From climate to top predators via a diverse, adaptable plankton community: new model approaches

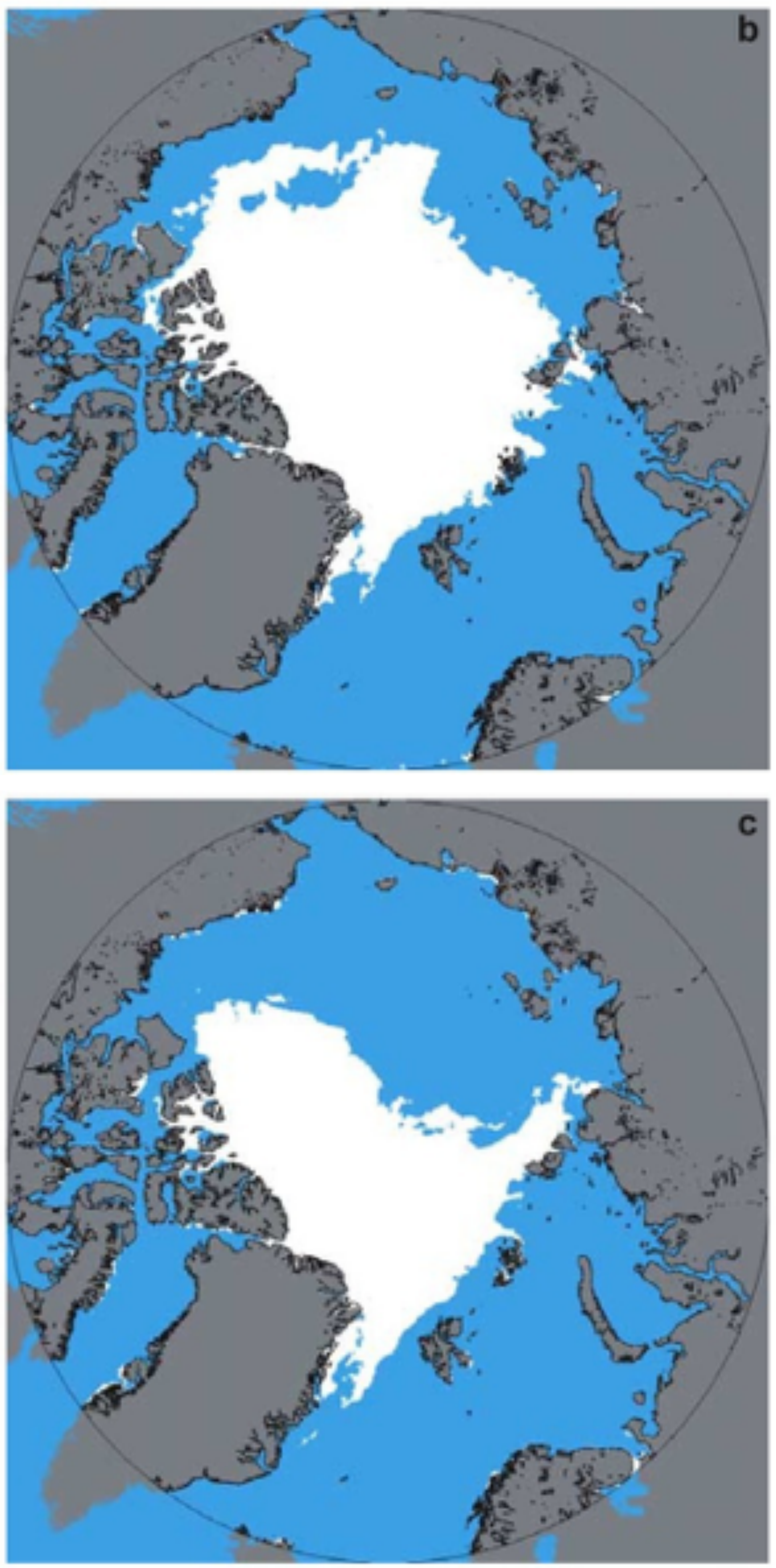
Neil Banas

Univ of Strathclyde, Glasgow

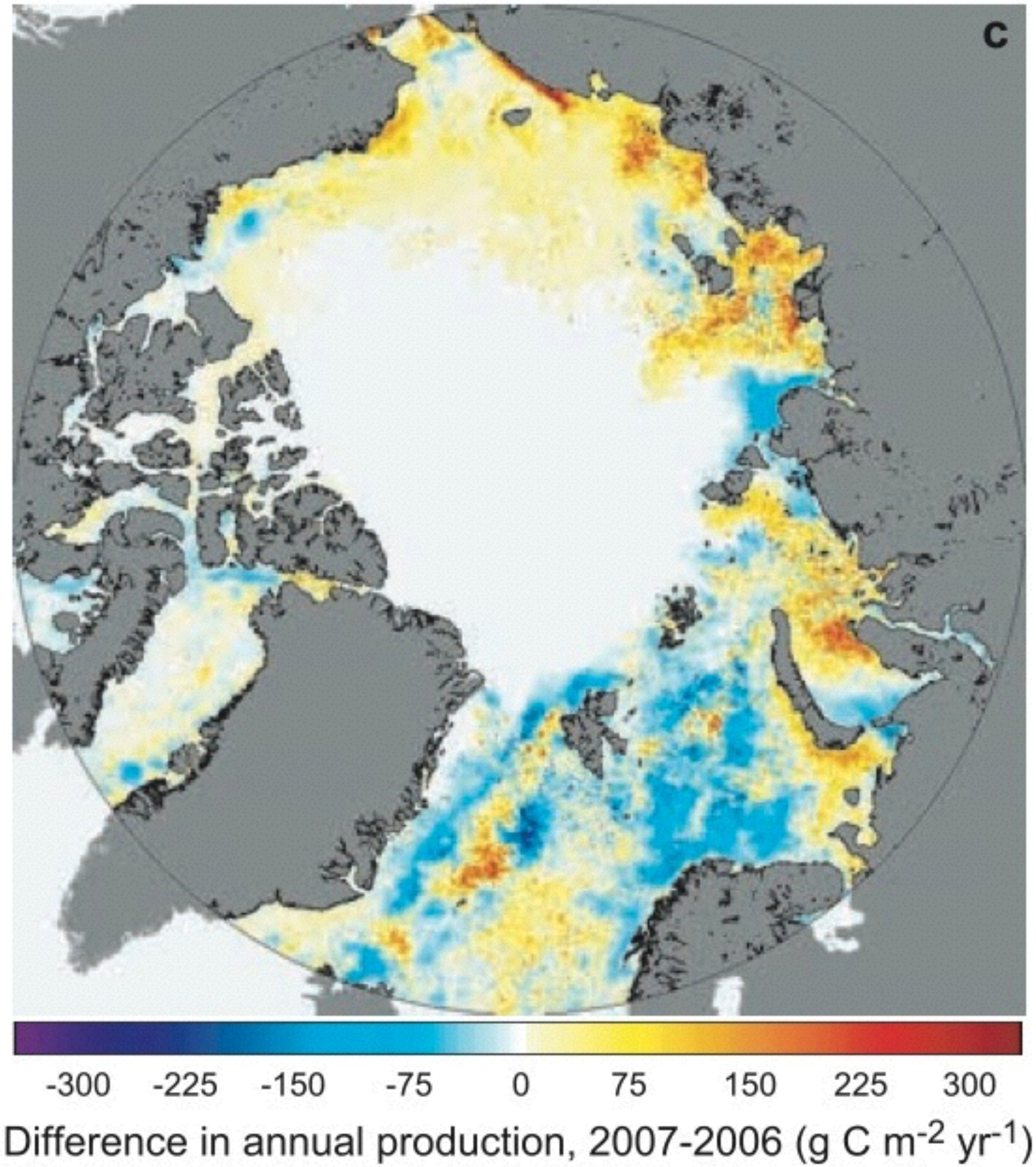
Arrigo et al. (2008) "Impact of a shrinking Arctic ice cover on marine primary production"

