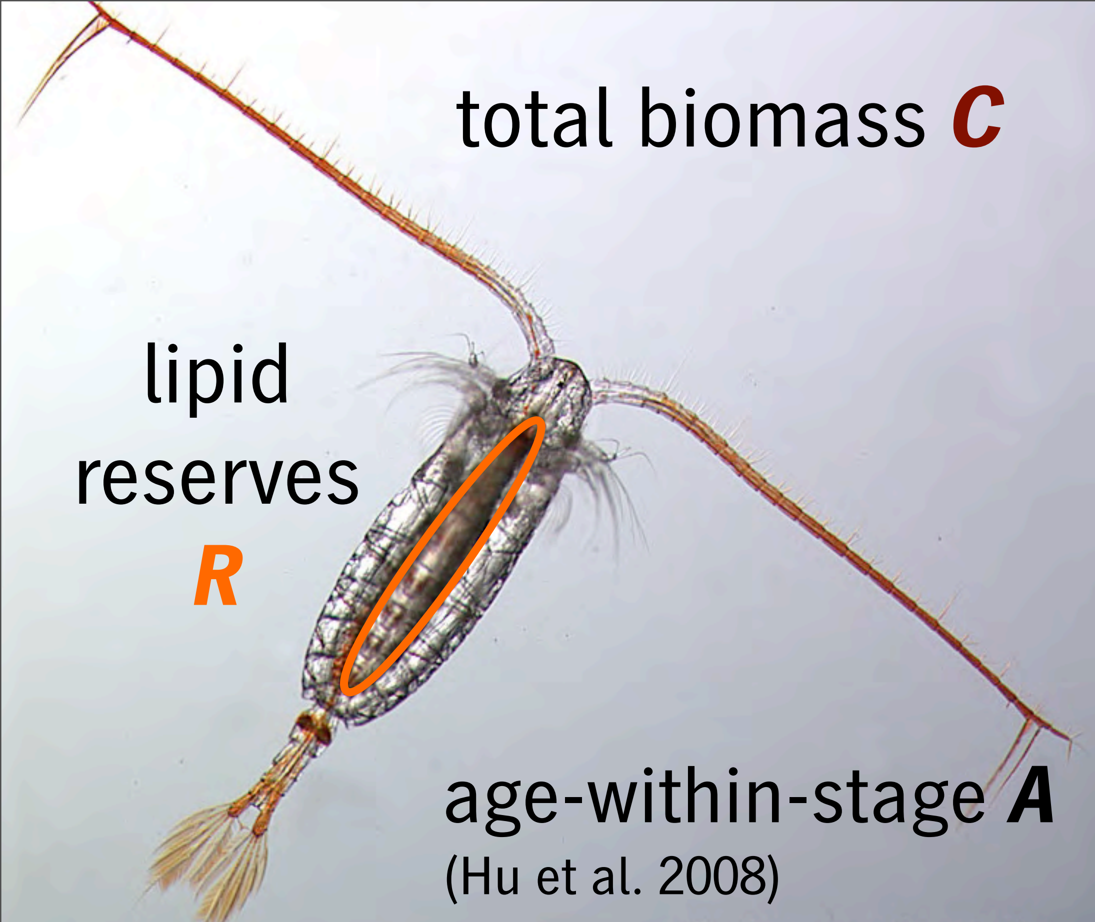
So what does?

Climate impacts on *Calanus* spp.

		cold years	**warm years**
ice cover	late winter prey availability (ice algae)		
	spring-summer prey availability	−	+
temperature	spring-summer growth & development rates		
	overwintering success		
	net effect	+	−

large copepods do better in cold years ***in spite of****, not because of, variability in total primary production*

(cf. Hunt et al. 2011)



