Spatial variations in late summer chlorophyll a and zooplankton distributions in the northeastern Bering Sea

Lisa Eisner, Alex Andrews, Kristin Cieciel, Jeanette Gann and Ellen Yasumiishi

Acknowledgements: We thank the Ecosystem Monitoring and Assessment (EMA) program and other NOAA, TINRO and volunteer cruise participants, and the crews of the Oscar Dyson, Sea Storm, NW Explorer, Epic Explorer, and Bristol Explorer.

Alaska Fisheries Science Center
NATIONAL MARINE FISHERIES SERVICE

AYK

U.S. FISH & WILDLIFE SERVICE

CIAP
Coastal Impact Assistance Program

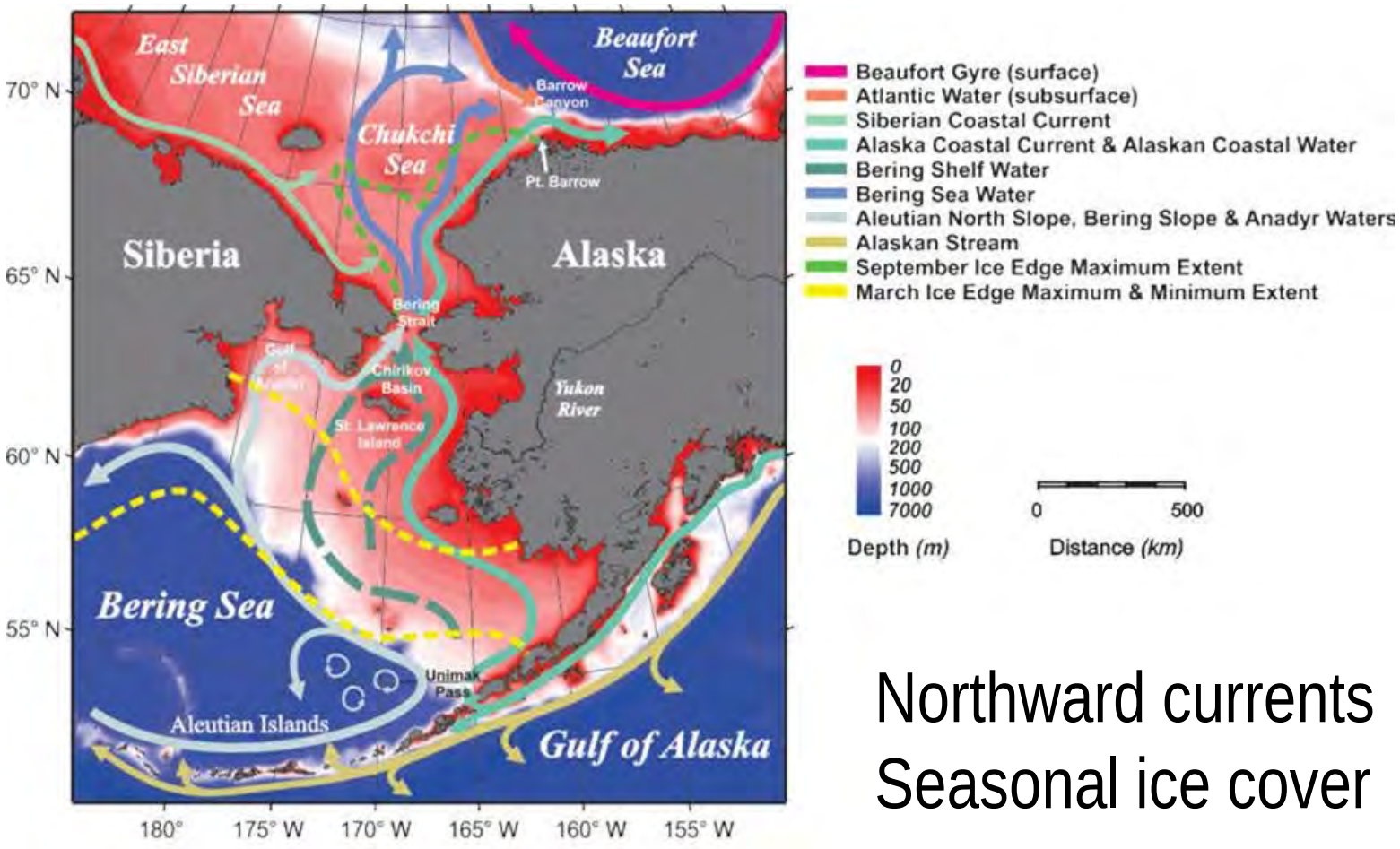
BOEM
Bureau of Ocean Energy Management

Arctic Eis

North Pacific Research Board

UAF
University of Alaska Fairbanks

Study area

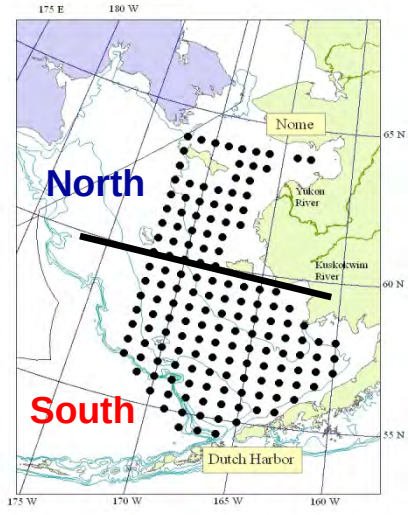


Northward currents
Seasonal ice cover

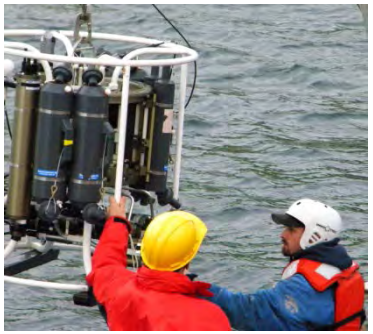
Courtesy of Danielson and Weingartner, UAF

Goals

- U.S. BASIS (2002-2015): eastern Bering Sea
  - **Chlorophyll a (Chla, phytoplankton biomass) and zooplankton communities in North and South (> or < 60 °N)**
    - **Spatial variations (temperature, salinity, nutrients, Chla)**
    - **Variations between warm and cold year stanza**
    - **Interannual variations**
    - **Relationship to environmental variables**
- Arctic Eis (2012-2013): north Bering and Chukchi seas
  - **Zooplankton communities**
    - **Spatial variations**
    - **Interannual variations**
    - **Relationship to environmental variables**

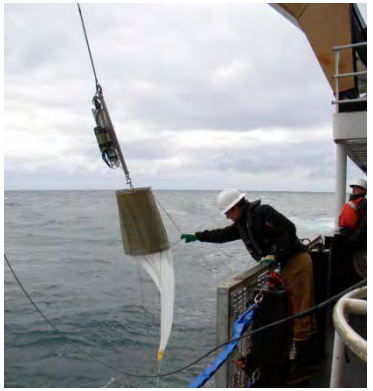


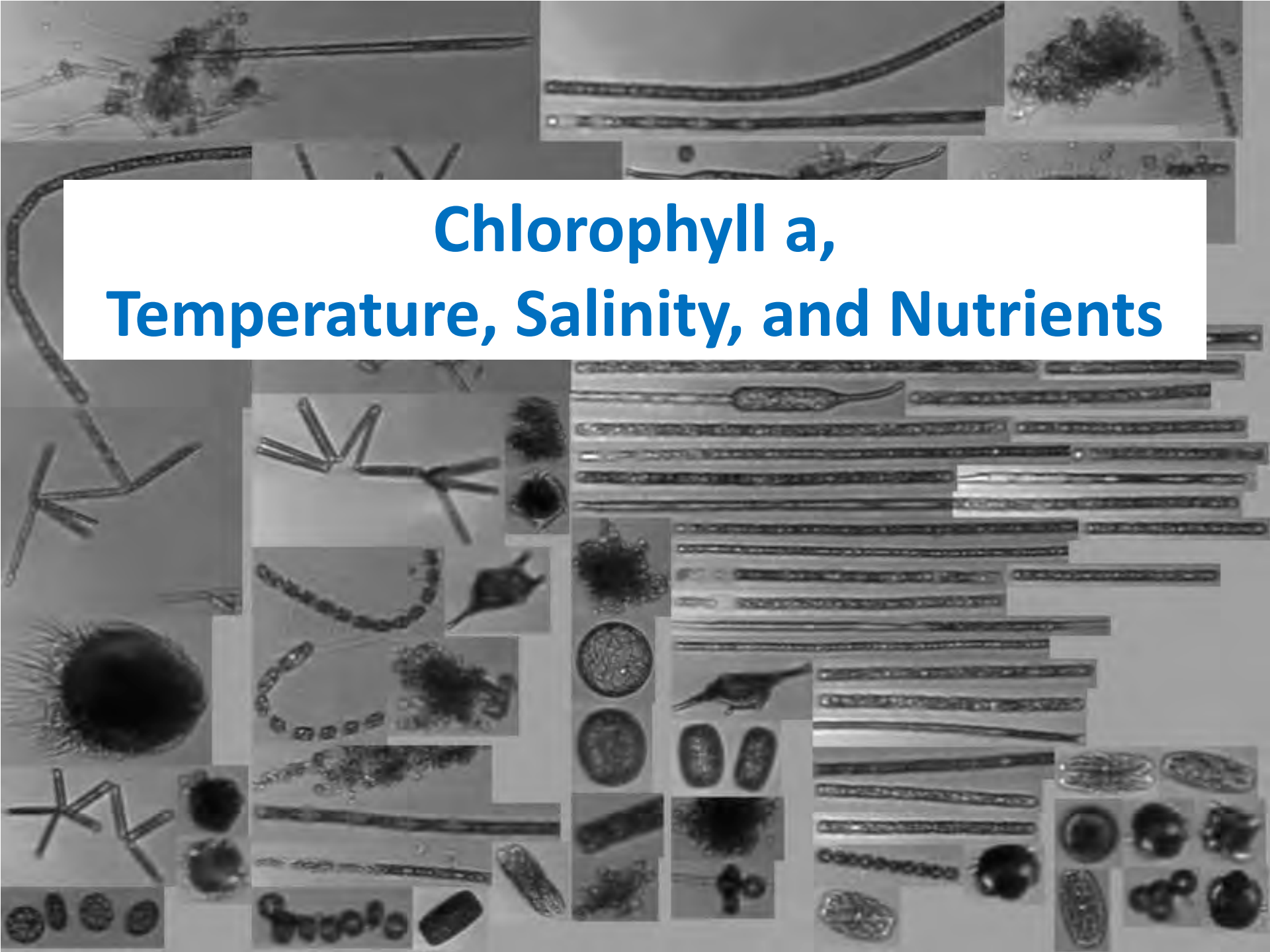
Data collection



- **Mid August – September (or early October)**
- **BASIS: 2002-2012, 2014-2015**
- **Arctic Eis: 2012, 2013**
- **Temperature, Salinity Nutrients, Chla**
  - Vertical CTD profiles
  - Nutrients: nitrate, nitrite, ammonium, phosphate, silicic acid
  - Integrated (top 50 m) Chlorophyll a (Chla) from calibrated *in situ* fluorescence
  - Chla size fractions: large (> 10 µm)