sea ice extent

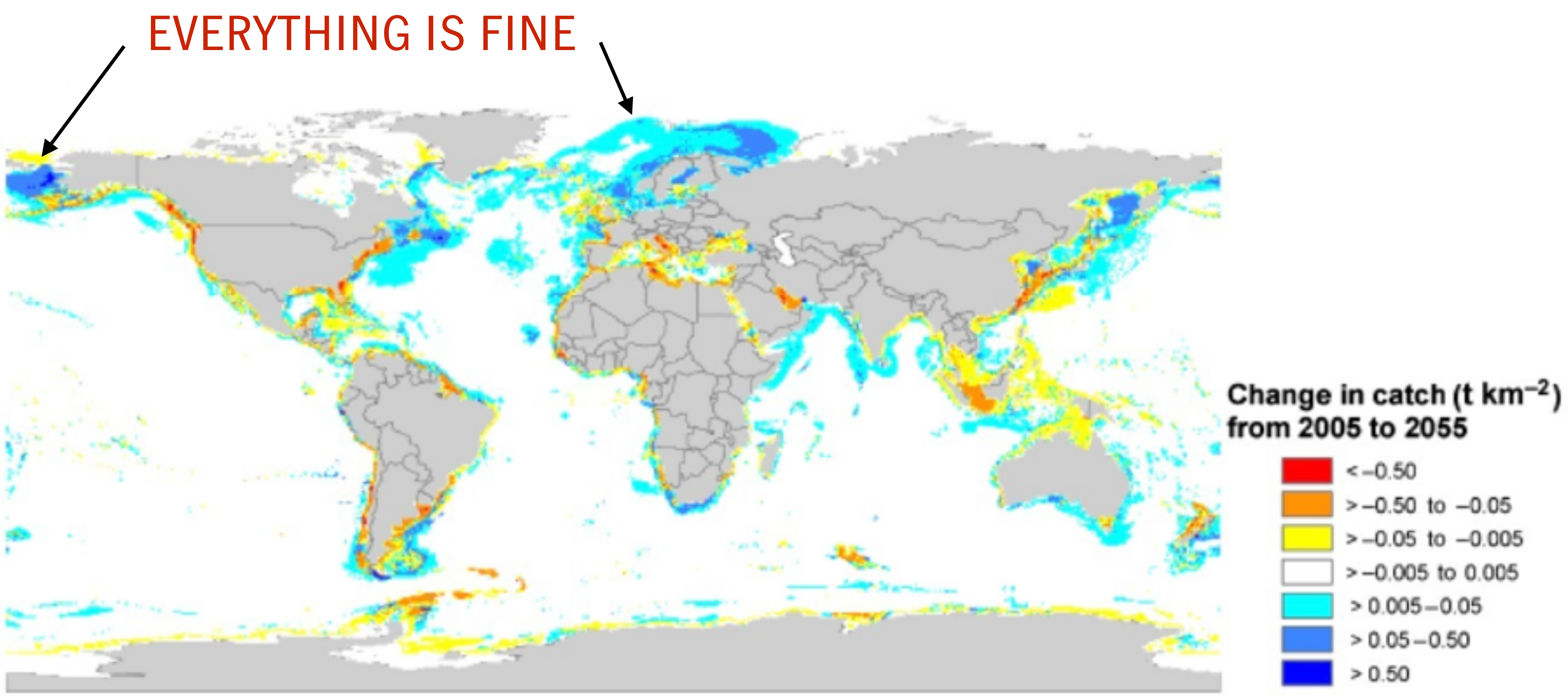
Minimum sea ice extent, 2006

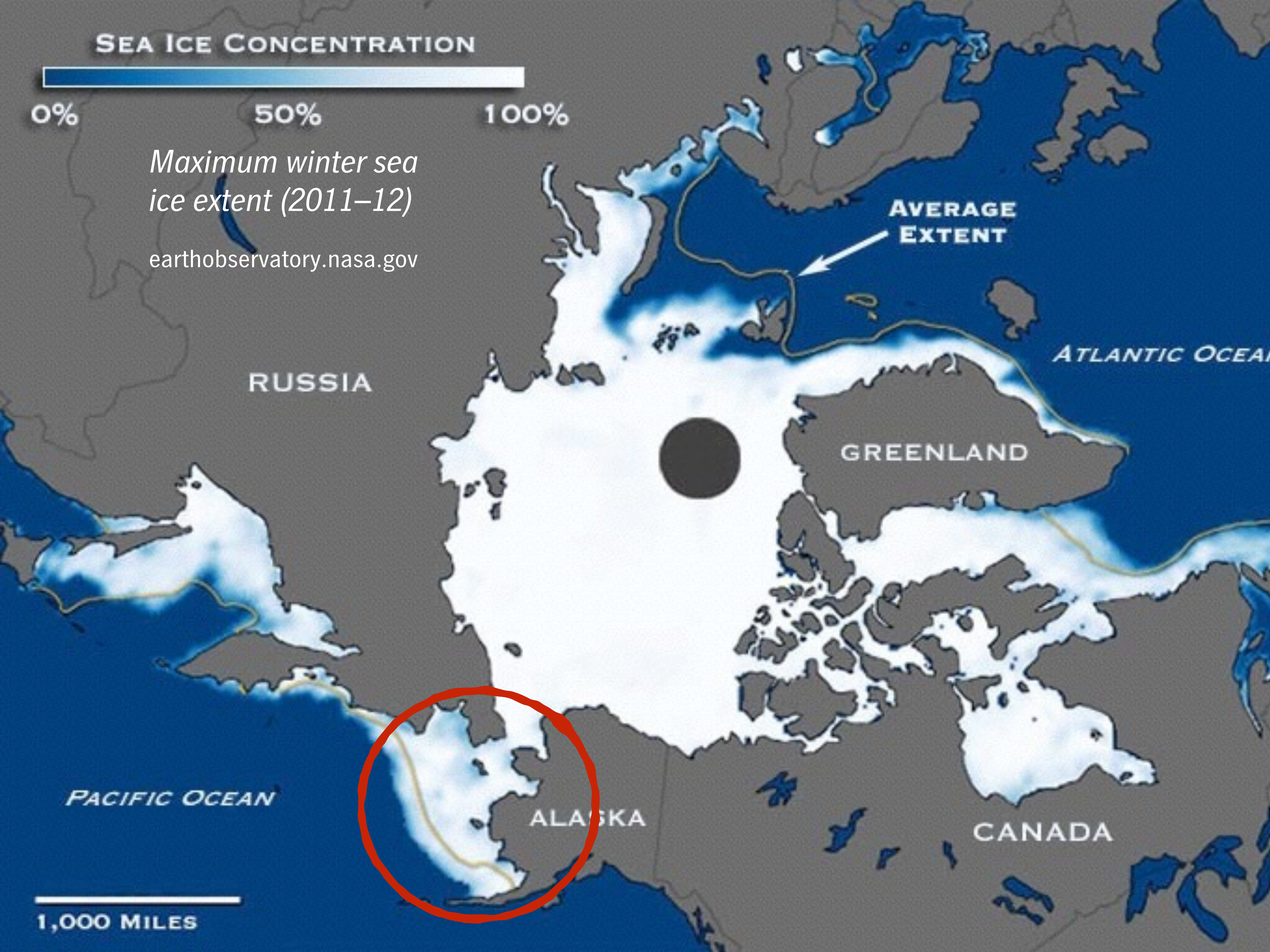


Minimum sea ice extent, 2007

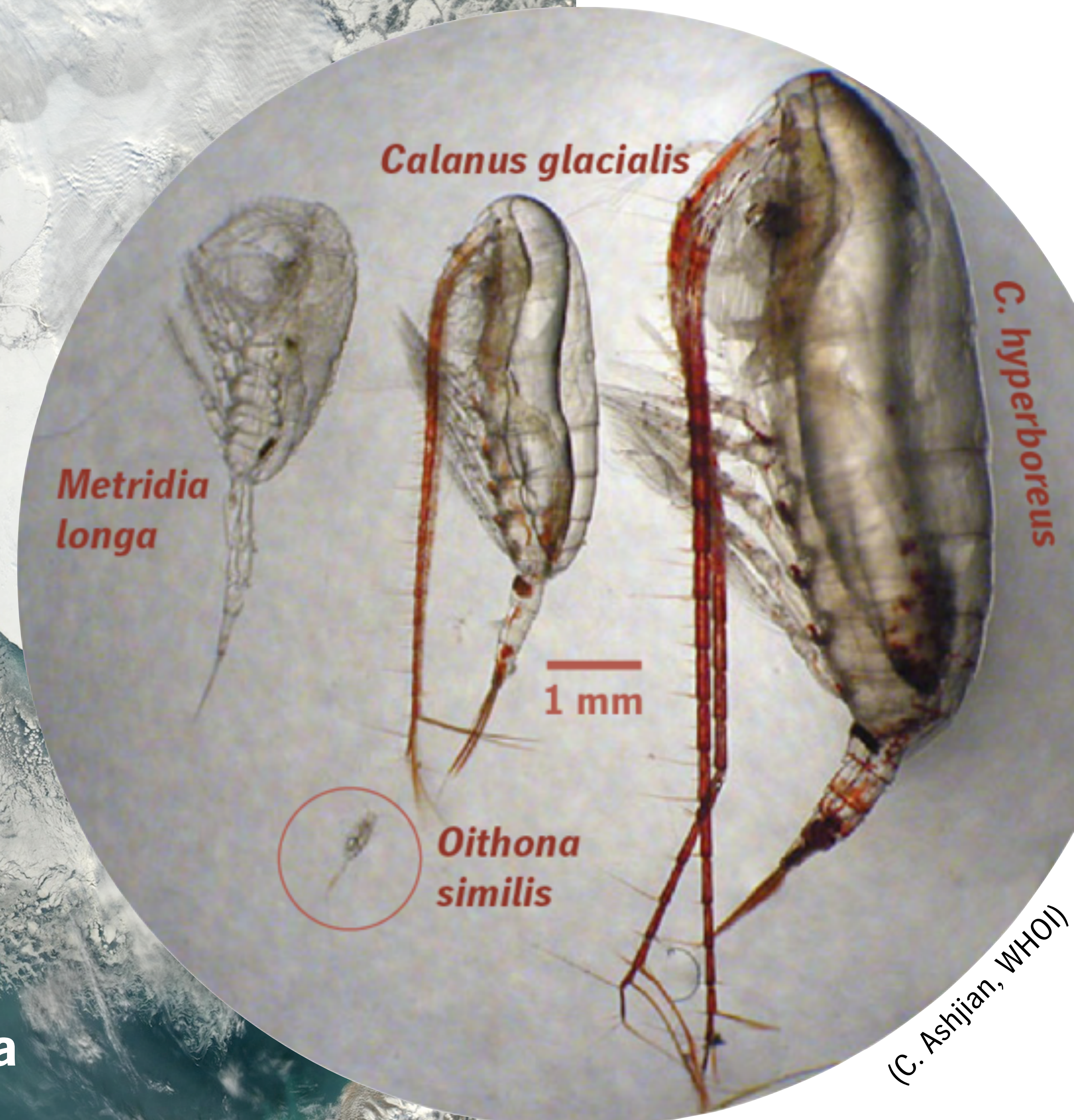


Cheung et al. (2010), “Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change”





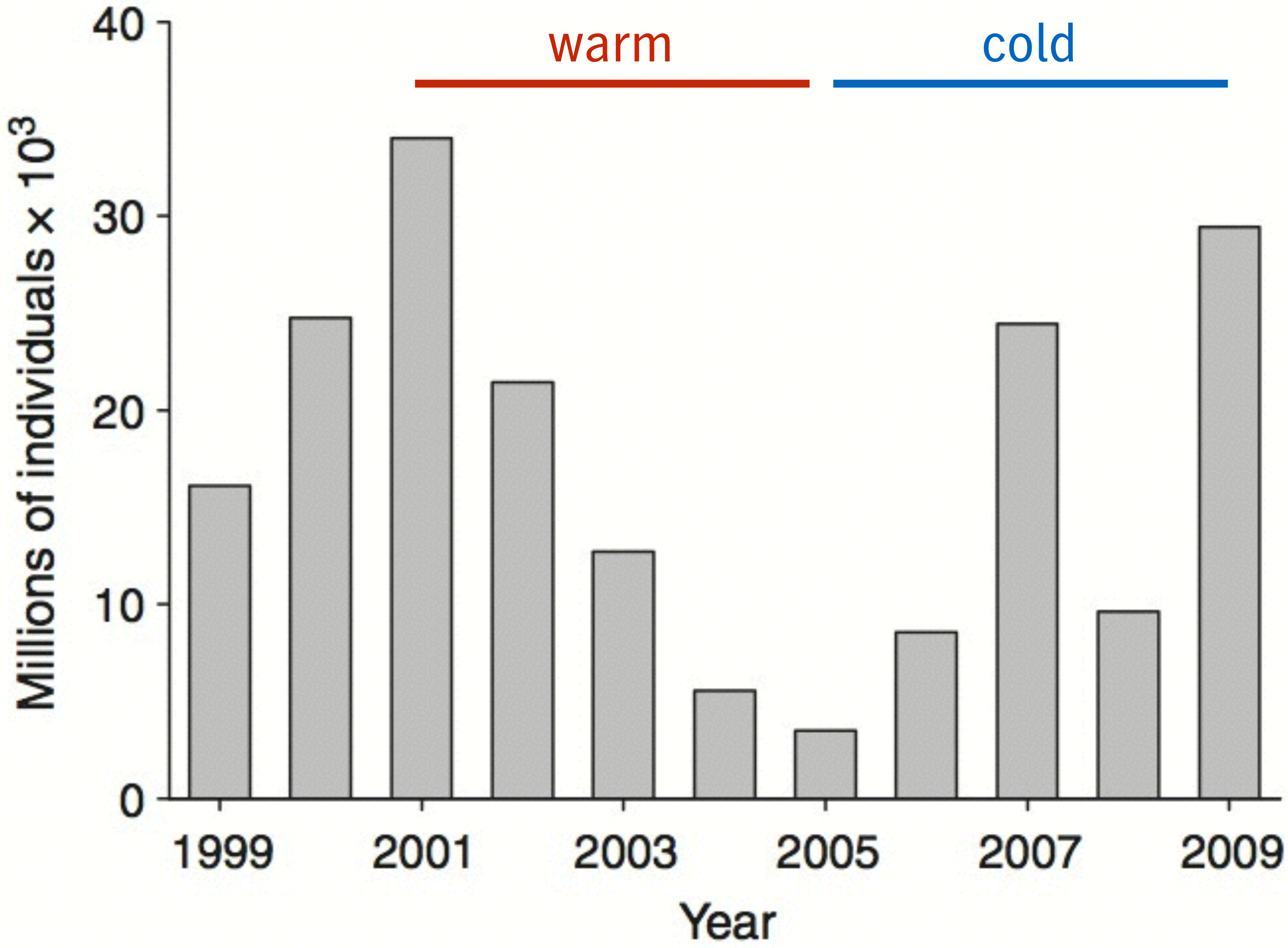
Sea Ice Concentration
0%
50%
100%
Maximum winter sea ice extent (2011–12)
earthobservatory.nasa.gov
Average Extent
Atlantic Ocea
Russia
Greenland
Pacific Ocean
Alaska
Canada
1,000 Miles



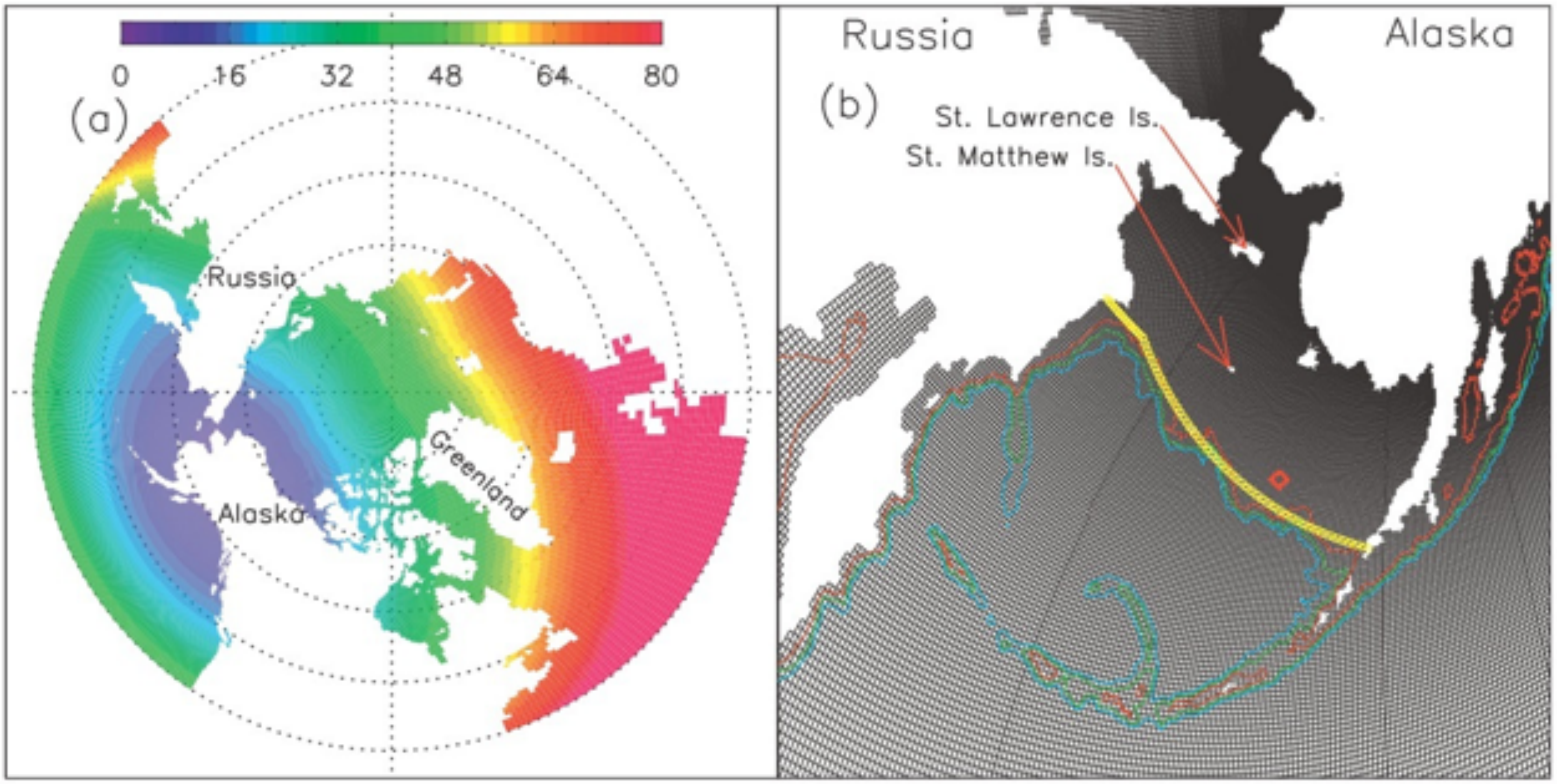
(C. Ashijian, WHOI)

Year-to-year variability in Bering Sea pollock (a $1Bn/yr fishery) has been linked to variation in the <u>composition</u> of their zooplankton prey: large, lipid-rich species are associated with cold, icy conditions