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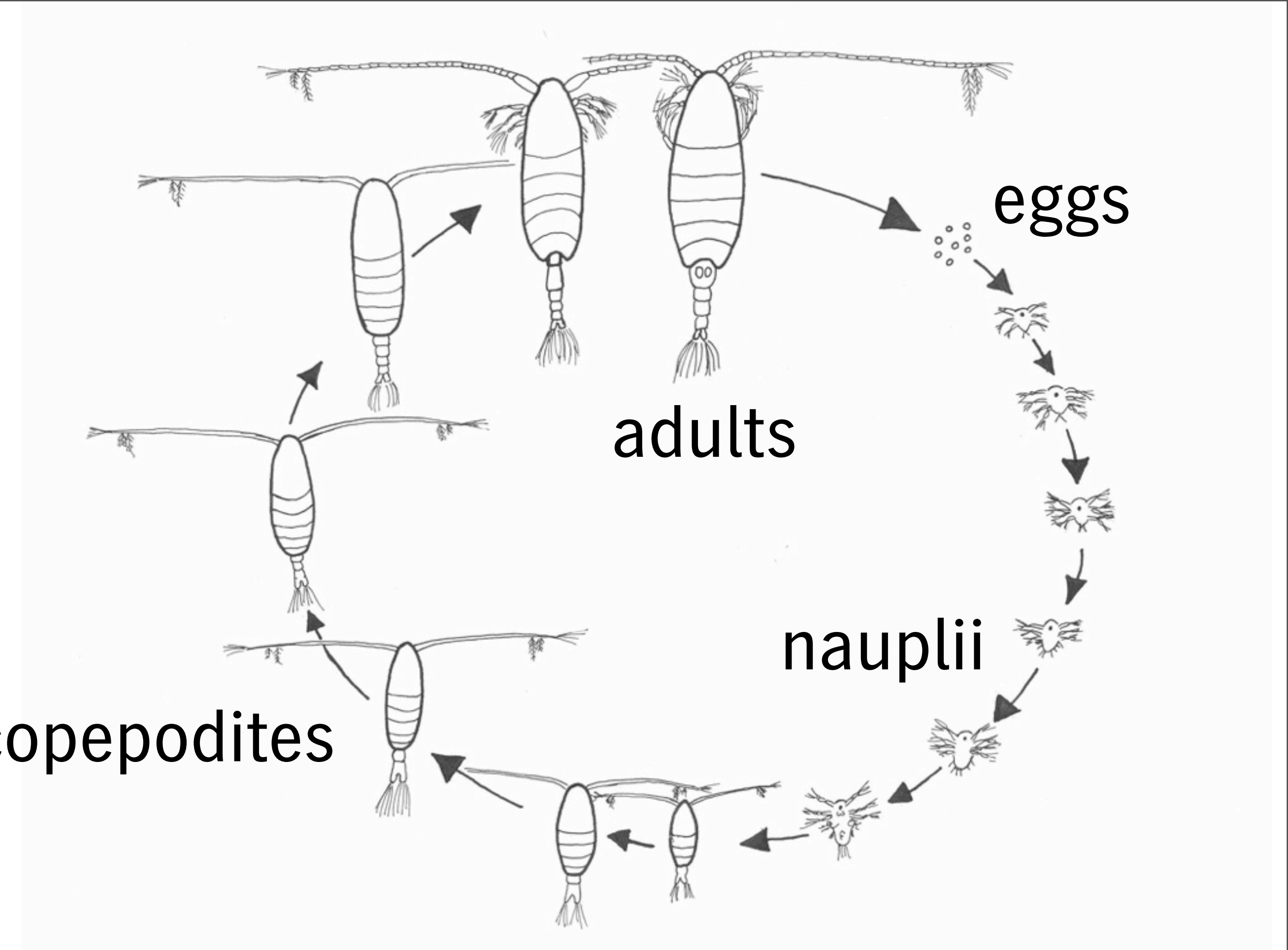


for each life stage,

d$\boldsymbol{C}$/dt = assimilation − metabolism − mortality − egg prod. + molting