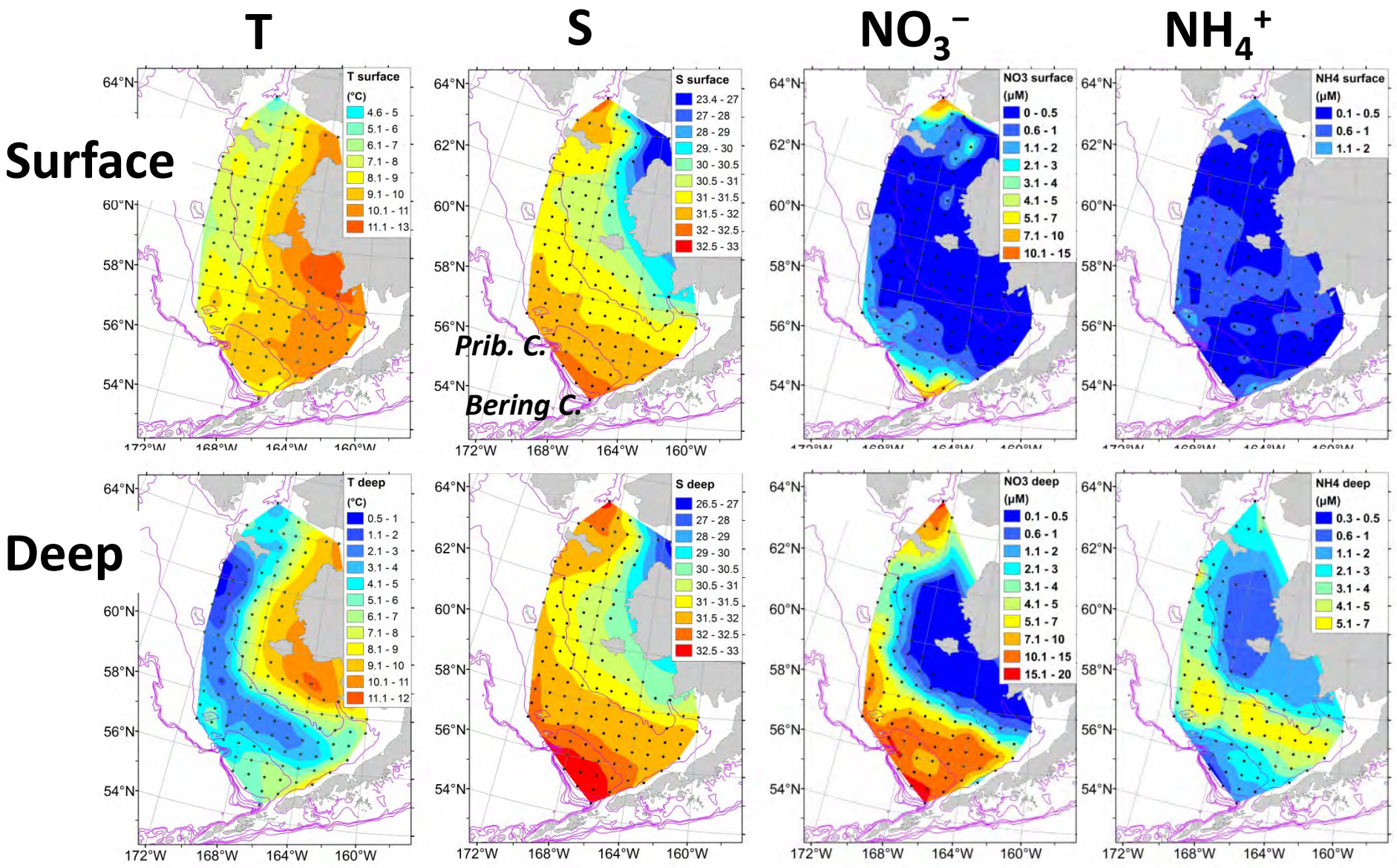
- **Zooplankton**
  - Large taxa: bongo oblique tows, 505 µm
  - Small taxa: Juday vertical tows, 168 µm or oblique bongo tows, 153 µm (Arctic Eis)





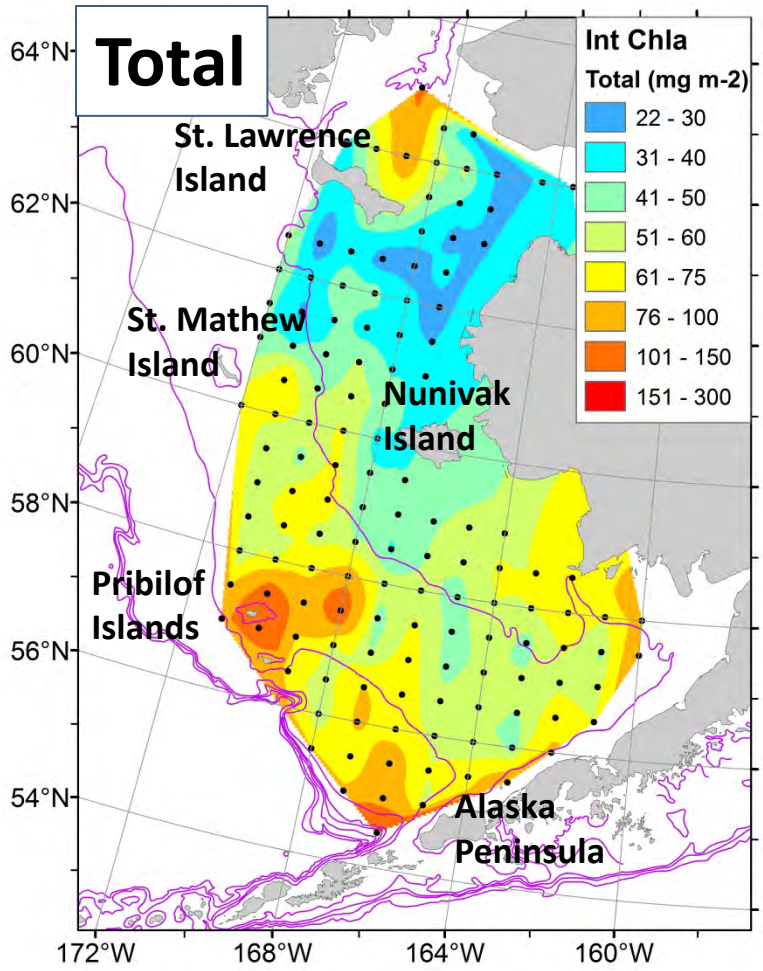
Chlorophyll a, Temperature, Salinity, and Nutrients

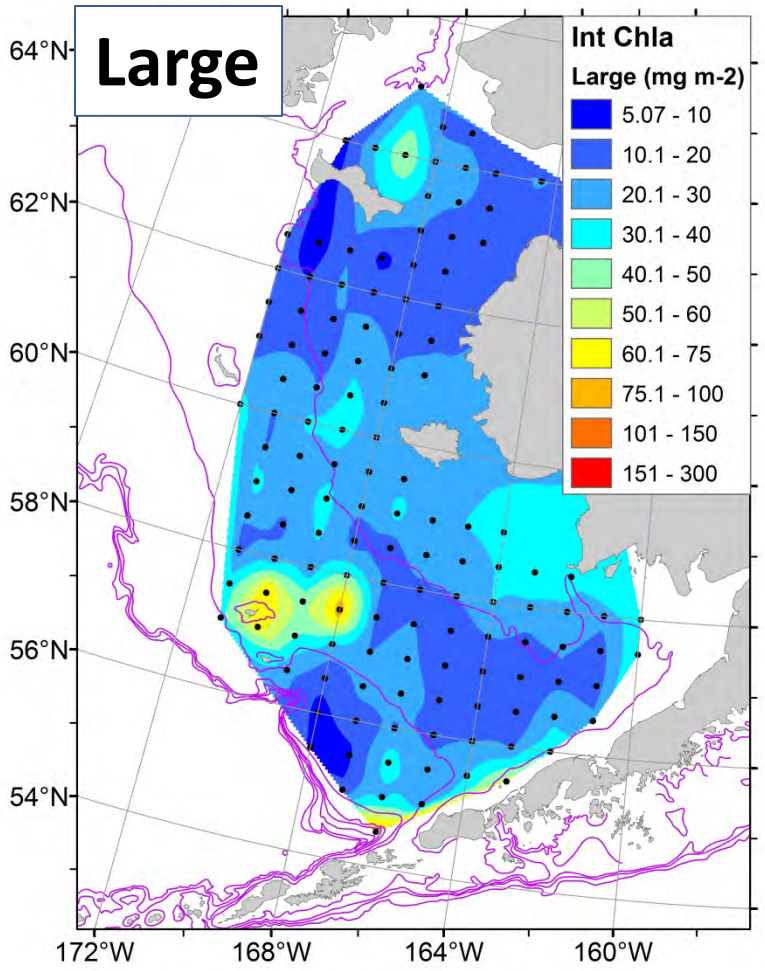
Surface and deep (above and below pycnocline) temperature, salinity, nitrate, ammonium: means 2003-2012