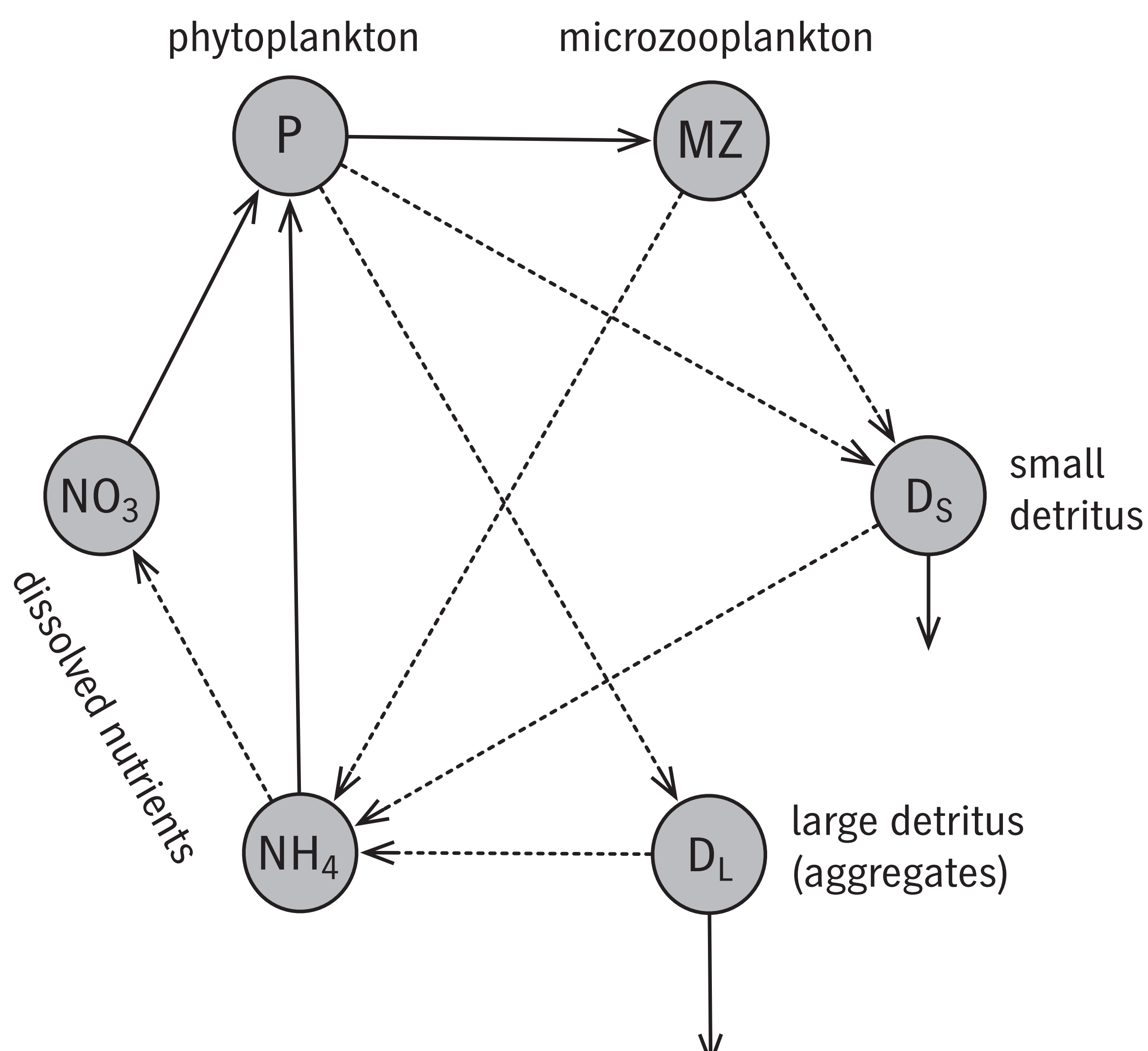
Figure 12. Age-1 pollock (*Theragra chalcogramma*) recruitment on the eastern Bering Sea shelf during the study period (Table 1.22 in Ianelli *et al.*, 2009).



Coyle et al. 2011

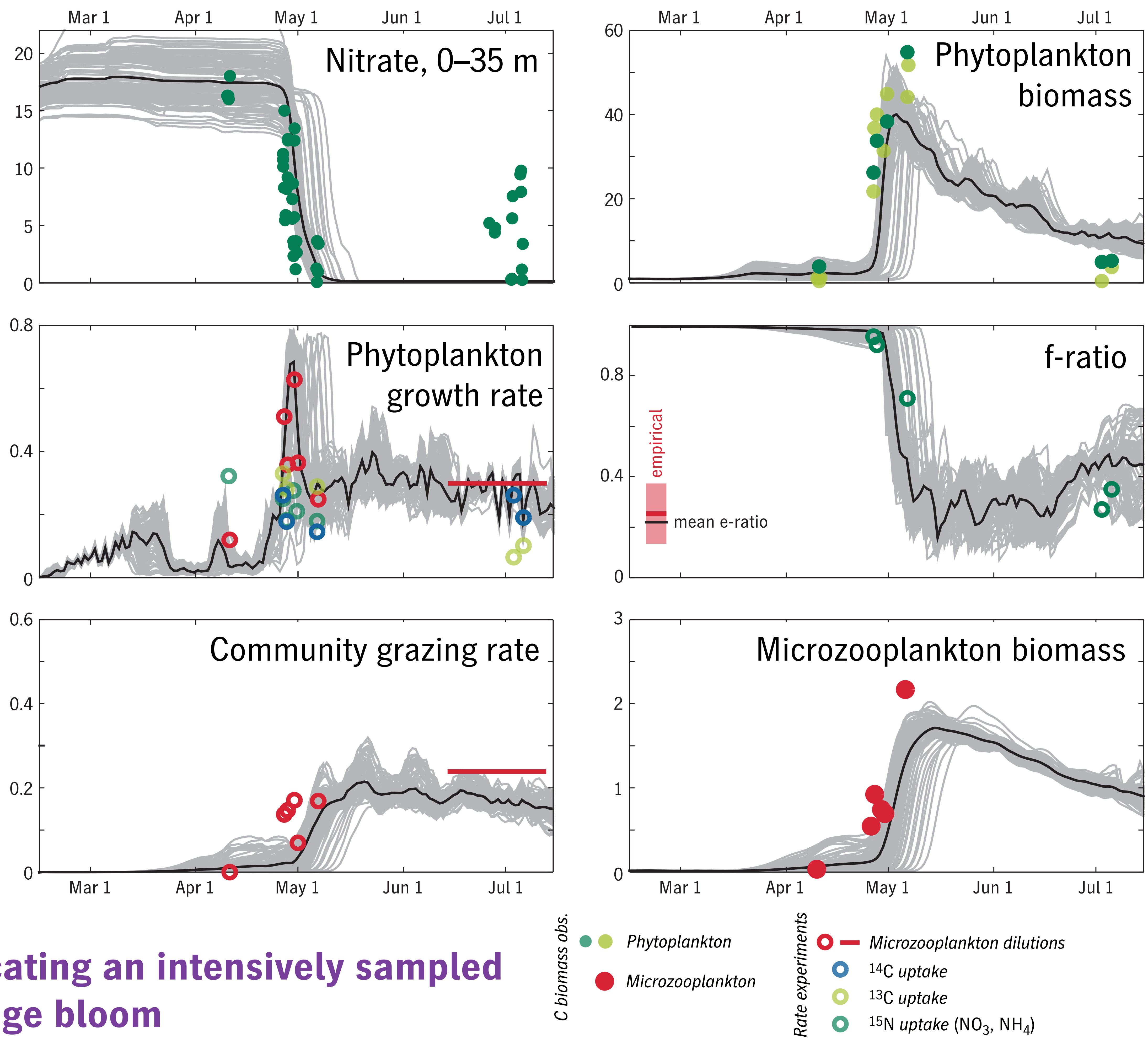


BESTMAS model
(Zhang et al. 2010)



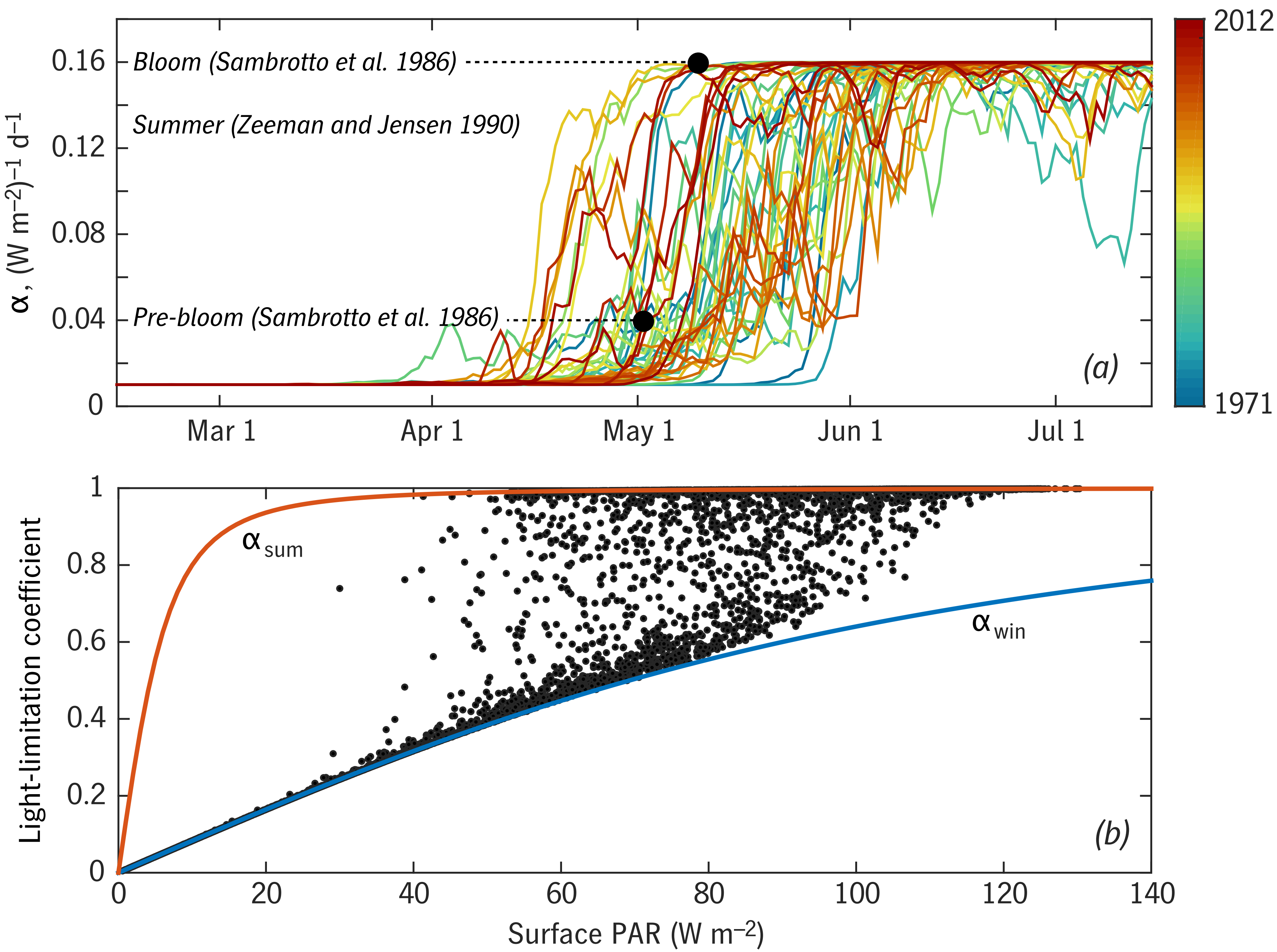
\+ *custom NPZ model*
(Banas et al., submitted)

\+ *four special issues' worth of results from a huge, multi-disciplinary field program (BEST/BSIERP, 2007–10)*



Replicating an intensively sampled ice-edge bloom

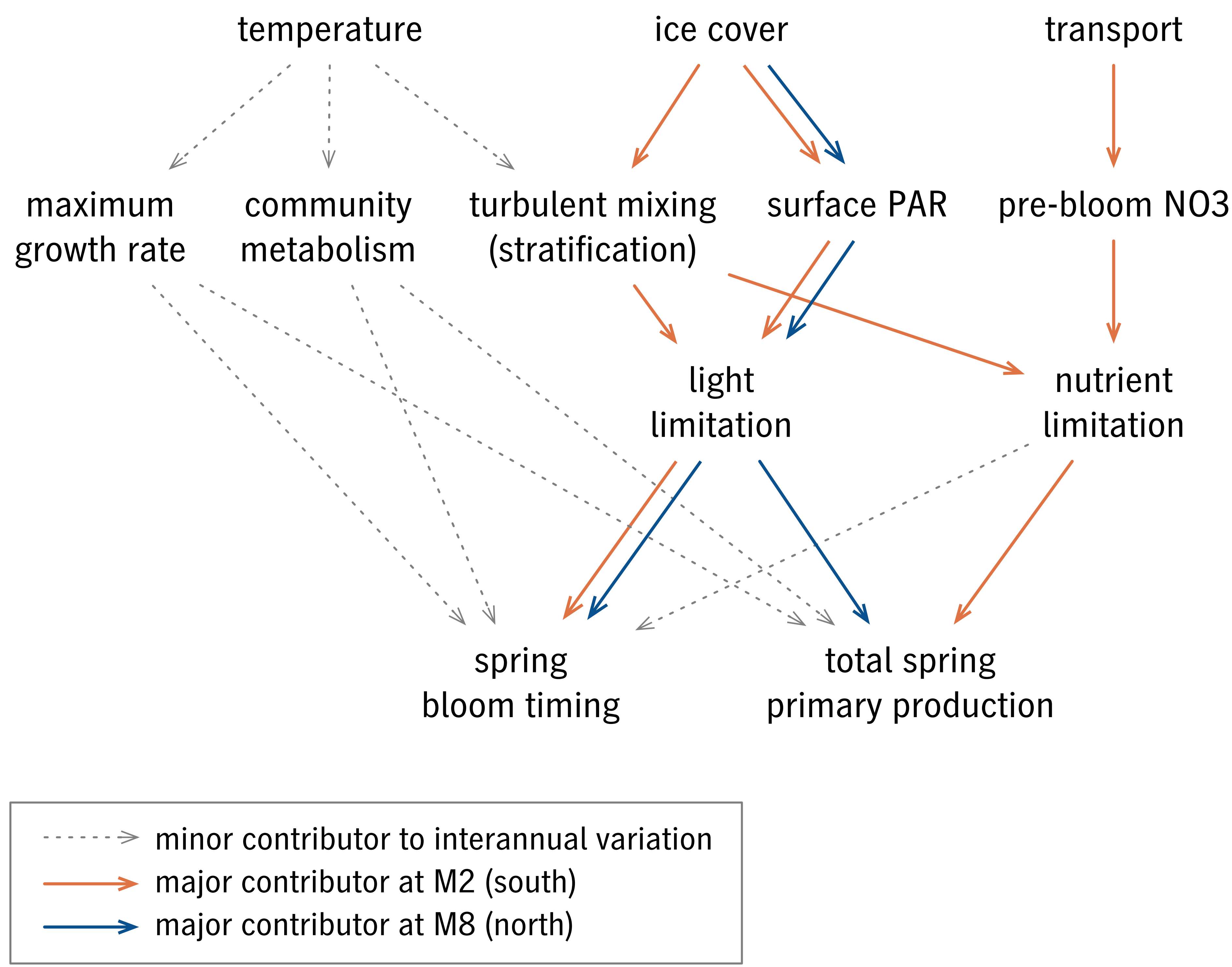
~200,000 model variants later:
the observed magnitude of the spring bloom (huge) and observed timing of the spring bloom (not especially early) are only possible if the phytoplankton community is **less light-sensitive when light is low**. This raises more questions than it answers!



