Large zooplankton in the warming Bering Sea: ecosystem and life-history modeling approaches

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The eastern Bering Sea is a vast continental shelf system with seasonal ice cover that yields nearly half of the total U.S. fisheries catch



(Wiese et al, *Deep Sea Res*, 2012). Interannual variability in recruitment of pollock and other key pelagic fisheries is linked strongly to variability in the abundance of large crustacean zooplankton (Hunt et al, ICES J Fish Res, 2011).

Hypothesized climate impacts on Calanus marshallae/glacialis and other large crustacean zooplankton, Eastern Bering Sea, middle-outer shelf (50–200 m depth)



Large zooplankton have been observed to decline in warm years with low ice cover and increase in cold years with high ice cover (Eisner et al, *Deep Sea Res*, submitted). The growing consensus (of which this work is a part; see also Lomas et al, Deep Sea Res, 2012), is that this is in spite of, not because of, variation in spring-summer conditions.

A future projection using the BESTMAS (Bering Ecosystem Study Ice-Ocean Modeling and Assimilation System: Zhang et al, J Phys Oceanogr, 2010; Deep Sea Res, 2012) suggests that ice cover in the 2040s will remain within the range of 1978–2012 historical variability, but that the relationship between ice cover and mean temperature will change.



Thus to predict climate impacts on large zooplankton, we need to isolate the independent effects of ice cover and water temperature—present-day warm years are not necessarily a reliable guide to plankton ecology under future climate. This poster gives highlights from two modeling studies intended to diagnose these mechanistic links.

Ice cover and spring primary production



A larger ensemble spanning the northern middle-outer shelf (50–200 m water depth, >60°N) was used to establish relationships among temperature, ice cover, bloom timing, and total springsummer production.

LowLaMB (Lower-trophic Lagrangian Model for the Bering Sea) Was built to synthesize rich observations from BEST (Bering Ecosystem Study) spring and summer cruises, 2007–2010. It is run as an ensemble of 1-D water columns, advected through the BESTMAS fields using mean 0–30 m currents, and forced by BESTMAS light, temperature, and vertical diffusivity.



Winter conditions and zooplankton life history

As a basis for assessing the sensitivity of *Calanus* spp. and other large zooplankton to temperature and prey availability over a full seasonal cycle, a new stage-resolved life history model was constructed, which allows for **plasticity in lipid storage, winter**



Apr 09

Apr 29





Date of ice retreat

On both interannual and interdecadal timescales, warm years are associated with early ice retreat, early spring blooms, and higher primary production overall. This does not help explain why large zooplankton fare better in cold years.



0–35 m, Feb 15–Jul 15 (°C)

Reducing winter

chl m–3 *to* 0

as much as

reduces

prey from 0.2 mg

population growth

several degrees of

winter warming.

As winter prey

ncreases, the

optimal strategy

round activity, not

still with high lipid

shifts to year-

diapause—but

storage.

availability

(Modeled relationships among these quantities on the southern, less ice-influenced shelf are highly sensitive to the treatment of early spring, low-light conditions. Colleagues who model phytoplankton adaptation to changing light environments, please introduce yourselves: I have a puzzle for you!)

pri

Mean

EcoFOCI mooring M8 (62°N, 70 m water depth; Sigler et al., *Deep Sea Res.*, submitted), which experiences

May 19 Jun 08

Jun 28

Since neither spring-summer primary production nor direct temperature effects seems to correlate positively with the increased success of large zooplankton in cold years, process of elimination points to ice-associated phytoplankton production in late winter (Cooper et al, Deep Sea Res, in press).

Indeed, the life history model shows that population growth is extremely sensitive to winter phytoplankton concentrations!

activity level, and reproductive strategy.

Each stage is represented by three state variables, total biomass C, lipid reserves *R*, and age-within-stage (after Hu et al, *MEPS*, 2008; not further discussed here).

here reserves fraction
$$ho = R/C$$

assimilation $F_{assim} = aq(1 - f_{egest})I_0 rac{P}{K_s + P}C$
metabolic losses $F_{metab} = rac{\delta + r_{ed}
ho}{\delta +
ho} aqr_{metab}I_0C$

a is activity level, controlled by windows in time (yearday) and stage that define diapause duration and intensity. q is a Q_{10} temperature dependence. r_{metab} is metabolic costs as a fraction of max ingestion I_0 . r_{ed} is the relative energy density of structural and reserve biomass. δ is a small shape parameter, = 0.1.

Mortality is linear. Egg production F_{eqq} is, for the adult stage only, equal to the net gain (assimilation minus metabolism) for structural biomass *C*–*R*.



Thus the *overall* effect of higher temperatures at M8 appears to work *against* the observed pattern in which cold years favor large zooplankton.

Conclusion

In-ice phytoplankton production in late winter, although small compared with spring production, may be crucial to interannual and long-term variations in the success of *Calanus* spp. in the eastern Bering Sea. The next step is to determine if the same is true for taxa with different life-history strategies.