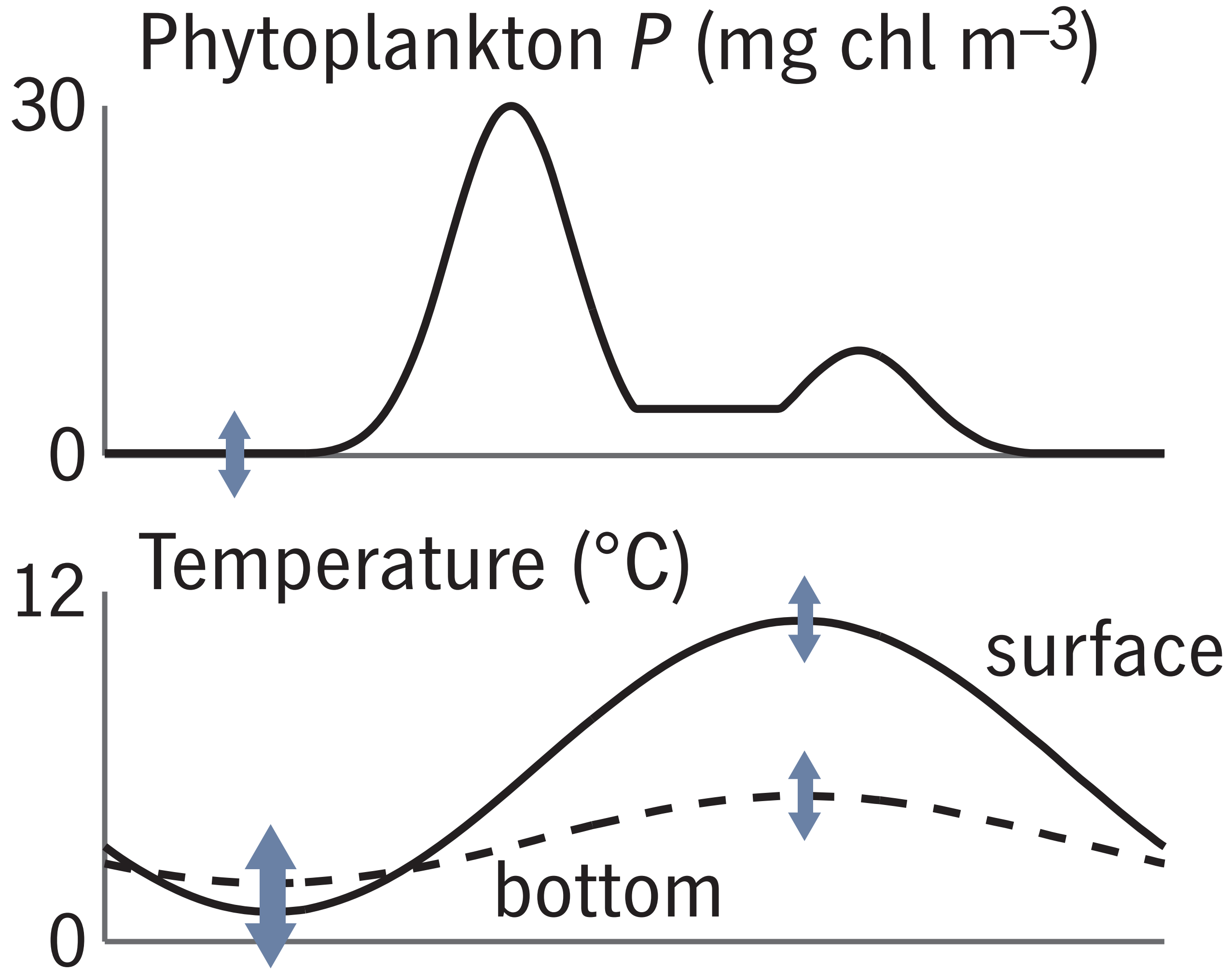
d$\boldsymbol{R}$/dt = f_S · assimilation − 1.0 · metabolism − $\boldsymbol{R}/\boldsymbol{C}$ · mortality …