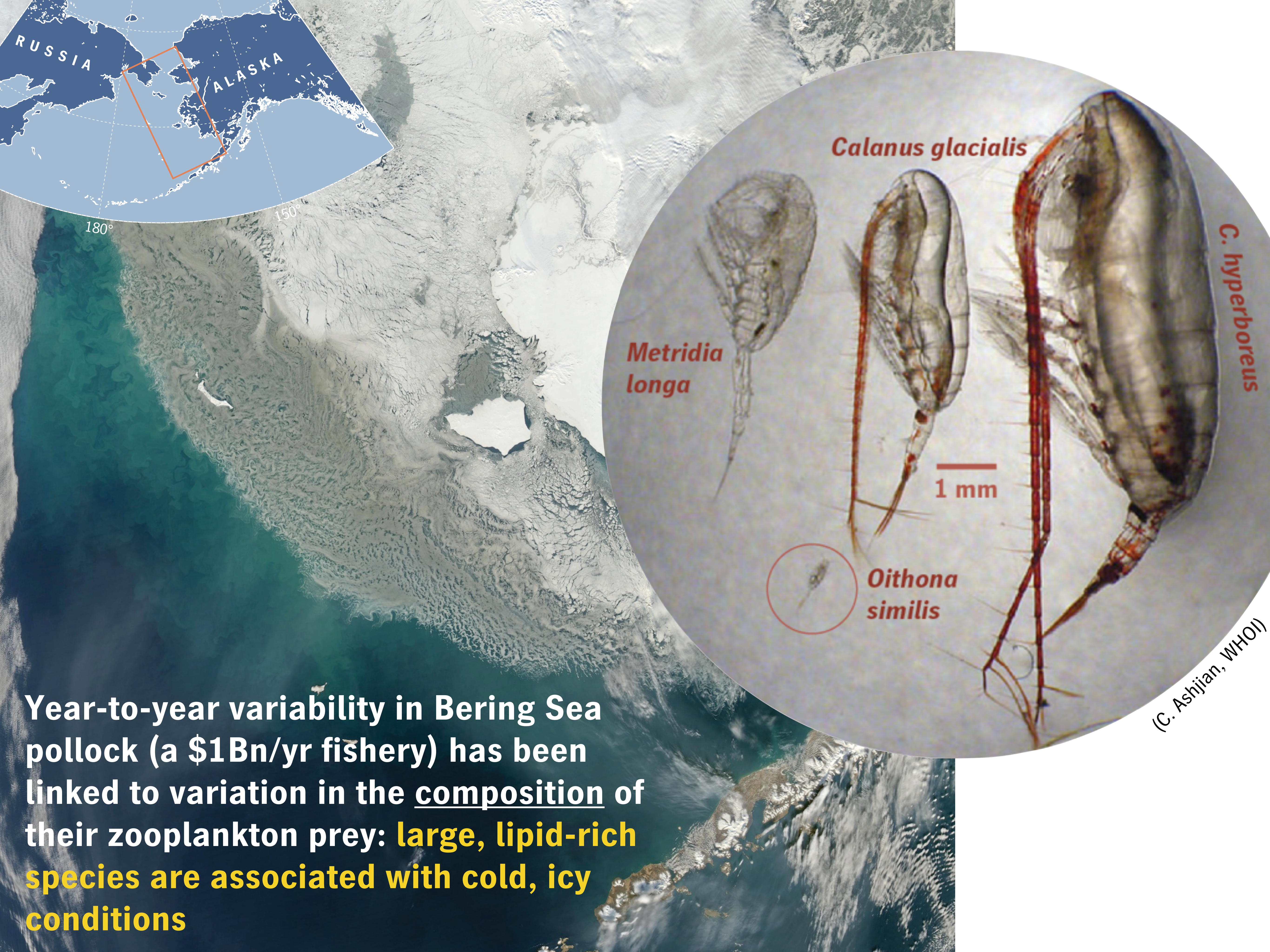
Major results from the Bering NPZ model:

1) Primary production is *higher* in warm, low-ice years (opposite the pattern in the large zooplankton)
2) Variations in *total primary production* (Feb–Jul) and variations in the *timing* of the spring bloom are *independent, uncorrelated* in the south

(Given this, what do we really need to know about primary production and climate?)

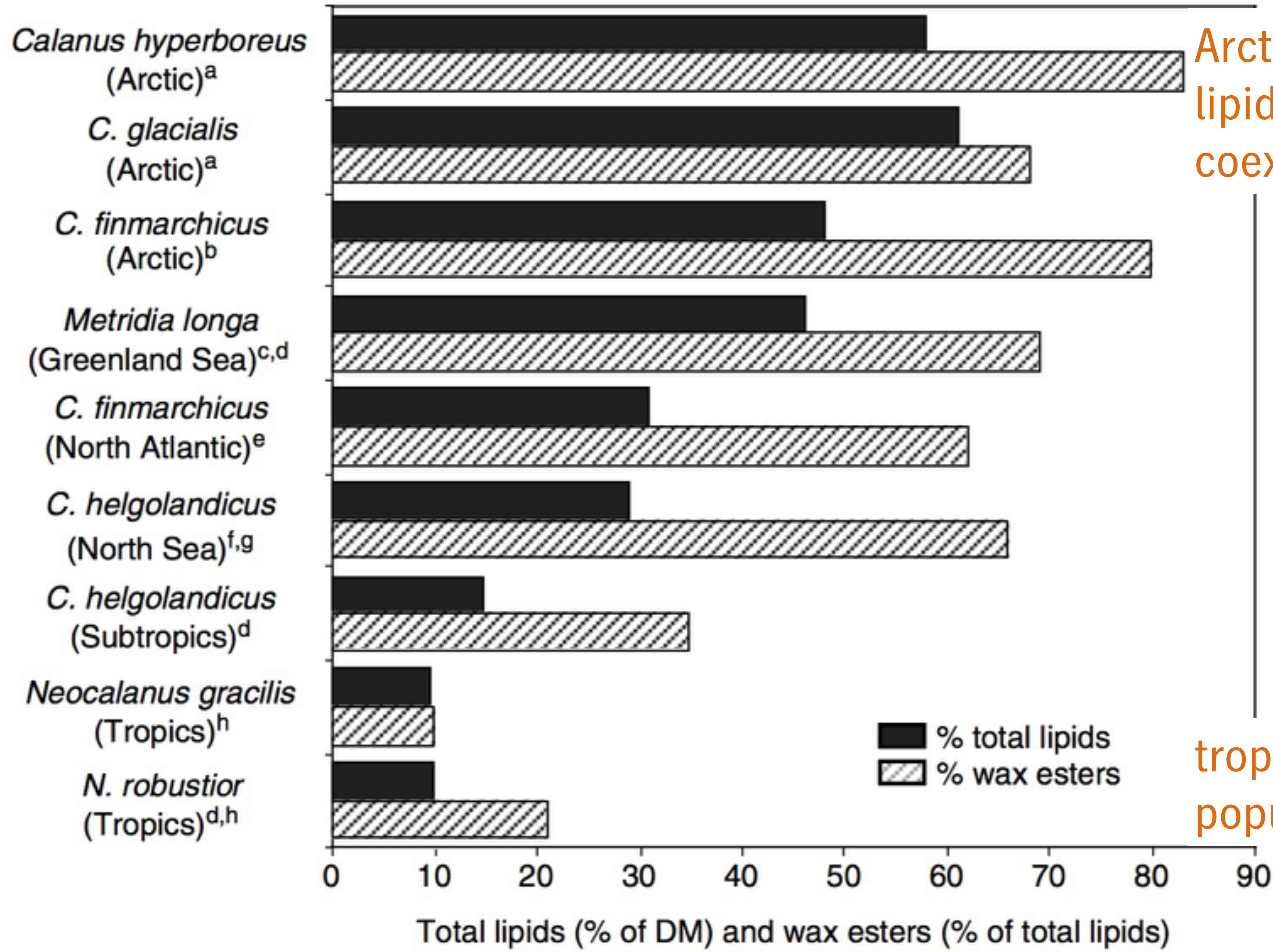


temperature
ice cover
transport
maximum growth rate
community metabolism
turbulent mixing (stratification)
surface PAR
pre-bloom NO3
light limitation
nutrient limitation
spring bloom timing
total spring primary production
minor contributor to interannual variation
major contributor at M2 (south)
major contributor at M8 (north)



Year-to-year variability in Bering Sea pollock (a $1Bn/yr fishery) has been linked to variation in the composition of their zooplankton prey: large, lipid-rich species are associated with cold, icy conditions

 (2008)



Arctic: very large, very lipid-rich populations coexist with small ones

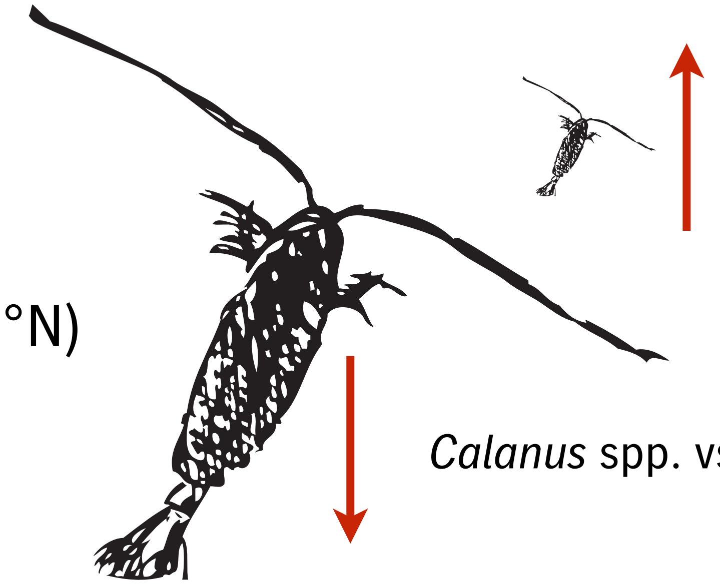
tropics: small, lipid-poor populations only

Fig. 11.1 General trends of total lipid content (% of dry mass) and wax esters (% of total lipids) of large copepod species (CV to females) from the Arctic to the tropics. Data compiled from [a]Lee et al. (2006), [b]Hagen (unpublished data), [c]Lee (1975), [d]Lee et al. (1971), [e]Jónasdóttir (1999), [f]Gatten et al. (1979), [g]Kattner and Krause (1989), [h]Kattner (unpublished data)

(note: species ≠ lipid composition)

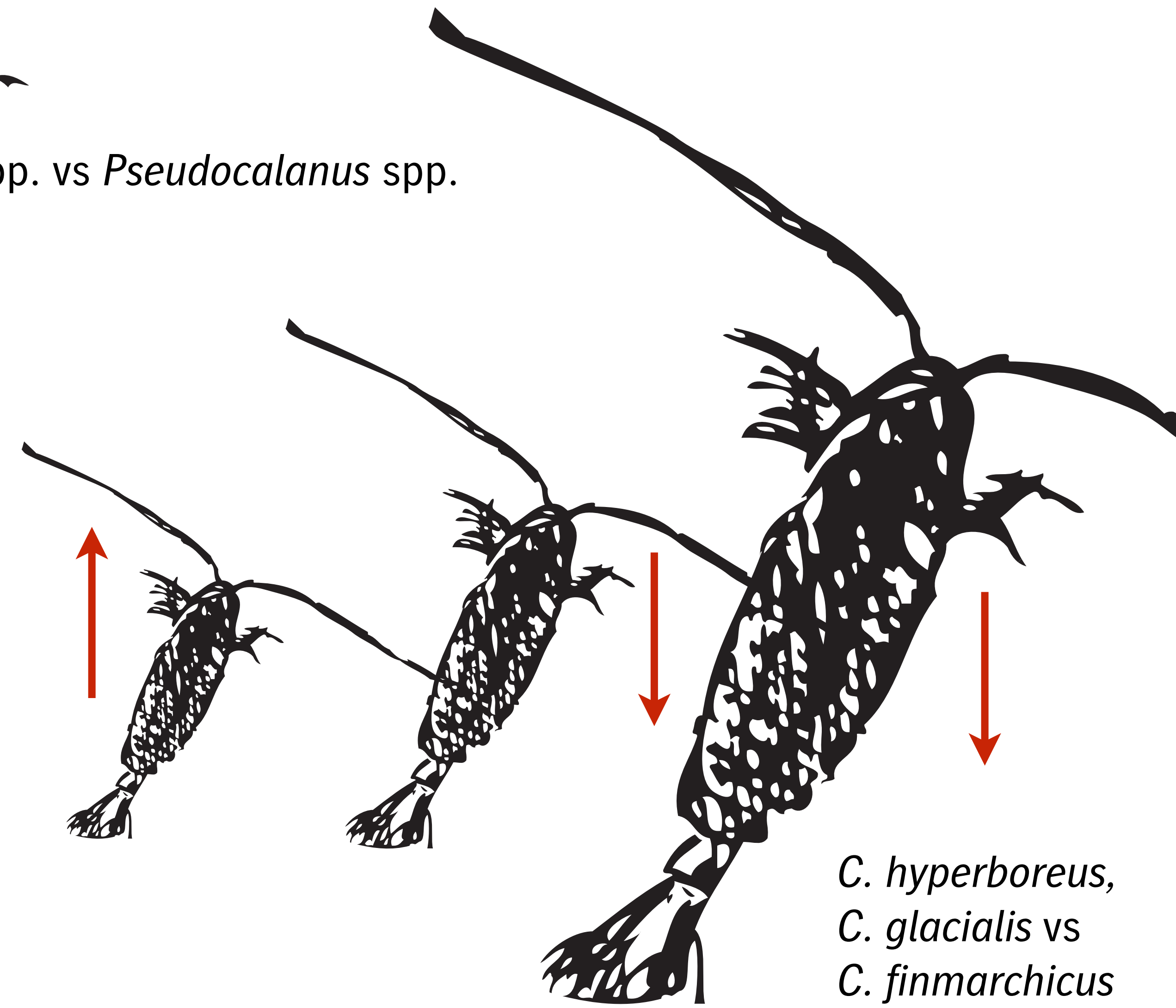
Region-specific shifts in zooplankton community composition