Eisner et al. 2015, DSRII

Integrated Chlorophyll a (Chla, mg m^{-2}) total and large (> 10 µm) size fraction, means 2003-2012

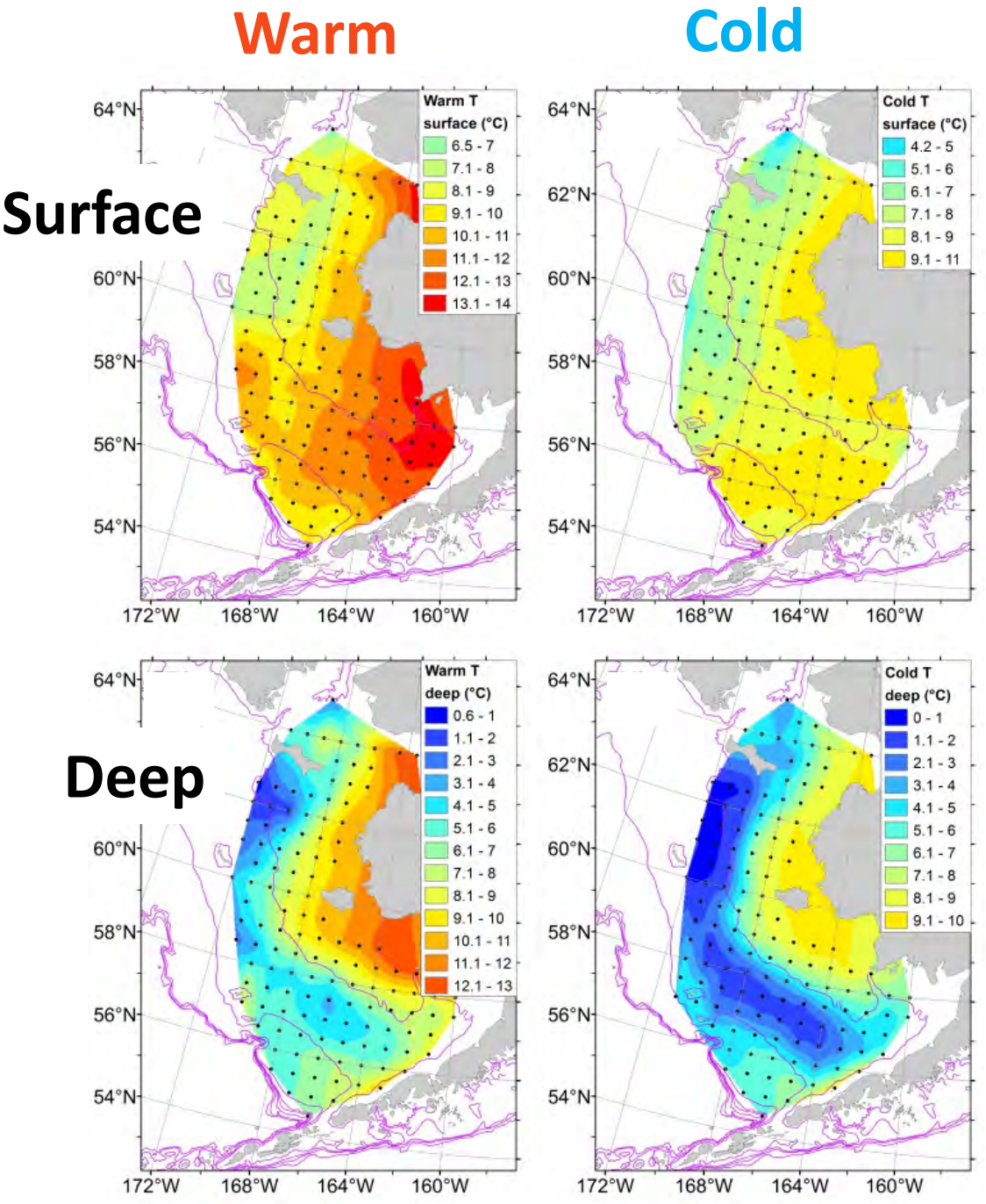




Eisner et al. 2015, DSRII

Surface and deep temperature:

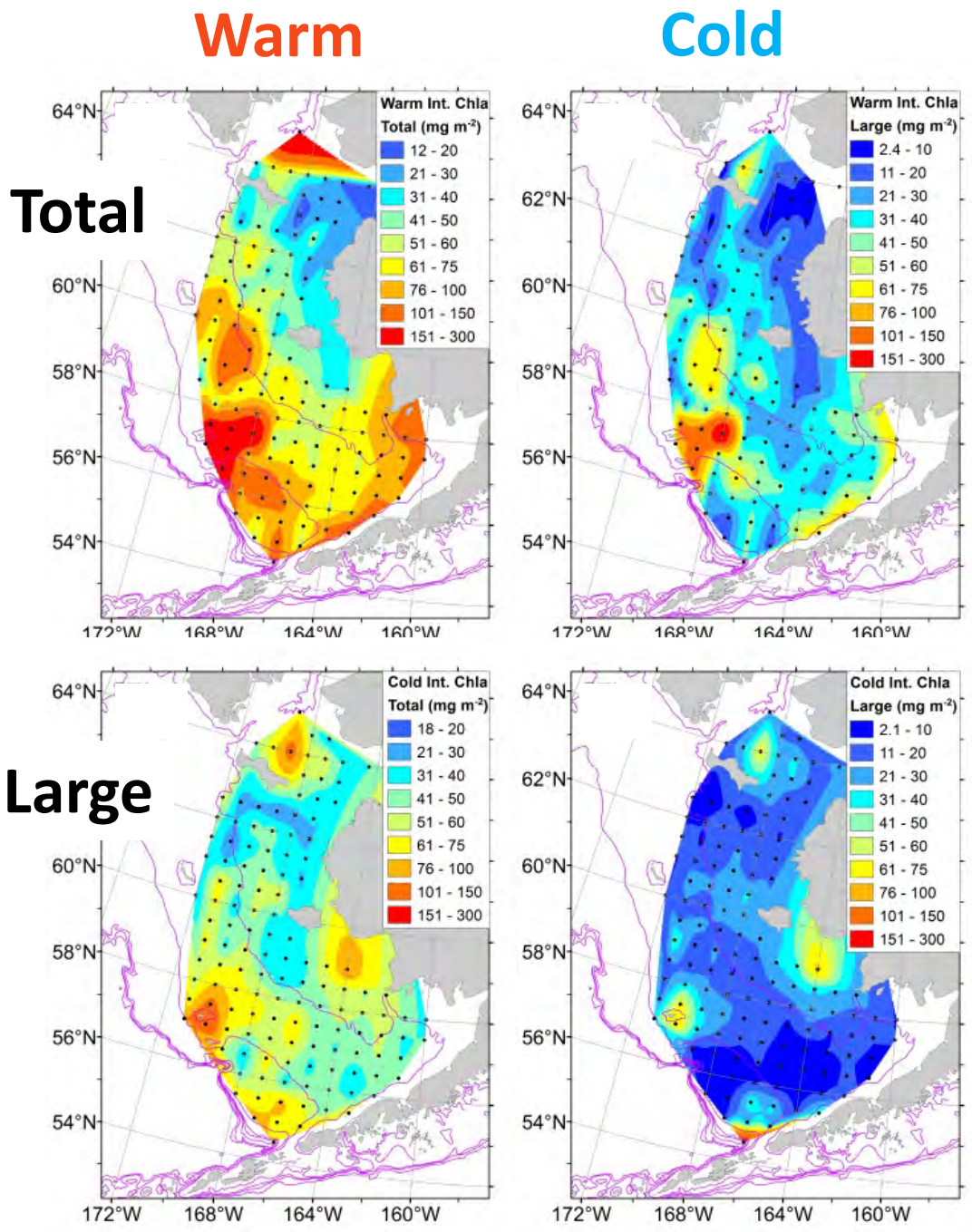
Means for warm (2003-2005) and cold (2007-2012) years



Eisner et al. 2015, DSRII

Integrated total and large size (> 10 µm) Chla:

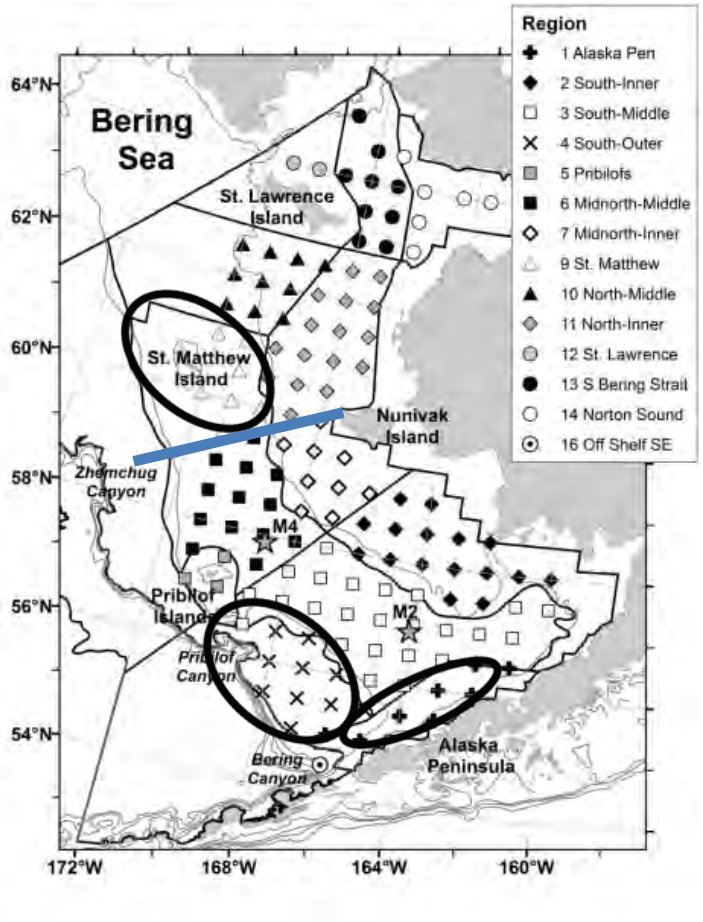
Means for warm (2003-2005) and cold (2007-2012) years



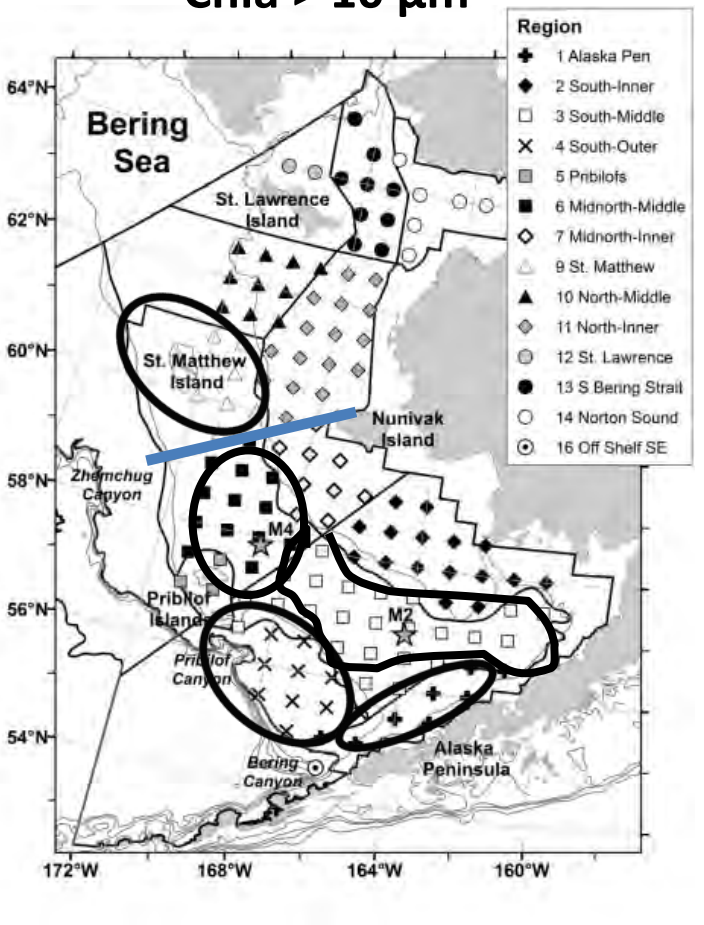
Eisner et al. 2015, DSRII

Ecoregions (Ortiz et al., 2012) with significant (P < 0.05) increases in integrated Chla in warm compared to cold years

Total Chla

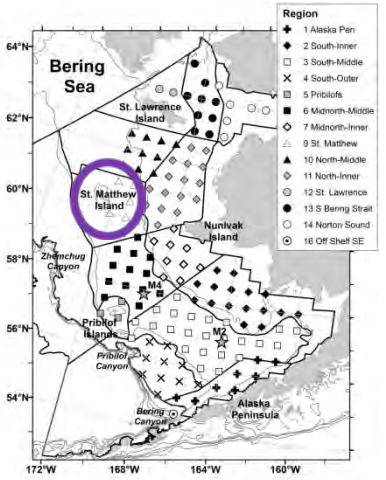


Chla > 10 µm



Eisner et al. 2015, DSRII

Mean temperature (°C) below the pycnocline (deep) by ecoregion and year



Red = positive anomaly

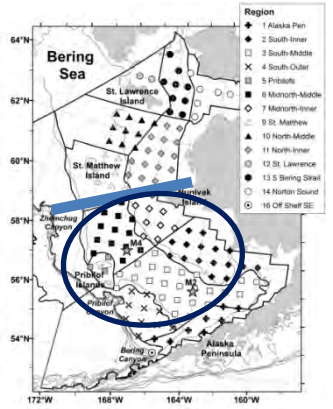
Blue = negative anomaly

(anomaly calculated separately for each region)

Domain	Region		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
North																
Inner	North	**11**	7.3	7.7	9.0	7.0	6.7	7.1		6.4	6.1	6.8	6.3	5.2	8.8	7.4
Middle	St Matthew	**9**	3.5	6.0	3.8	4.0	2.5	0.8		0.7	0.7	1.9	1.0		2.5	0.6
	North	**10**	4.6		3.2	1.3	1.4	1.0		1.3	1.4	0.9		0.6	2.1	0.1
> 63°N	St Lawrence	**12**	6.2	4.4	7.0		4.7	6.4		3.9	5.4	3.9	5.5	5.6		3.3
	S Bering Strait	**13**	5.4	5.8	6.9	7.4	4.7	6.1		3.7	5.5	5.1	3.2	3.3	5.5	5.9
	Norton Sound	**14**	7.3	10.2	11.4		8.1	10.3		8.0	8.6	7.5	6.8	8.2	8.9	8.8
South																
Inner	South	**2**	8.7	9.3	9.5	9.2	7.9	6.3	6.5	7.3	7.1	7.0	6.5		6.3	7.3
	Mid-north	**7**	9.5	9.9	9.9	8.4	7.6	7.9	6.1	7.6	7.3	7.2	6.5		6.1	7.2
Middle	AK Penn	**1**	7.7	7.8	7.8	7.8	7.9	5.3	6.8	7.0	6.0	6.9	5.4		7.2	7.9
	South	**3**	4.9	5.2	5.2	5.9	4.1	2.9	2.9	2.6	2.2	3.9	2.0		4.8	5.3
	Pribilofs	**5**	4.1		7.6	7.5	5.5	4.2		4.2		5.0	3.6		5.9	
	Mid-north	**6**		5.7	4.3	5.5	2.2	2.9	1.9	3.4	1.9	3.5	2.2		3.4	3.9
Outer	South	**4**	6.9	6.8	6.1	6.3	6.0	5.4		5.6	5.0	5.3	5.3		5.5	6.3

Eisner et al. 2016, http://access.afsc.noaa.gov/reem/ecoweb/Index.php.

Linear regressions of means by ecoregion: Deep temp and integrated Chla, 2003-2012

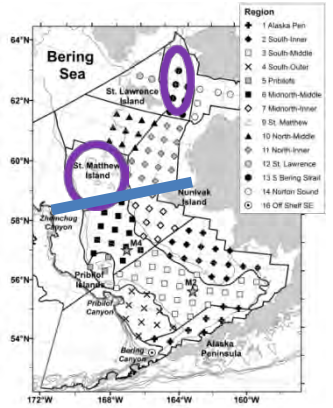


P-values shown, * significant (P < 0.05), positive (+) or negative (–) relationship indicated

Region	South Inner **2**	Mid-North Inner **7**	South Middle (M2) **3**	Mid-North Middle (M4) **6**	South Outer **4**	St. Matthew **9**	South Bering Strait **13**
Chla total	(+)		(+)	(+)	(+)	(+)	(–)
P -value	0.048*	0.13	0.026*	<0.001*	0.042*	0.008*	0.028*
Adjusted R^2	0.33	0.17	0.42	0.81	0.39	0.60	0.45
Chla >10 µm (large)		(+)	(+)	(+)		(+)	(–)
P -value	0.10	0.029*	0.008*	0.009*	0.35	0.006*	0.015*
Adjusted R^2	0.22	0.40	0.55	0.54	0.00	0.63	0.54

Eisner et al. 2015, DSRII

Linear regressions of means by ecoregion: Deep temp and integrated Chla, 2003-2012