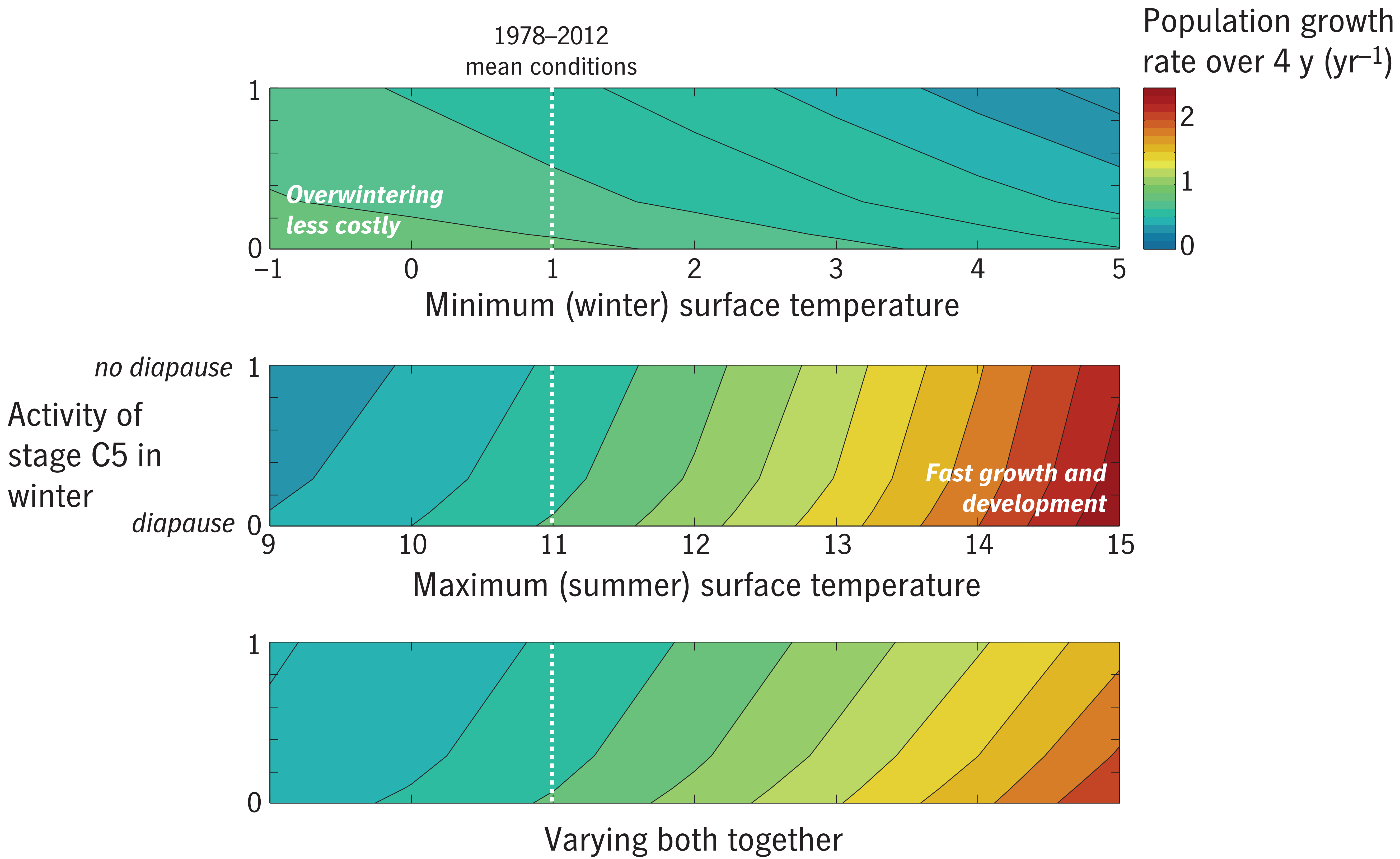
assimilation = $a\ q\ I_{max} P\ /\ (K+P)\ \boldsymbol{C}$

Q_{10} temperature dependence

life-history parameters:
lipid storage fraction
activity (diapause vs. winter grazing & reproduction)

Sensitivity experiments based on semi-idealized seasonal cycles from EcoFOCI mooring M8 (62°N, 70 m depth) (Sigler et al., submitted)