Bering Sea (60°N)
warm years;
US Pacific Northwest (45°N)
warm decades

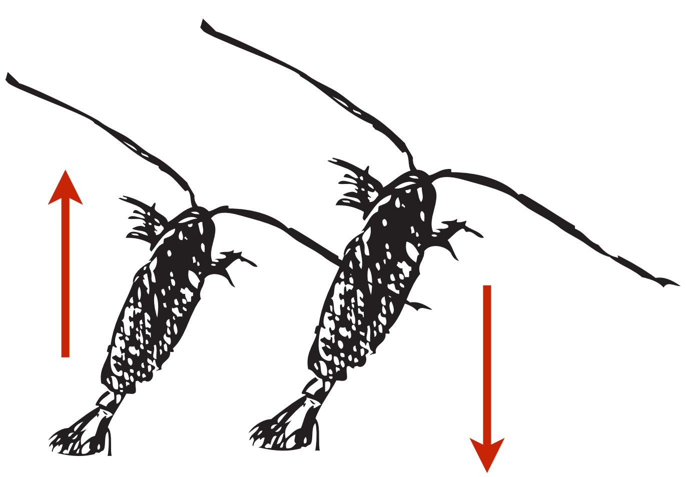


Calanus spp. vs *Pseudocalanus* spp.

Disko Bay, West Greenland
warm deep-water intrusions in 2000s



C. hyperboreus,
C. glacialis vs
C. finmarchicus

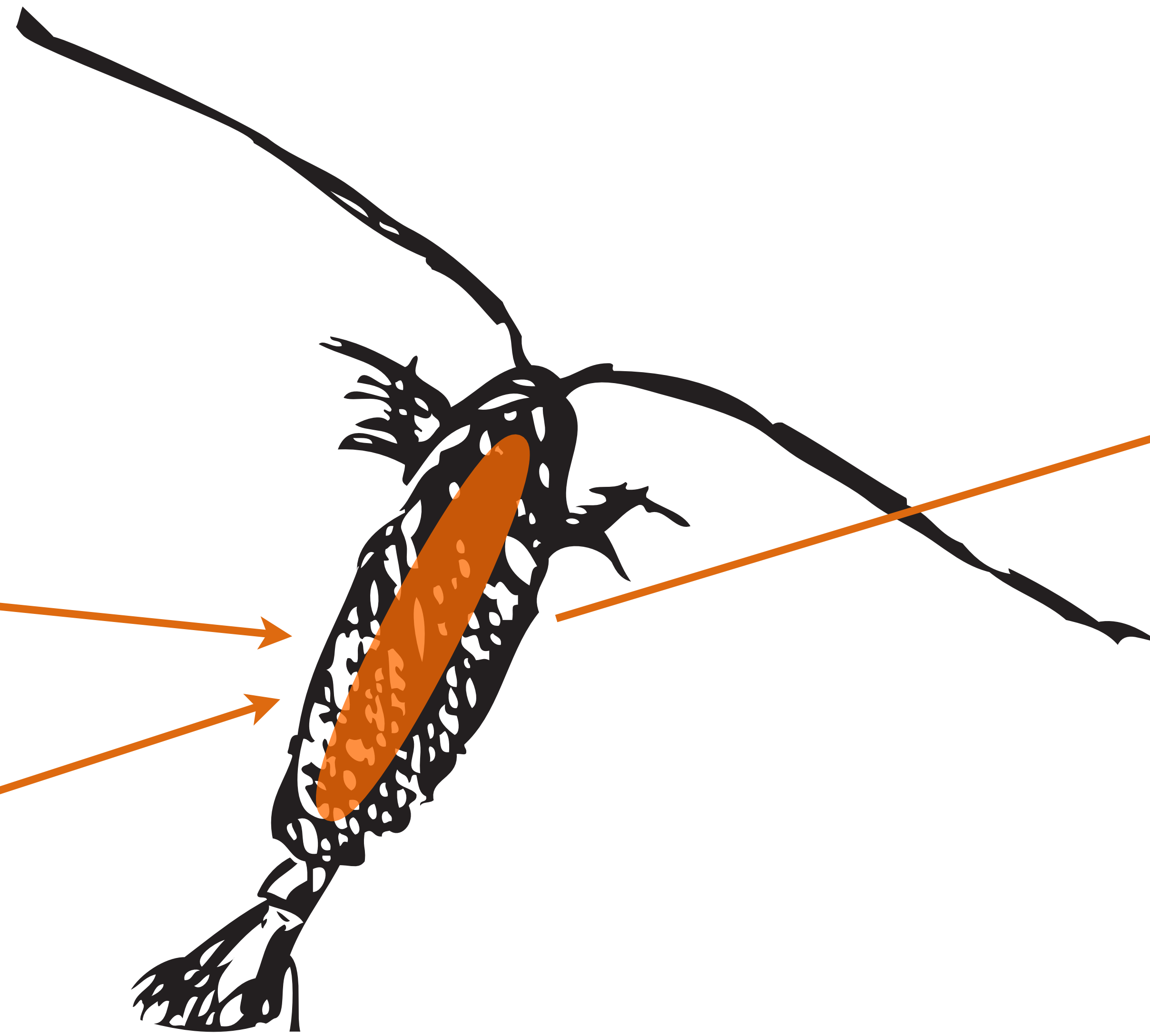


North Sea
warming trend, 1960s–

C. finmarchicus vs *C. helgolandicus:*
cf. recent work by Robert Wilson,
Strathclyde Maths and Stats

impacts on pollock, salmon, cod,
forage fish like herring and sandeels,
seabirds, whales….

Idea: to model climate impacts on fish, birds, and mammals, model the life-history strategy of their *prey*



Overwinter survival (function of phytoplankton phenology, temperature)

Optimizing reproductive timing (also a function of phytoplankton phenology, temperature)

Value as prey

Past approaches

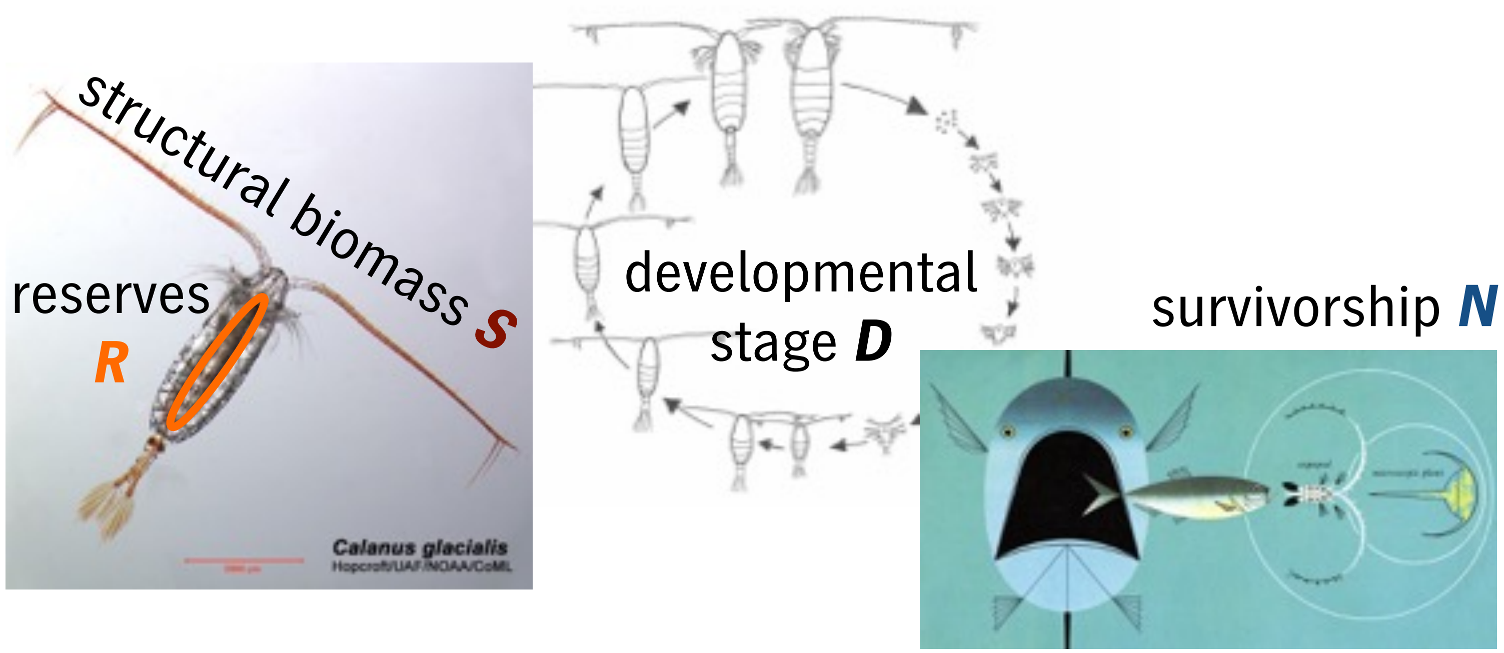
Optimal annual routines for copepod populations via state-dependent dynamic programming (Varpe et al. 2007, 2009; cf. Houston & McNamara 1999, Clark & Mangel 2000)

Emergent copepod communities from a genetic algorithm with explicit coupling through losses to predation (Record et al. 2013)

focus on reserves and timing

trait-based metacommunity

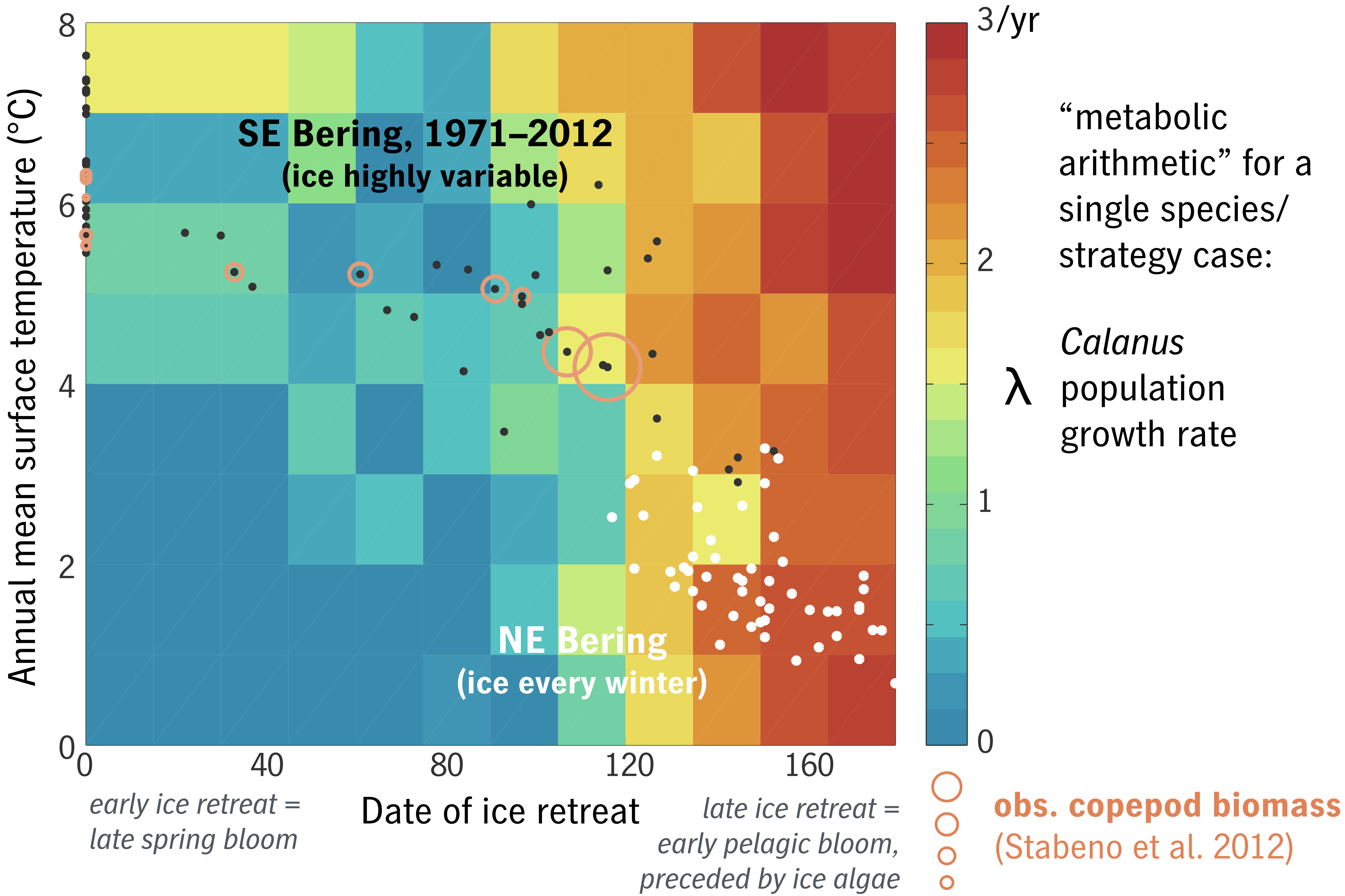
Coltrane (Copepod Life-history traits and adaptation to novel environments)