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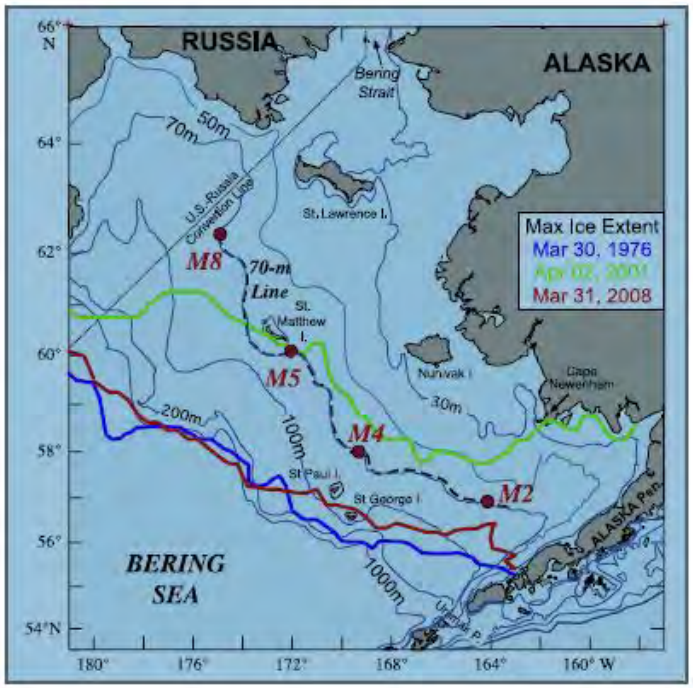
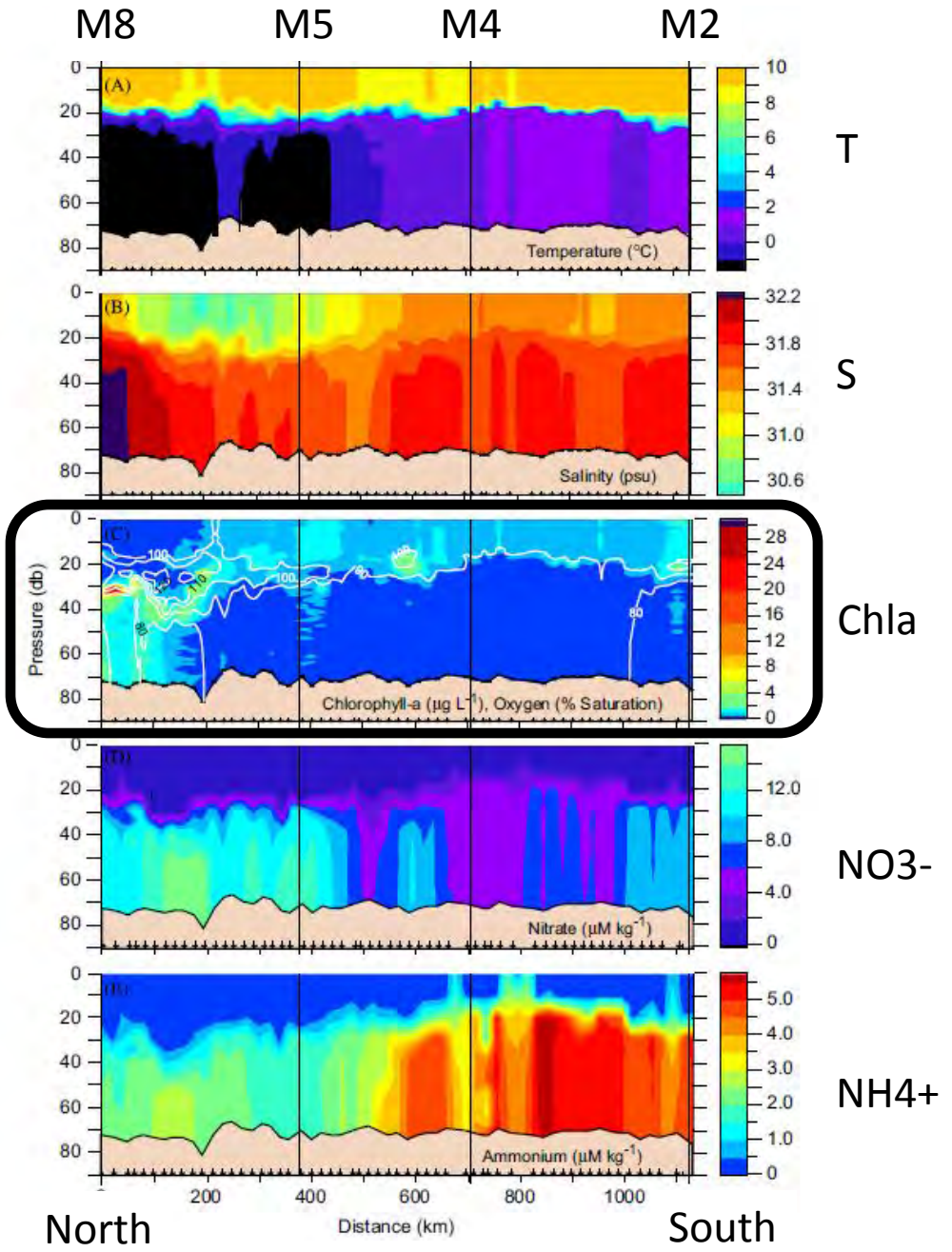
Surface T and Chla: significant **negative** relationship for **Region 13**, total and > 10 µm Chla
significant **positive** relationship for **Region 1**, total and > 10 µm Chla

Eisner et al. 2015, DSRII

Hydrographic data (PMEL, NOAA) along the 70-m isobath,

1–5 Sept, 2008

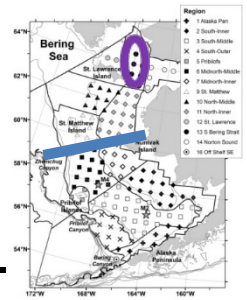




Stabeno, P. et al., 2012. A comparison of the physics, of the northern and southern shelves of the eastern Bering Sea and some implications to the ecosystem. Deep Sea Res. II 65-70:14-30.

Zooplankton Assemblages

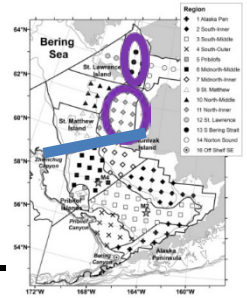
T, S, large and small zooplankton abundance and juvenile salmon biomass by Ecoregion: Means for 2002-2011 Red = high/maximum and blue = minimum values.



Ecoregions north of 60°N	T Top (° C)	T Bottom (° C)	S Top	S Bottom	Beam c (% light trans.)	Large zoo abund. (# m-3)	Small zoo abund. (# m-3)	Juvenile salmon biomass (kg km-2)
Norton Sound (14)	9.70	8.92	27.00	28.29	65	41	13037	575
S. Bering Strait (13)	7.51	5.15	31.11	31.59	82	2418	10399	2287
St. Lawrence (12)	7.65	2.97	31.80	32.20	89	183	13108	194
North Inner (11)	8.25	6.53	30.63	30.92	82	84	104127	3706
North Middle (10)	7.83	1.26	31.15	31.57	83	90	54969	819
St. Matthew (9)	7.61	1.33	31.32	31.74	84	67	5941	930

Gann, unpublished

T, S, large and small zooplankton abundance and juvenile salmon biomass by Ecoregion: Means for 2002-2011 Red = high/maximum and blue = minimum values.



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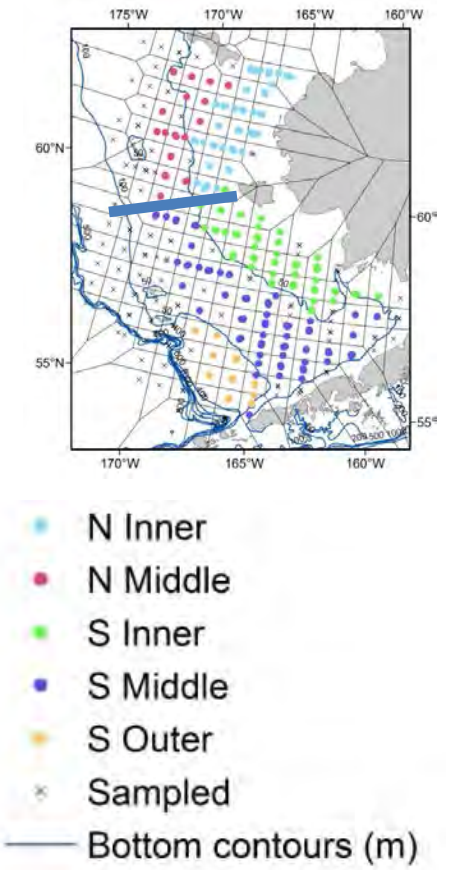
Gann, unpublished

Differences in zooplankton community structure (using abundance data) between warm (2003-2005) and cold (2006-2009) stanzas (*P value < 0.05 is significant)

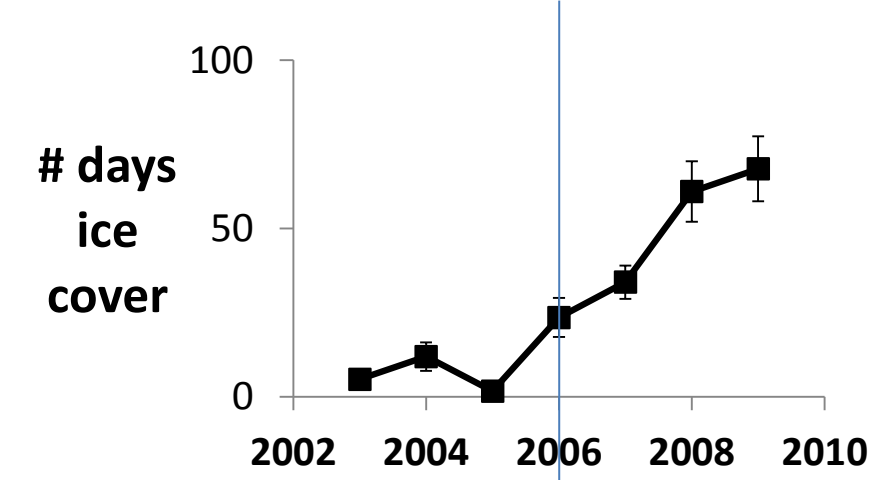
Domain	Large Zoo P(perm)	Small Zoo P(perm)
N Inner	**0.15**	**0.44**
N Middle	**0.024***	**0.029***
S Inner	**0.002***	**0.005***
S Middle	**0.001***	**0.001***
S Outer	**0.008***	**0.73**