1978–2012
mean conditions
Population growth
rate over 4 y (yr−1)
2
1
0
Overwintering
less costly
1
0
−1
0
1
2
3
4
5
Minimum (winter) surface temperature
no diapause
1
Activity of
stage C5 in
winter
diapause
0
Fast growth and
development
9
10
11
12
13
14
15
Maximum (summer) surface temperature
1
0
Varying both together

Climate impacts on *Calanus* spp.

		cold years	warm years
ice cover	late winter prey availability (ice algae)		
	spring-summer prey availability	−	+
temperature	spring-summer growth & development rates	−	+
	overwintering success	+	−
	net effect	+	−

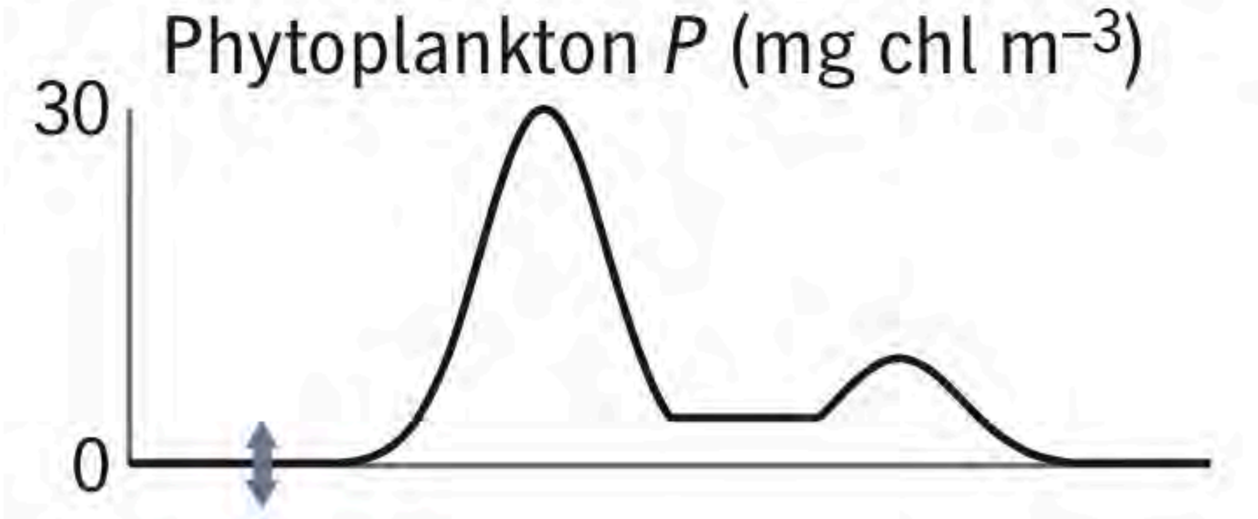
Climate impacts on *Calanus* spp.

		cold years	**warm years**
ice cover	late winter prey availability (ice algae)	+	−
ice cover	spring-summer prey availability	−	+
temperature	spring-summer growth & development rates	−	+
temperature	overwintering success	+	−
	net effect	+	−

HYPOTHESIZED (applies to late winter prey availability (ice algae))

Maybe timing is everything.

In other high-latitude systems, early reproduction in time to match juveniles with the spring bloom is crucial for copepods (Varpe et al. 2007)



winter phytoplankton concentration (mg chl m^{-3})	start of egg production (yearday)	egg production per unit biomass (yr^{-1})	*Calanus* population growth over 4 y (yr^{-1})
0.01	104	1.0	**0.4**
0.2	97	0.8	**0.8**
0.5	89	0.5	**1.6**
1.0	86	0.3	**2.9**