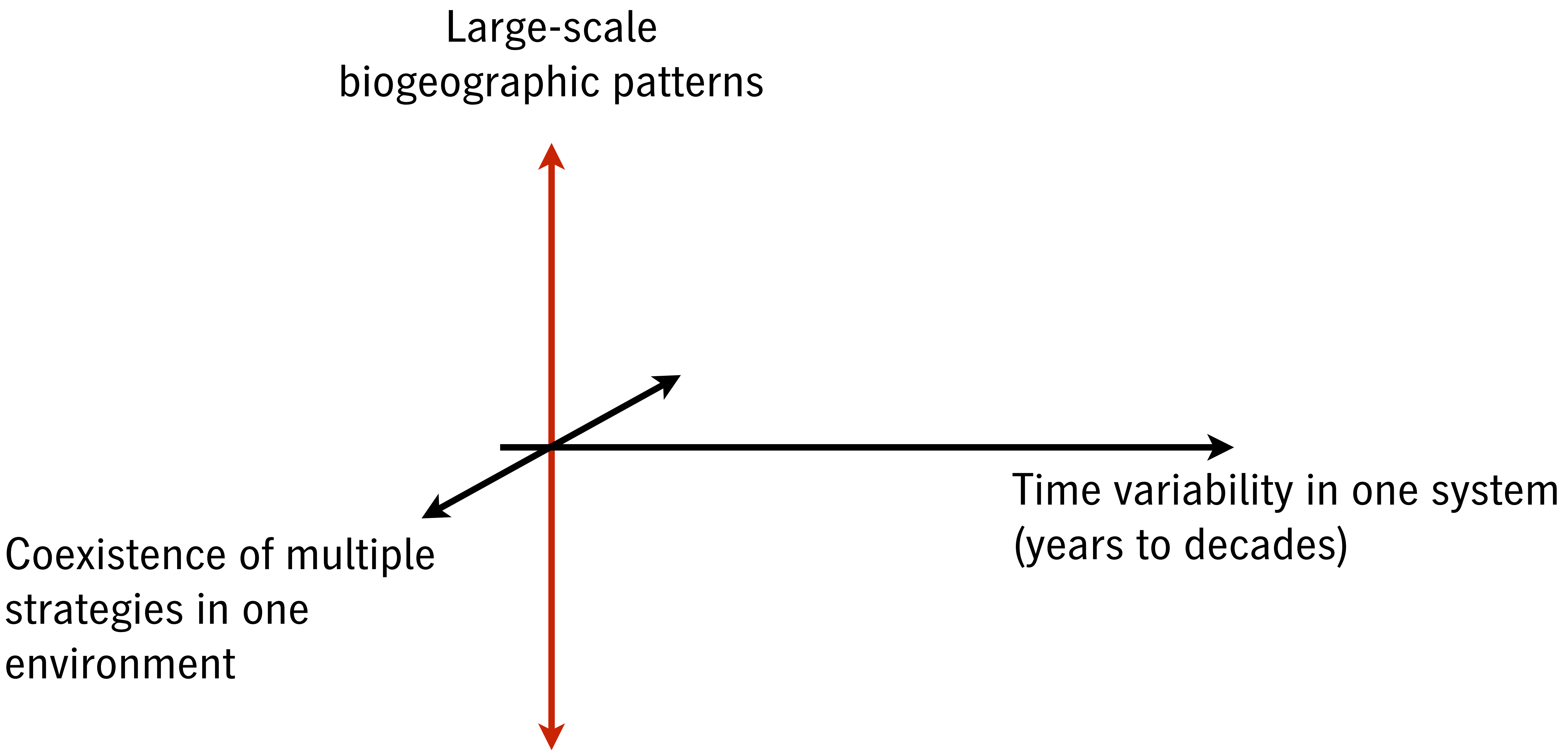


→ **population:** annual cycle, net growth rate

×

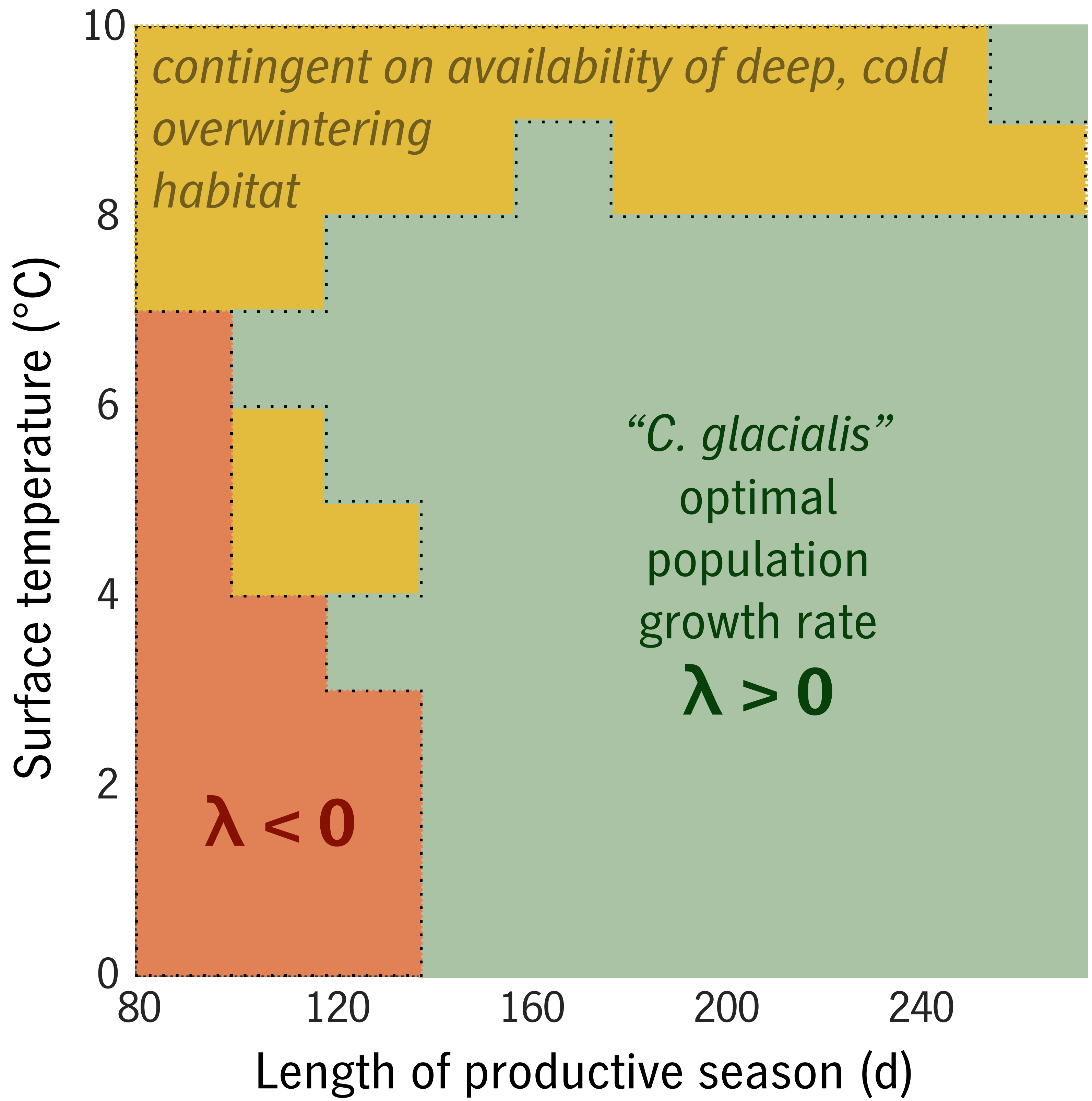
small number of variable traits → **community** associated with a given environment


SE Bering, 1971–2012
(ice highly variable)
NE Bering
(ice every winter)
Annual mean surface temperature (°C)
8
6
4
2
0
0
40
80
120
160
Date of ice retreat
early ice retreat =
late spring bloom
late ice retreat =
early pelagic bloom,
preceded by ice algae
3/yr
2
1
0
λ
“metabolic
arithmetic” for a
single species/
strategy case:
Calanus
population
growth rate
obs. copepod biomass
(Stabeno et al. 2012)


Large-scale
biogeographic patterns
Time variability in one system
(years to decades)
Coexistence of multiple
strategies in one
environment

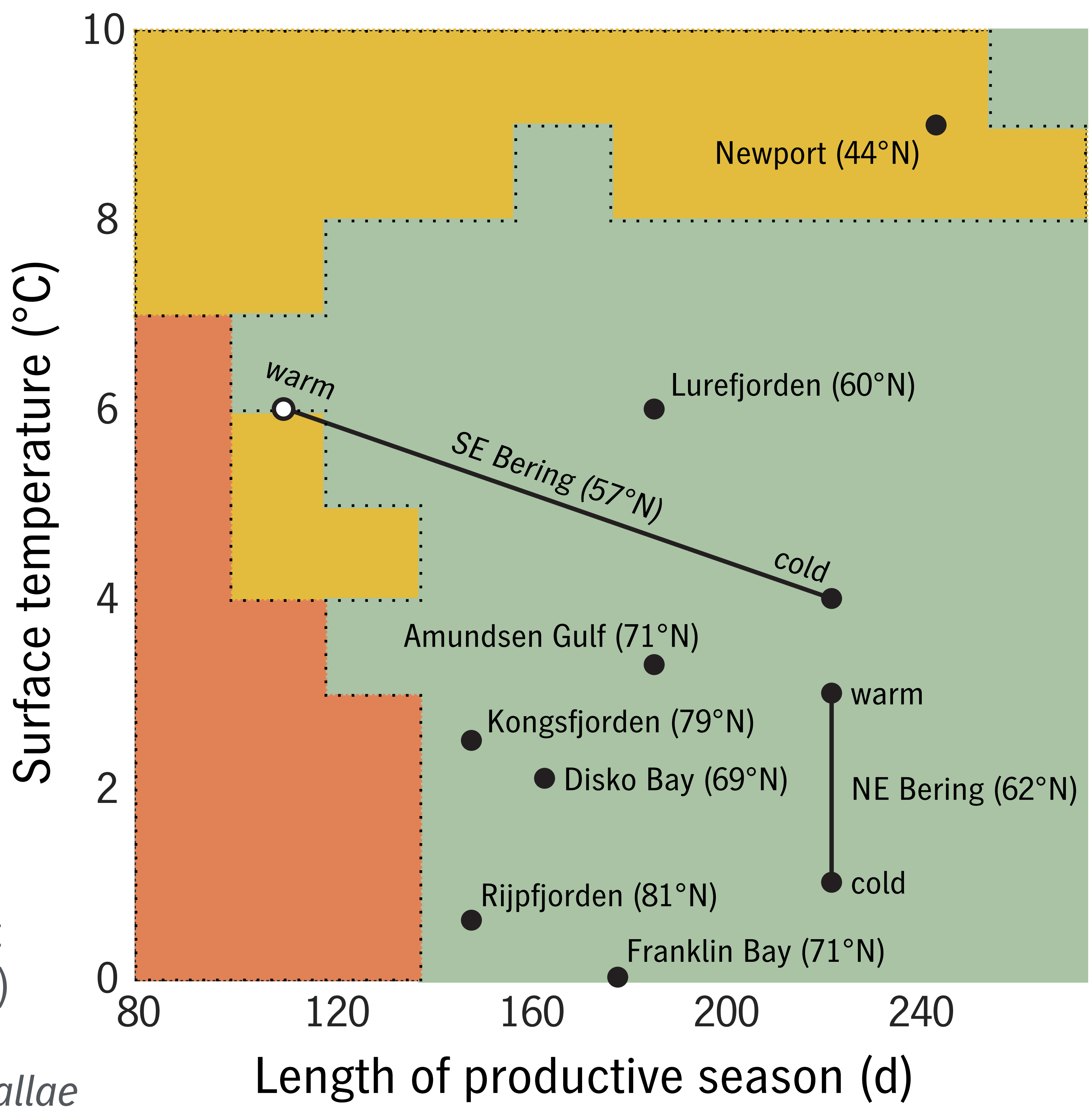
Gaussian window of prey availability; temperature held constant

As in Bering case but optimizing across a timing trait: t_{egg} = delay between maturation and egg production