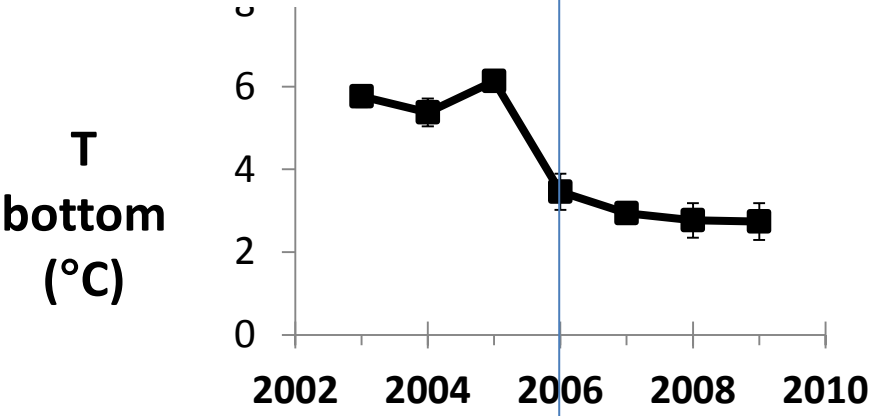
Primer-E, PERMANOVA test

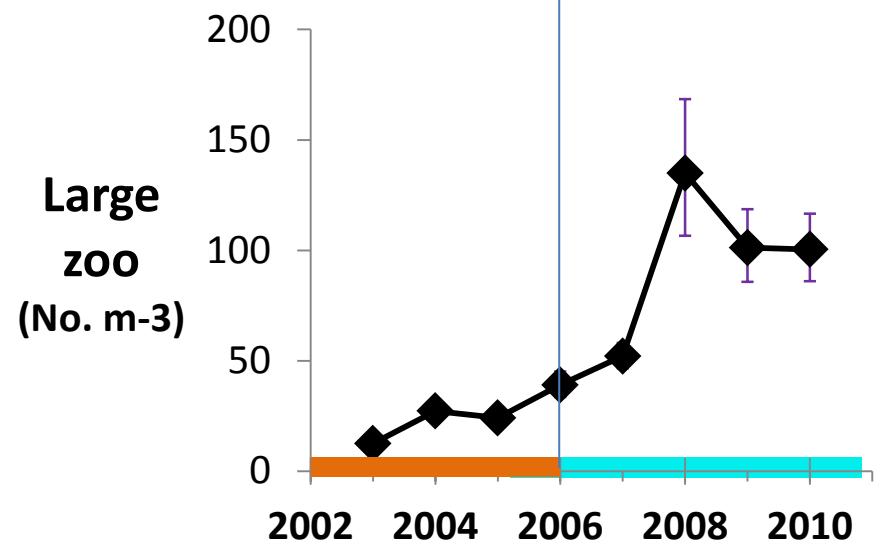


Eisner et al. 2014, DSRII

Ice cover, deep T and large zooplankton in SE Bering Sea







Eisner et al. (2014) DSRII

Large Zooplankton
Environmental variables in best-fit models:

P-values

Variable	S Inner	S Middle	S Outer	N Middle
Longitude	-	-	0.01	-
Latitude	-	-	-	0.01
Temp deep	-	0.001	-	0.001
Temp surface	0.03	0.001	-	-
Salinity deep	-	0.001	-	-
Integrated Chla	0.01	-	-	-
Ice retreat timing	-	-	0.01	0.08
Winter wind direction	0.01	-	-	-

Primer-E, PERMANOVA test

Eisner et al. 2014, DSRII

Small Zooplankton
Environmental variables in best-fit models

P-values

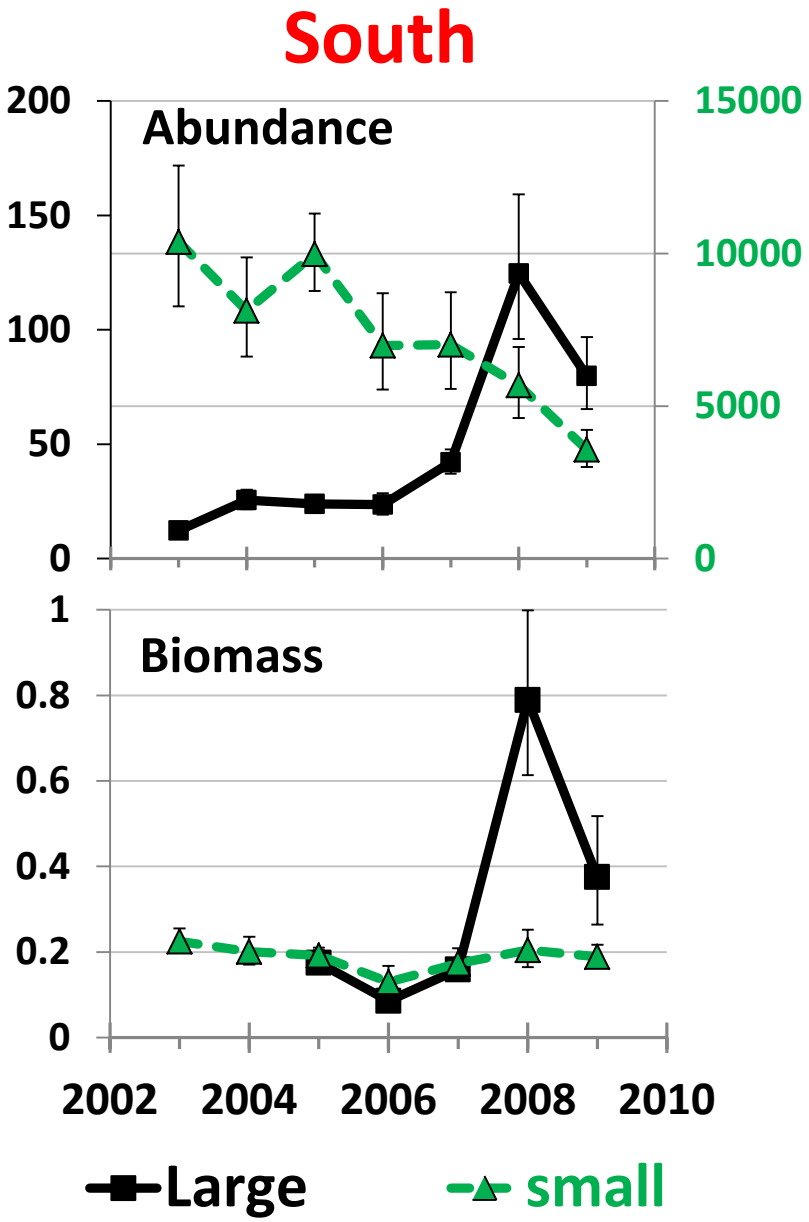
Variable	S Inner	S Middle	N Middle
Longitude	-	0.03	0.02
Latitude	-	-	0.04
Temp deep	0.001	0.003	-
Temp surface	0.001	0.001	-
Stability	-	0.001	-
Ice retreat timing	-	-	0.20

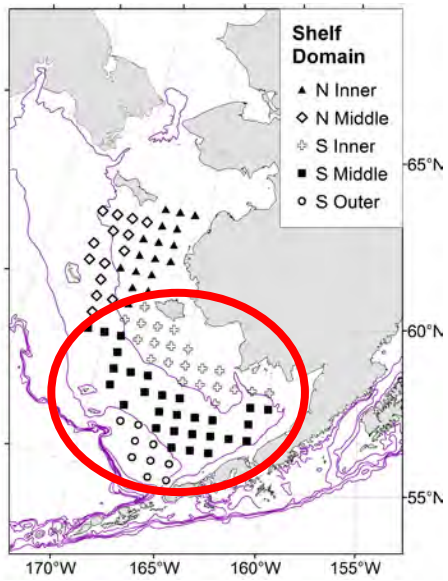
Primer-E, PERMANOVA test

Eisner et al. 2014, DSRII

Total abundance (No. m^{-3}) and biomass (wet wt, g m^{-3})