Question 2

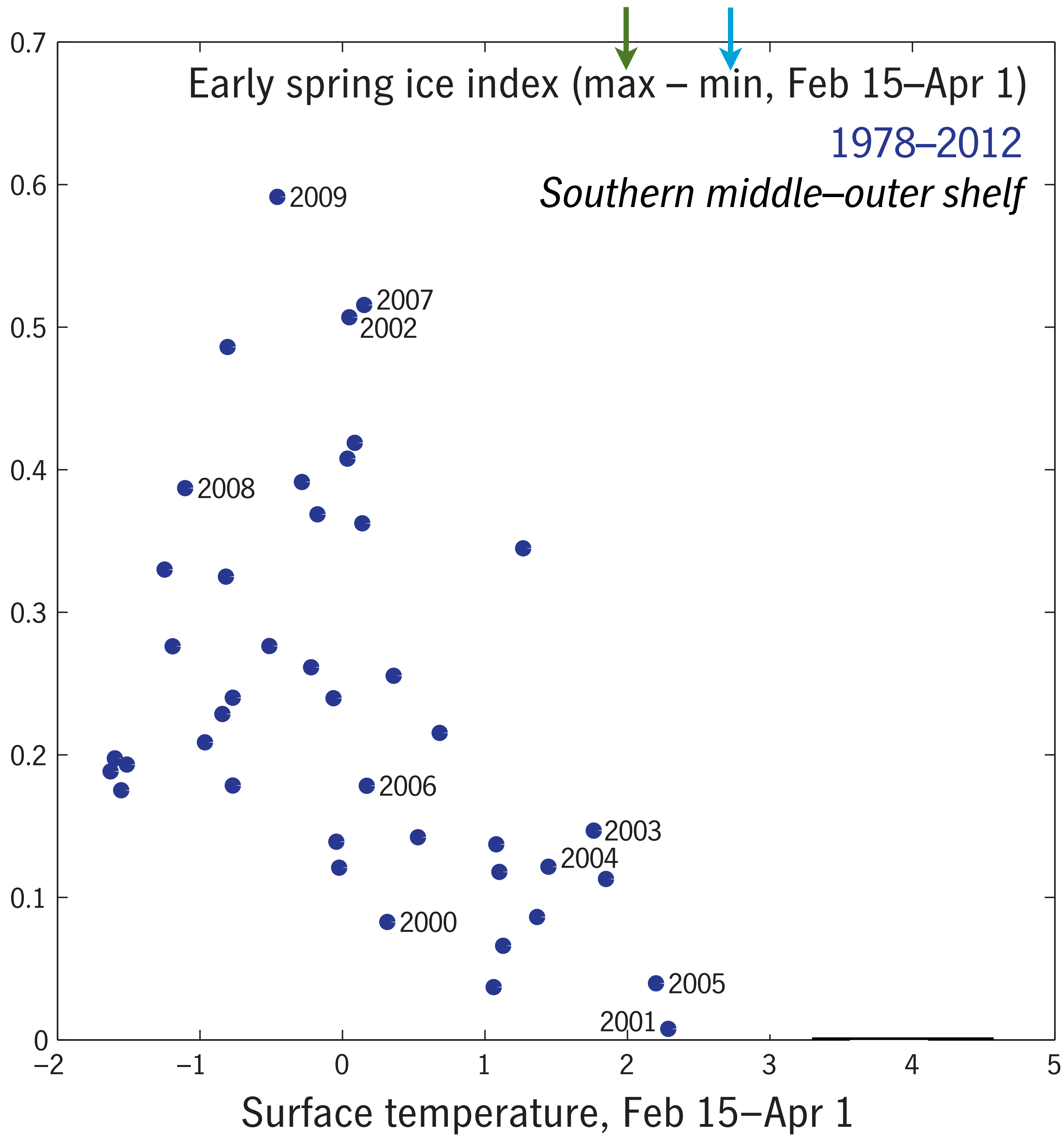
So if spring/summer phytoplankton dynamics don't explain why large crustacean zooplankton do better in cold years, what does?

Prey availability before the spring bloom (and its effect on reproductive timing) is the most plausible hypothesis—moreso than direct temperature effects.

Question 3

What does all this mean for a warmer future?