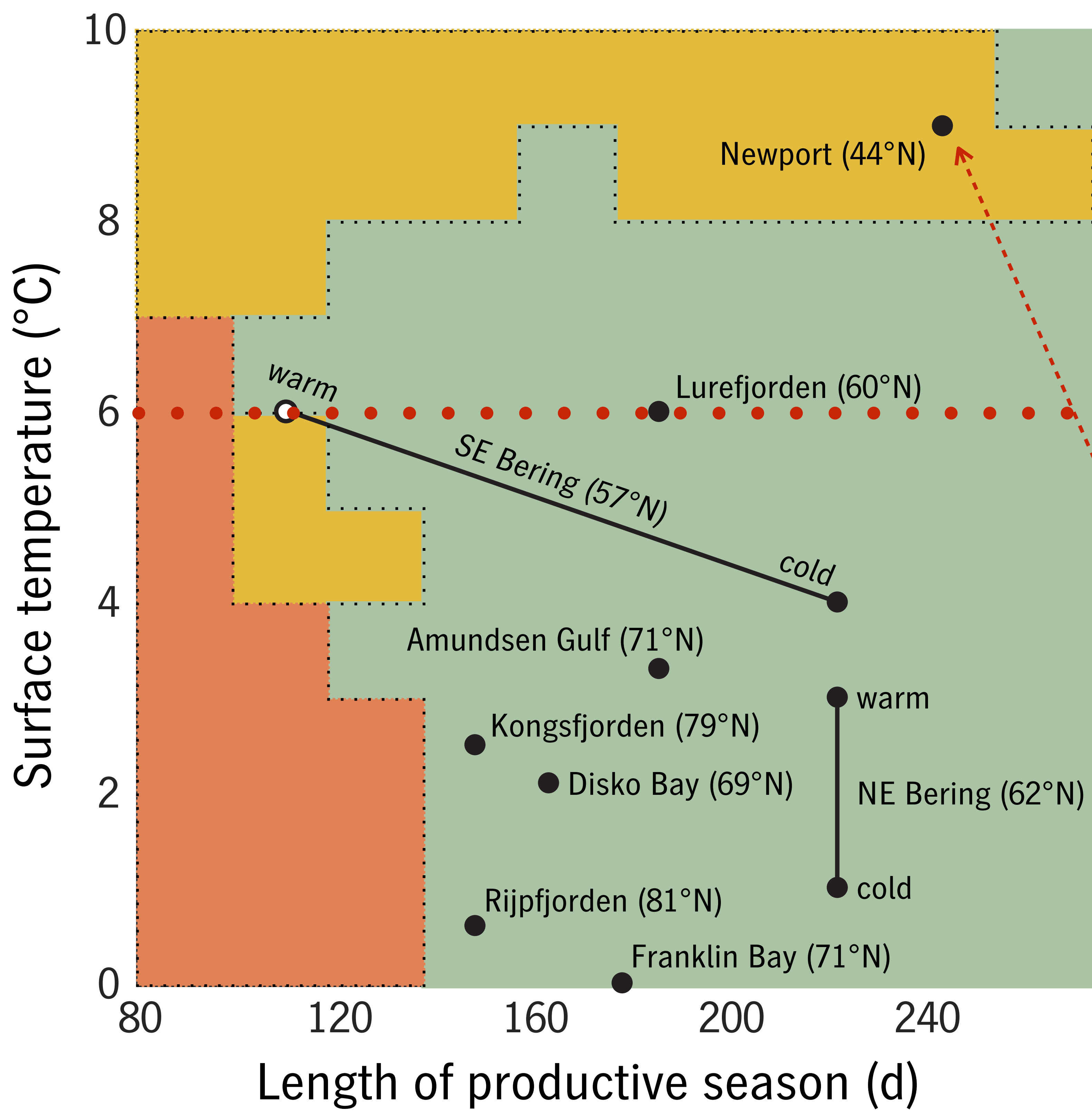


Gaussian window of prey availability; temperature held constant

As in Bering case but optimizing across a timing trait: t_{egg} = delay between maturation and egg production

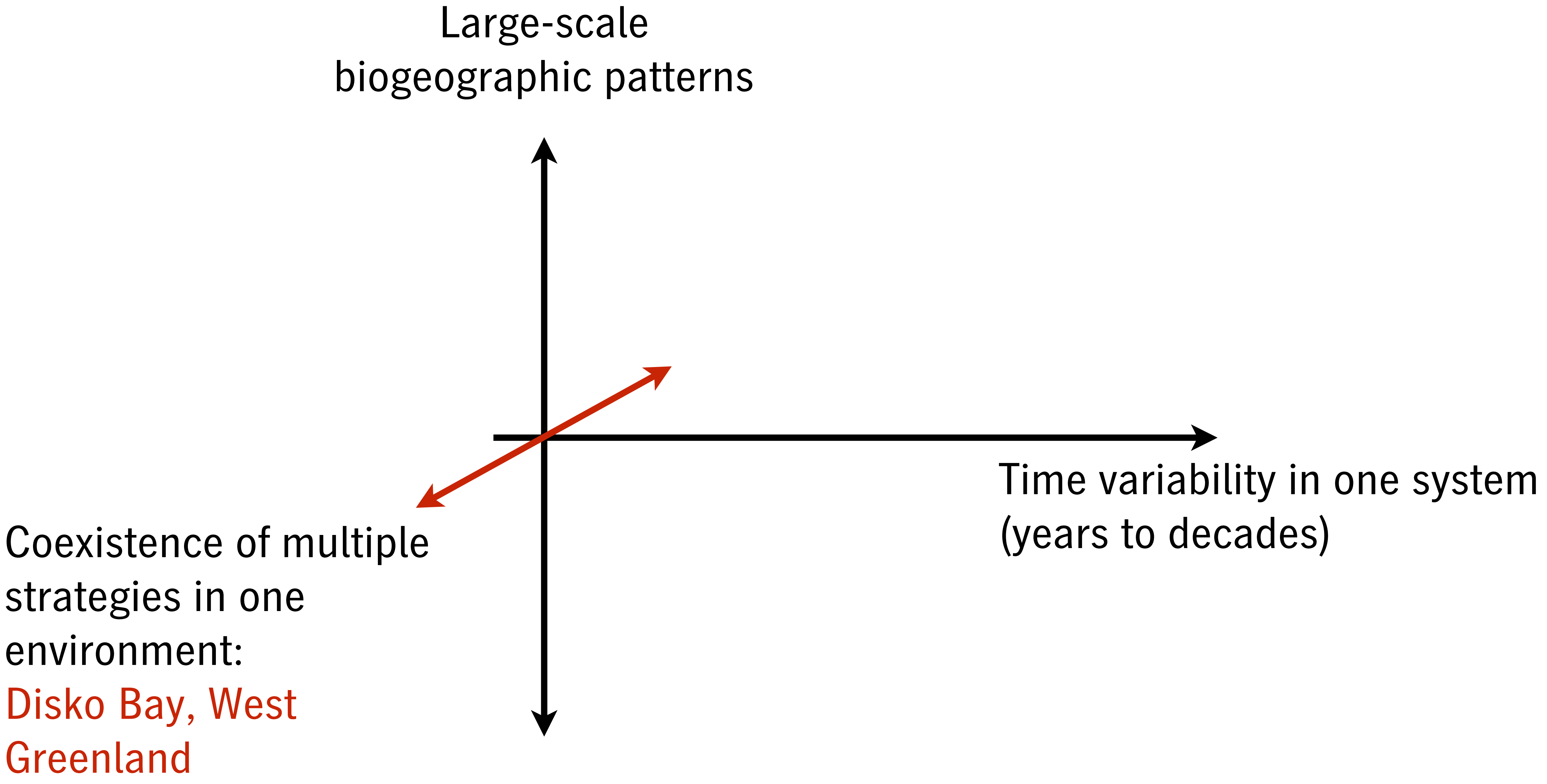


Atlantic Arctic *C. glacialis* habitat (Daase et al. 2011) + *C. glacialis/marshallae* habitat in the Pacific

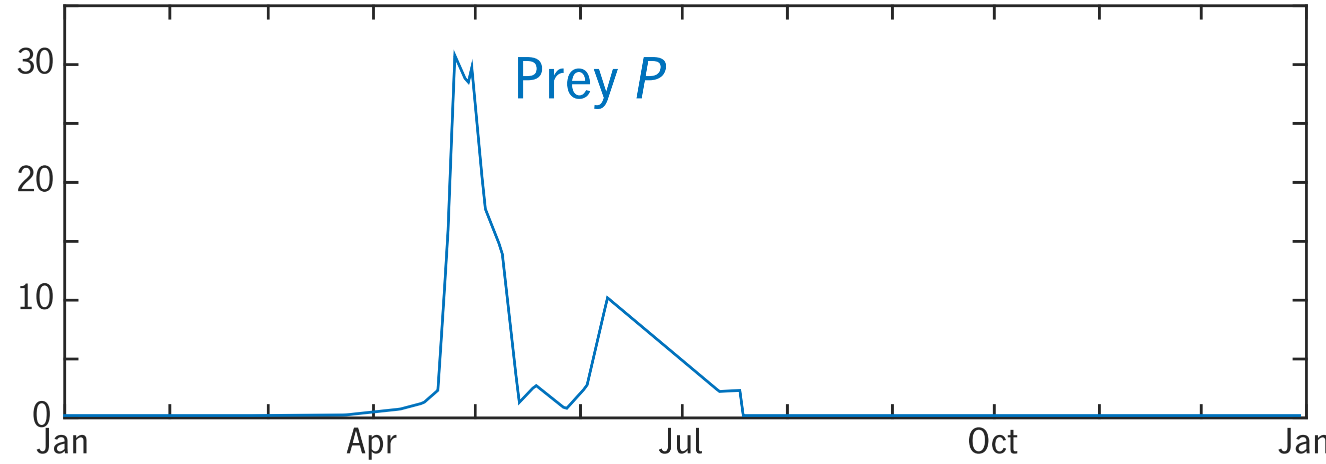


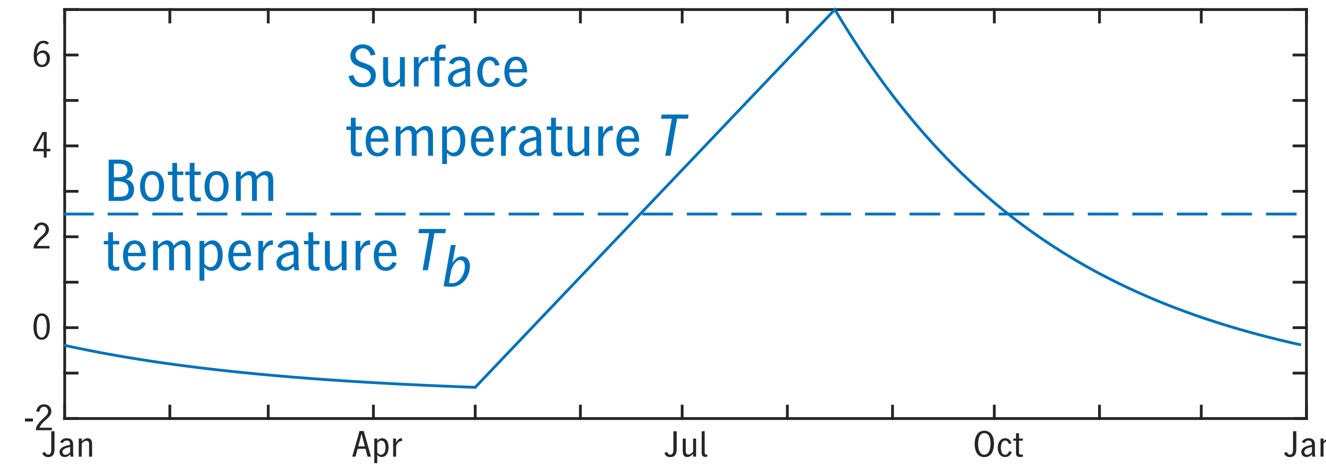
Alcaraz et al. (2014) found a metabolic tipping point for *C. glacialis* at 6°C—

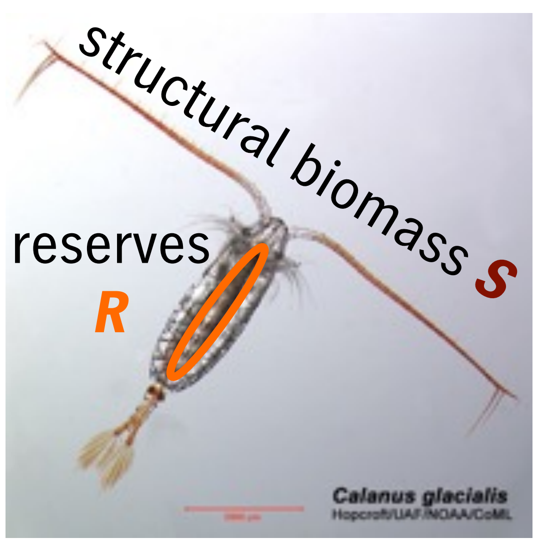
—but this appears to be a population-level *response or strategy*, not a fundamental *constraint*

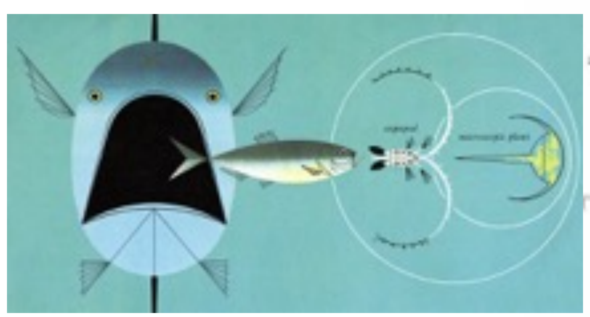

Large-scale
biogeographic patterns
Time variability in one system
(years to decades)
Coexistence of multiple
strategies in one
environment:
Disko Bay, West
Greenland

Disko Bay, 2008
(Swalethorp et al. 2011)