geometric mean, SE





Eisner et al. 2014, DSRII

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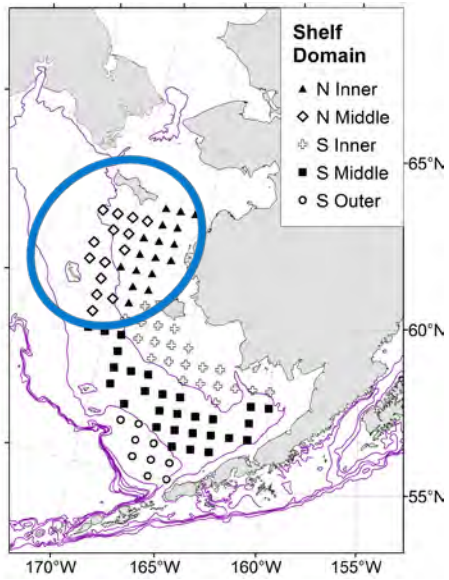
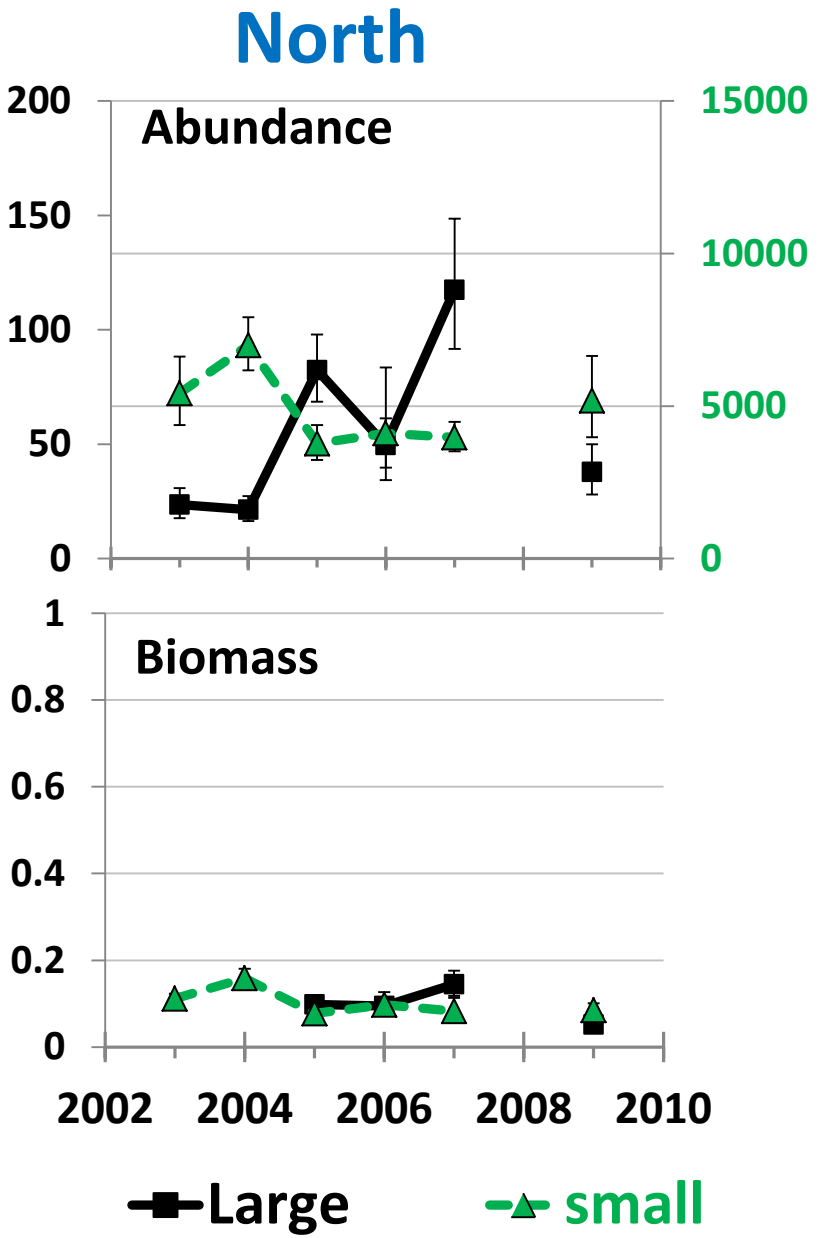
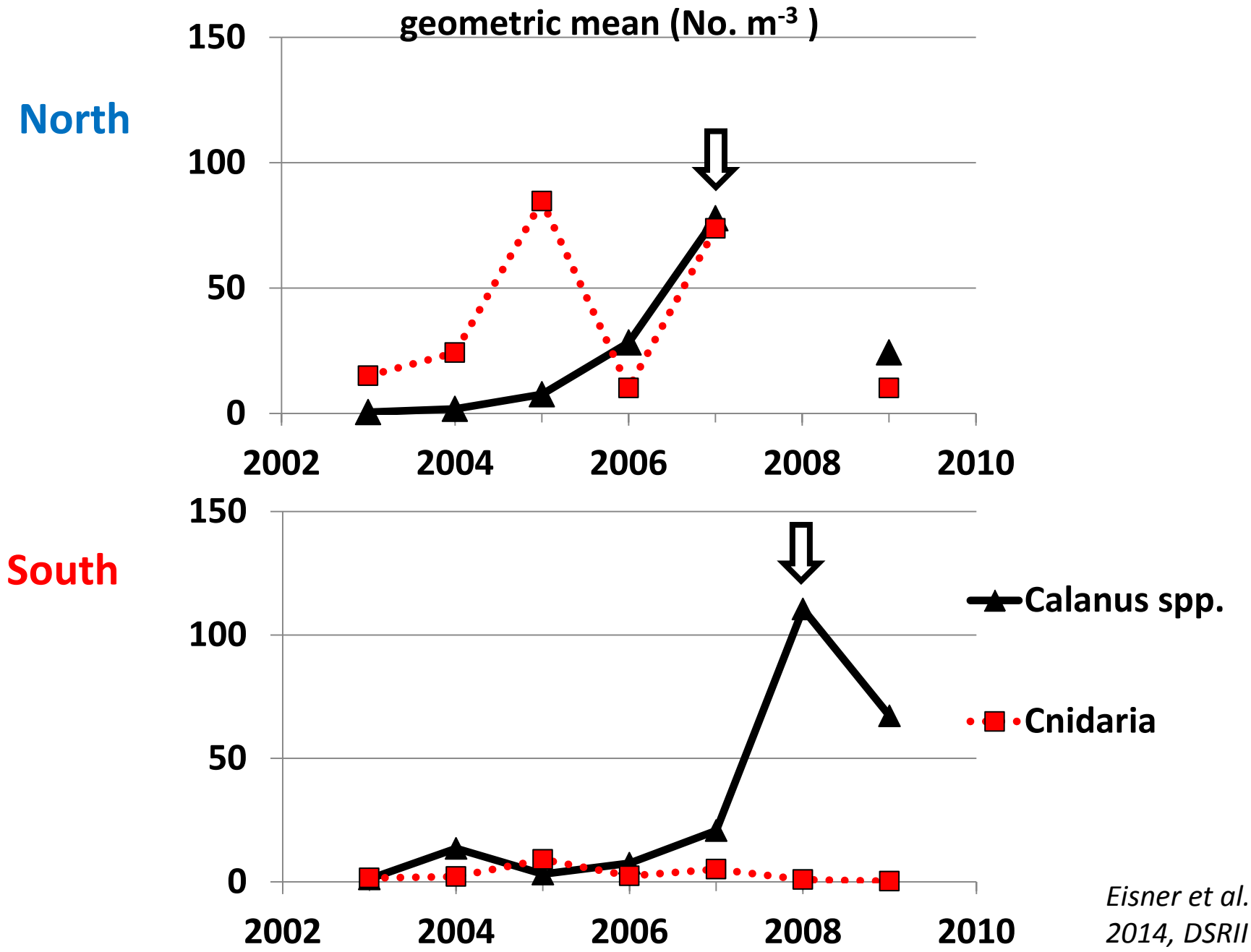




Eisner et al. 2014, DSRII

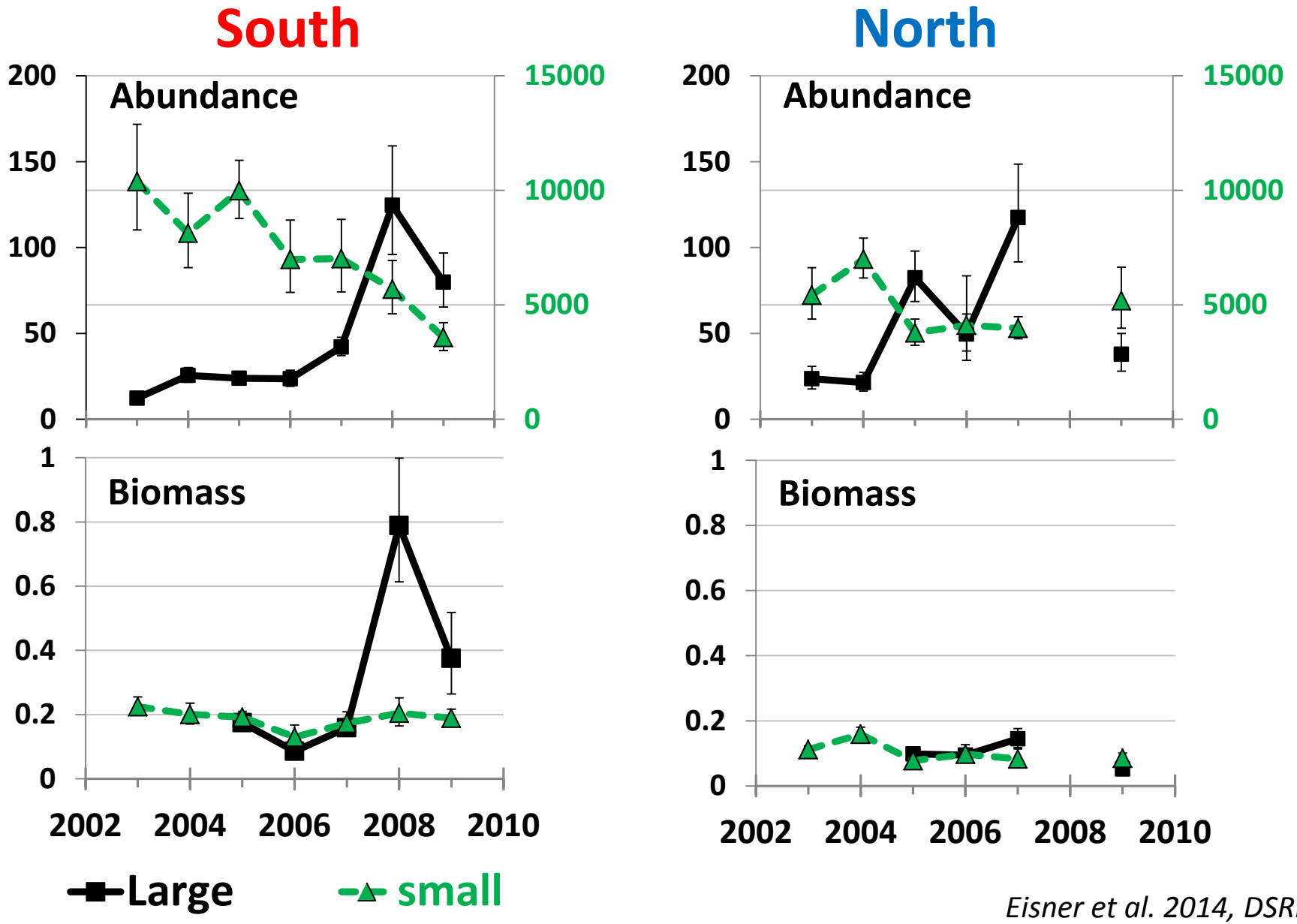
Zooplankton abundances,



Eisner et al. 2014, DSRII

Total abundance (No. m^{-3}) and biomass (wet wt, g m^{-3})