Hypothesis: Large crustacean zooplankton need ice algae to be **produced** and also **released** in late winter/early spring



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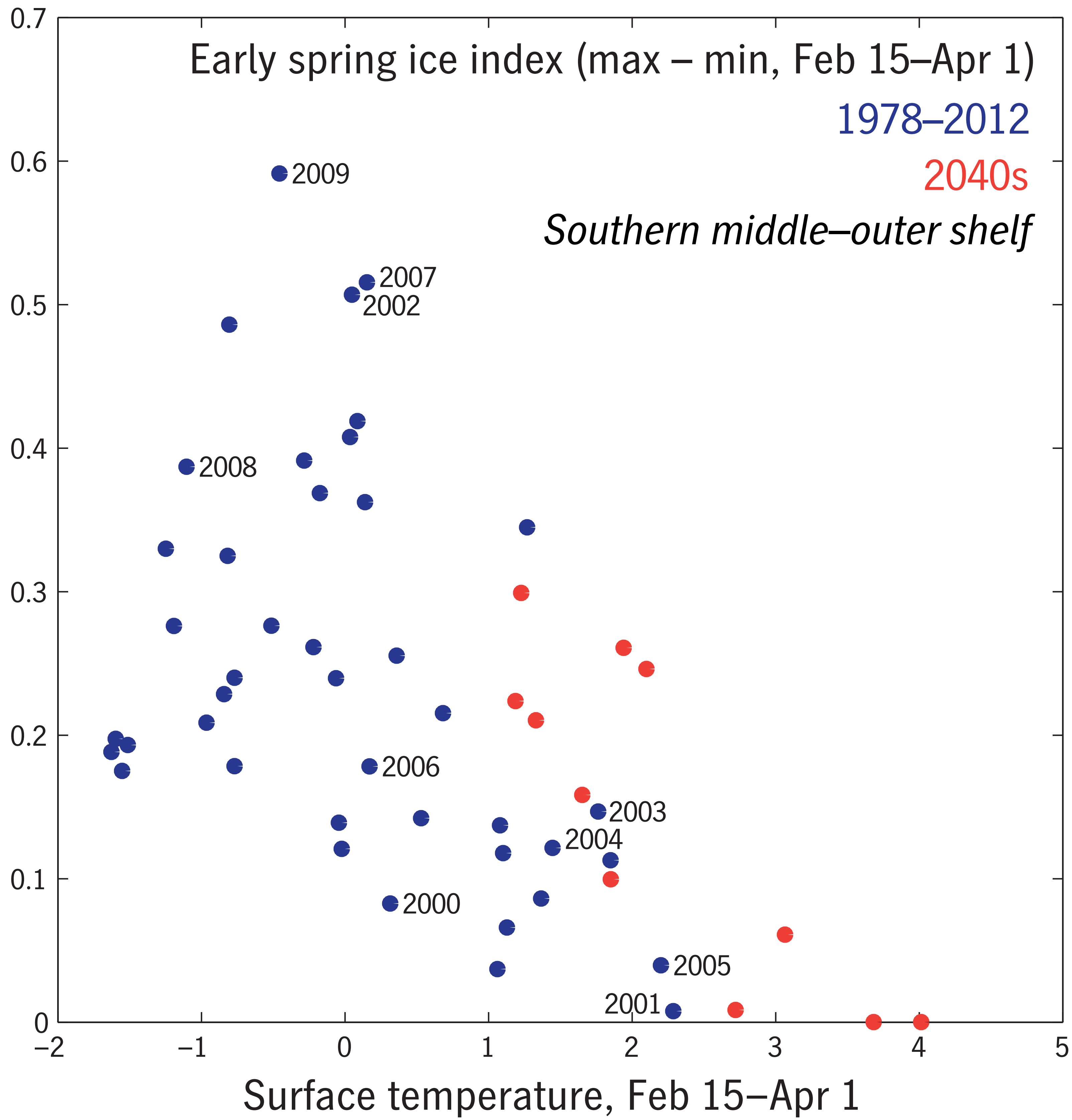

Question 3

What does all this mean for the future?

Broadly speaking, these models suggest that plankton and pollock recruitment in an average year in the 2040s will resemble the warm years of the 2000s (which were very bad for pollock recruitment)…

…but the news is not nearly as bad as a direct extrapolation from present-day correlations with temperature would suggest.