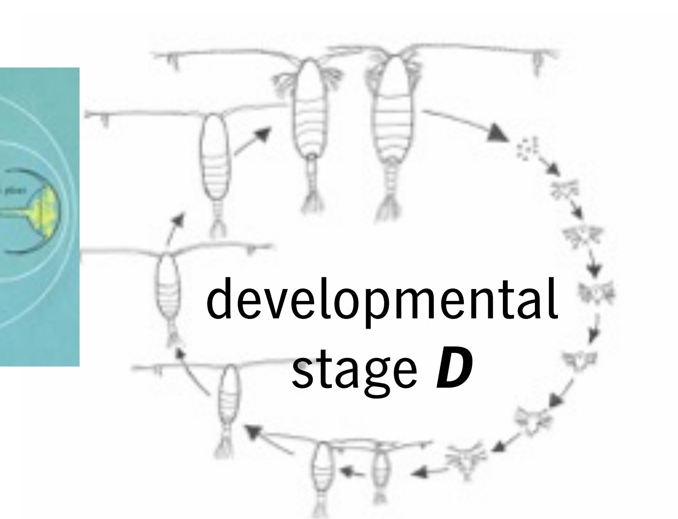








survivorship ***N***

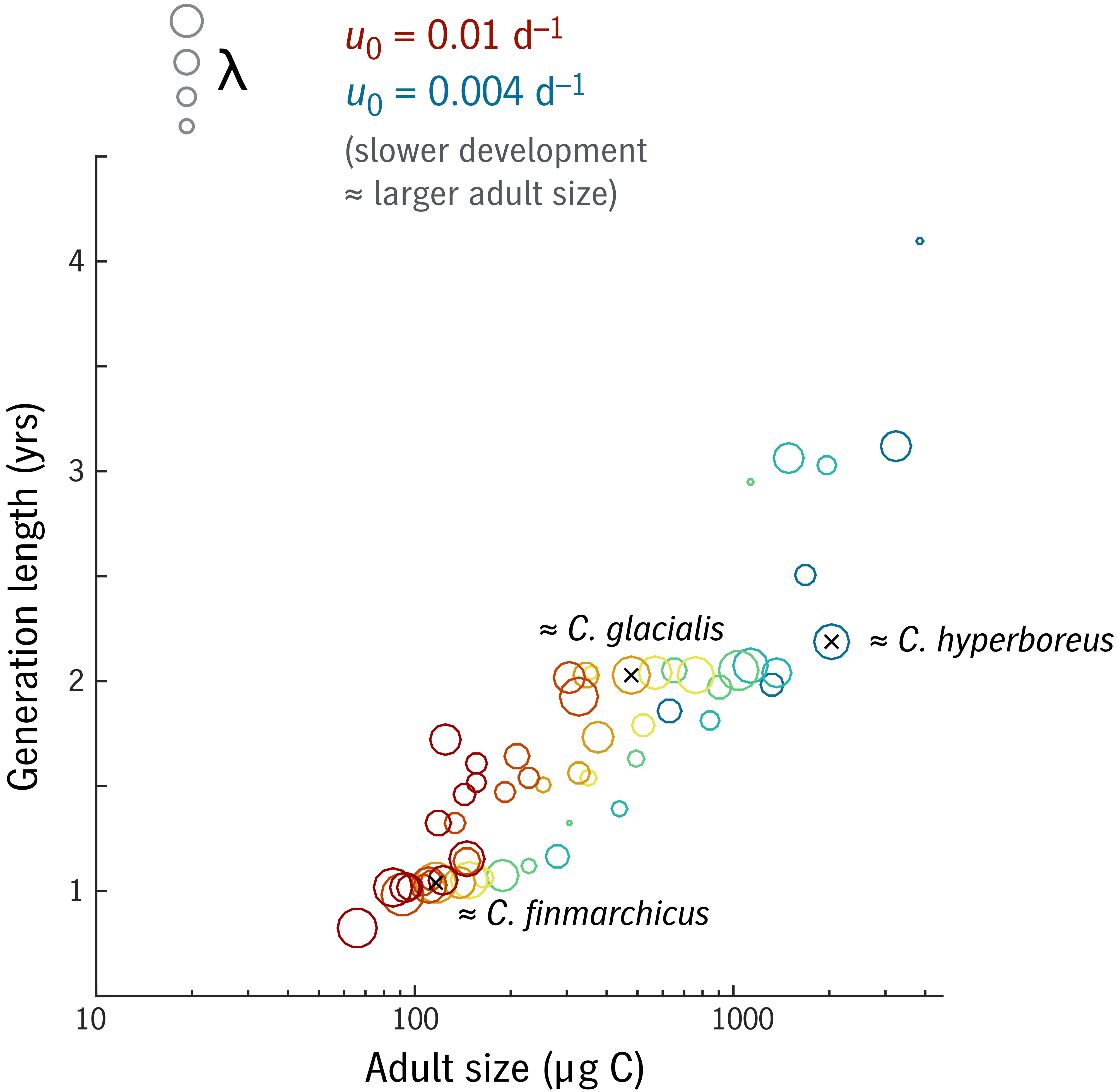


×

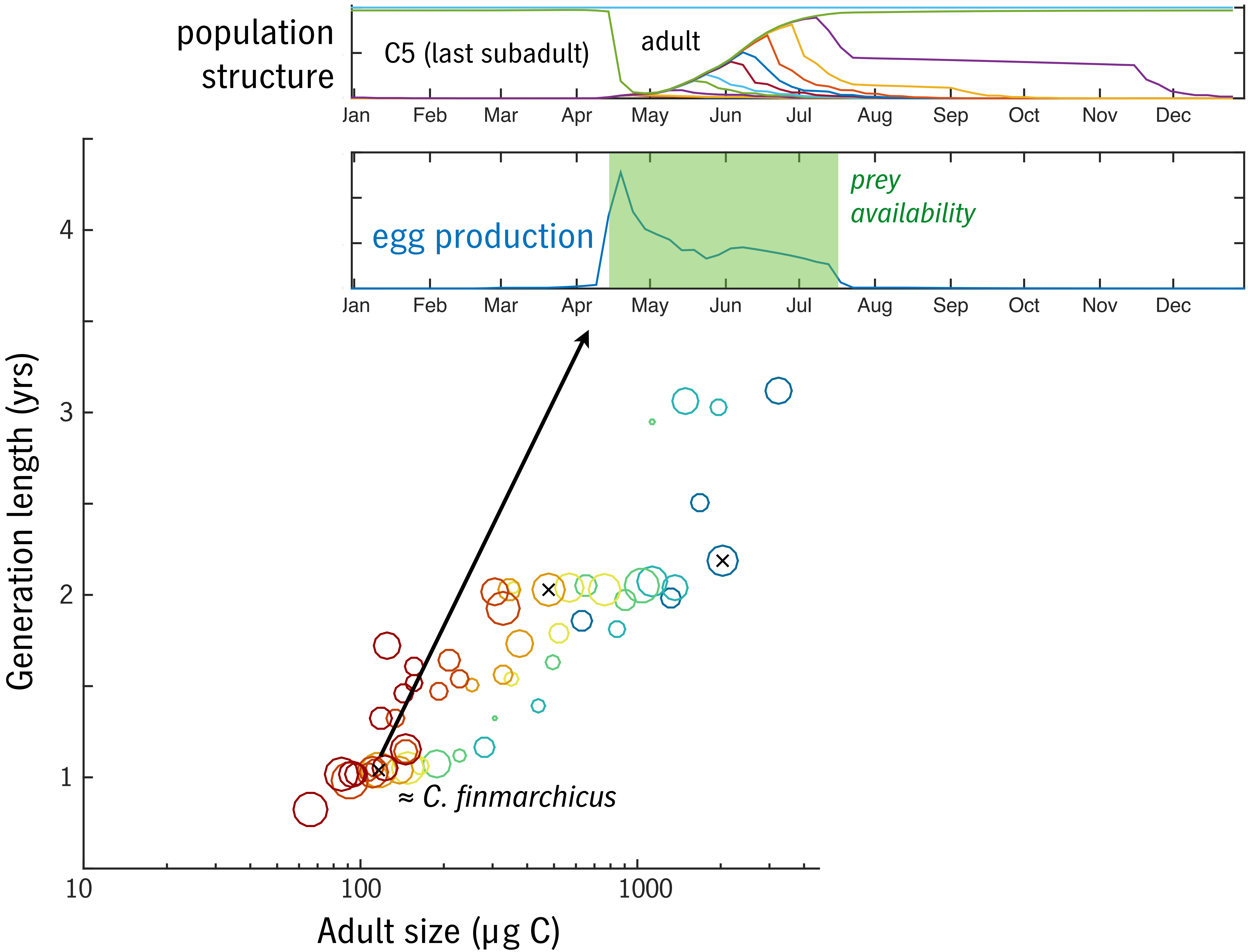
two timing traits

(t_{egg} = delay between maturation and spawning;

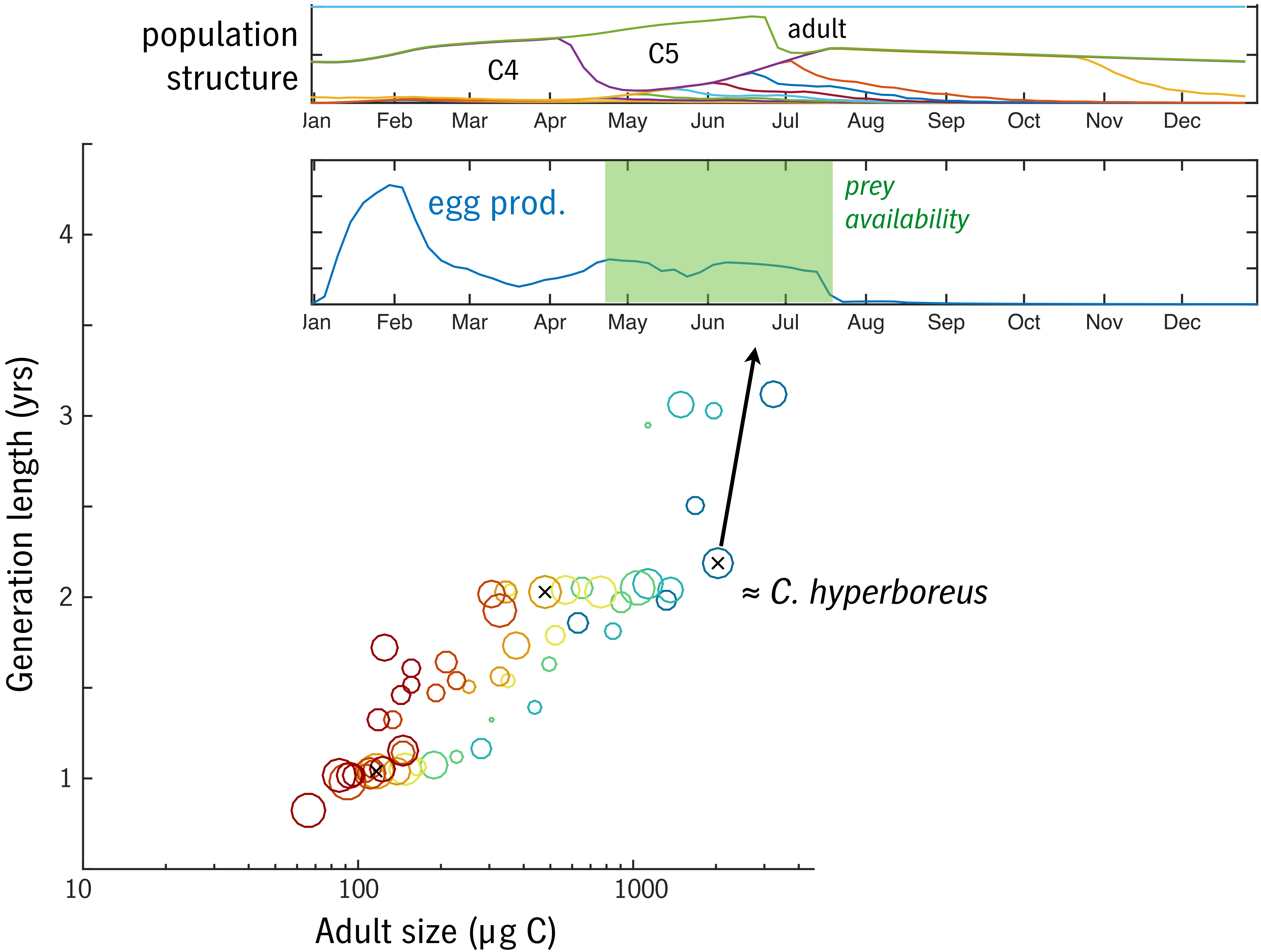
u_0 = development rate at 0°C)



λ
u_0 = 0.01 d⁻¹
u_0 = 0.004 d⁻¹
(slower development
≈ larger adult size)
Generation length (yrs)
4
3
2
1
10
100
1000
Adult size (µg C)
≈ C. glacialis
≈ C. hyperboreus
≈ C. finmarchicus



population
structure
C5 (last subadult)
adult
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
egg production
prey
availability
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Generation length (yrs)
4
3
2
1
≈ C. finmarchicus
10
100
1000
Adult size (µg C)



population
structure
adult
C5
C4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
egg prod.
prey
availability
Generation length (yrs)
4
3
2
1
≈ C. hyperboreus
10
100
1000
Adult size (µg C)

neilbanas.com/projects/
neilbanas.com/projects/positions-available

Where from here?

– How does phytoplankton community light response vary seasonally, and why, and how should we theorize it in models? *(Are there existing datasets we have not fully exploited? How far behind the observational cutting edge is the modeling community on this front?)*

– Can we refine and combine existing DVM and diapause models into a unified view of zooplankton behaviour and energetics across light and ice regimes? *(How far can we push Arctic ABC as a laboratory for quantifying the tradeoffs?)*

– What are the viable ways to be a copepod in the Arctic basin (with and without advective links to elsewhere)? Is the answer going to change with climate change? (*Coltrane could run as a "translation layer" atop SINMOD, Nemo/ Medusa, other pan-Arctic or IPCC-class models.)* A depressing hypothesis to test:

> *In ice-influenced seas, climate change will bring a shift toward* lower quality *prey for fish, birds, and mammals (in terms of lipid content and size), to a degree that outweighs accompanying increases in primary production.*

(Especially interesting to find hotspots where the hypothesis is wrong….)