geometric mean, SE



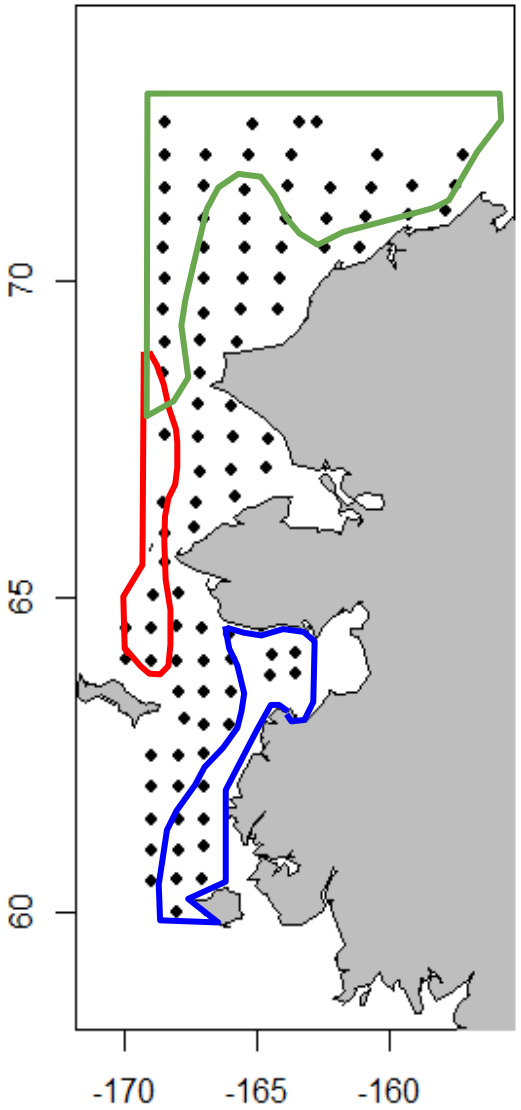
Eisner et al. 2014, DSRII

Northern Bering and Chukchi

Zoogeography Study using 2012 Arctic Eis data
(zooplankton, pelagic fish, benthic fish and invert., seabirds)

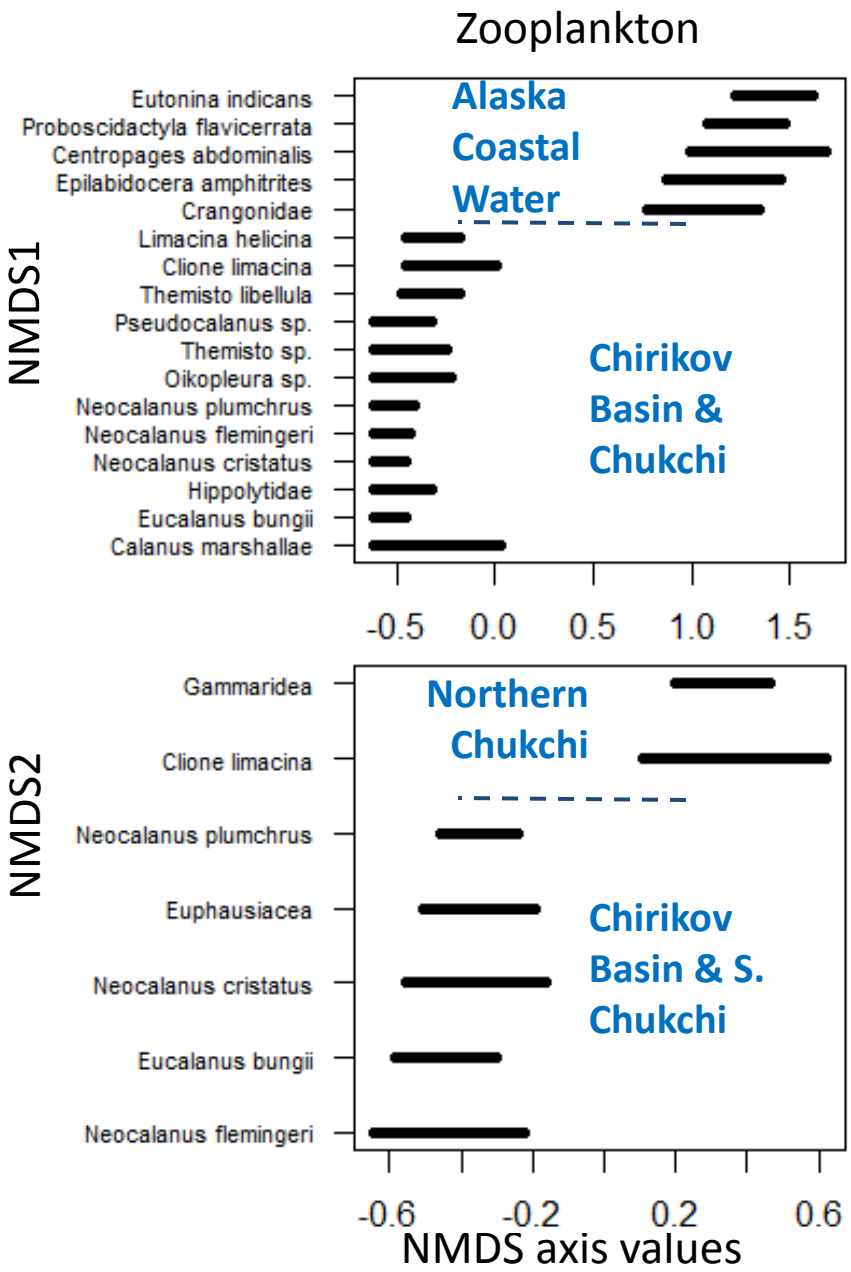
Cross-assemblage groupings

colder, saltier, but not as nutrient rich	Northern Chukchi shelf community
colder, saltier, nutrient rich	Chirikov Basin and southern Chukchi community
warmer, fresher, nutrient poor	Alaska Coastal Water community



Sigler et al. 2016. Summer zoogeography of the northern Bering and eastern Chukchi Seas, DSRII

Multivariate analysis



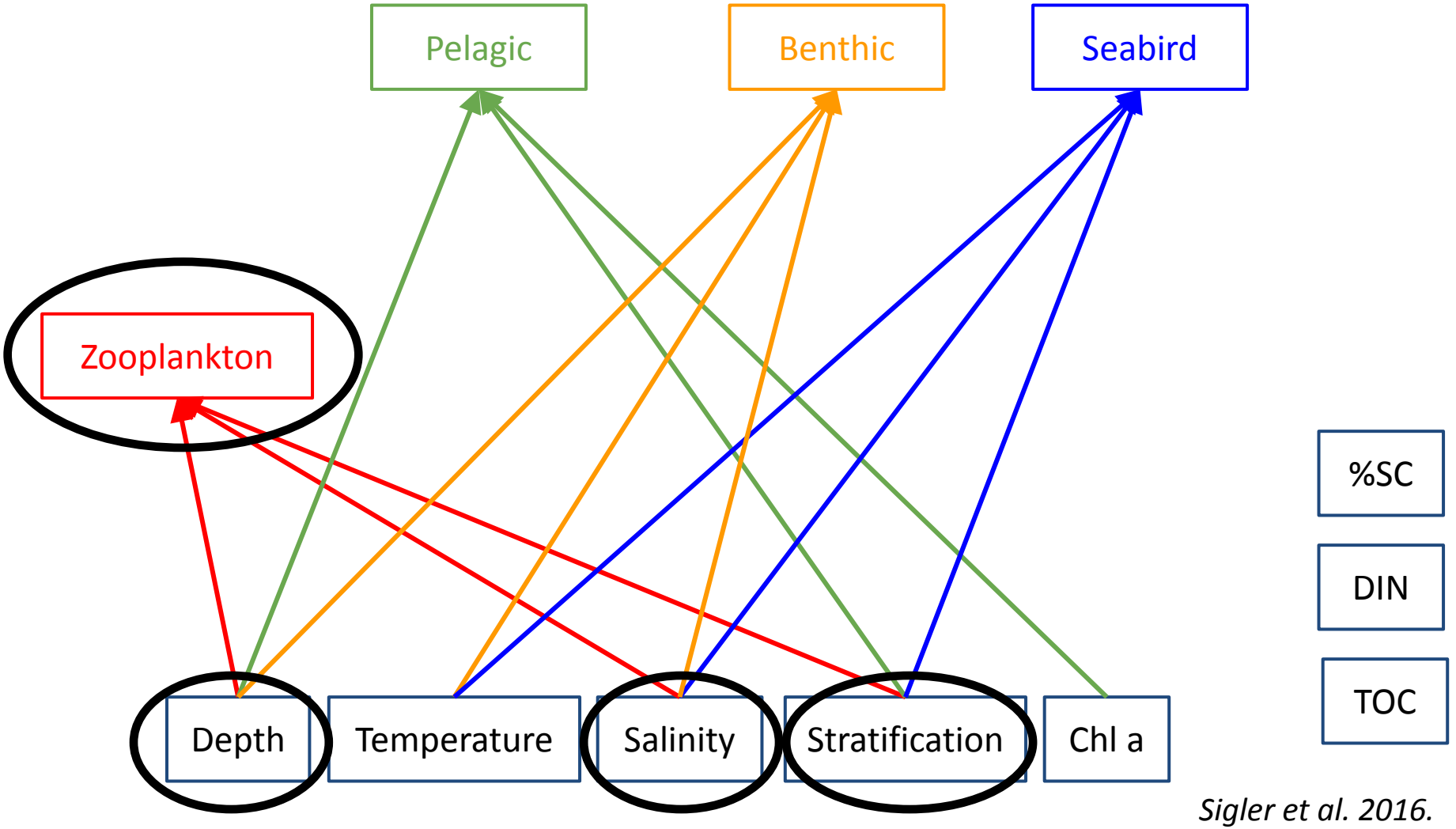
Zooplankton Species: gradients abrupt

Nearshore to Offshore

North to South

Sigler et al. 2016.

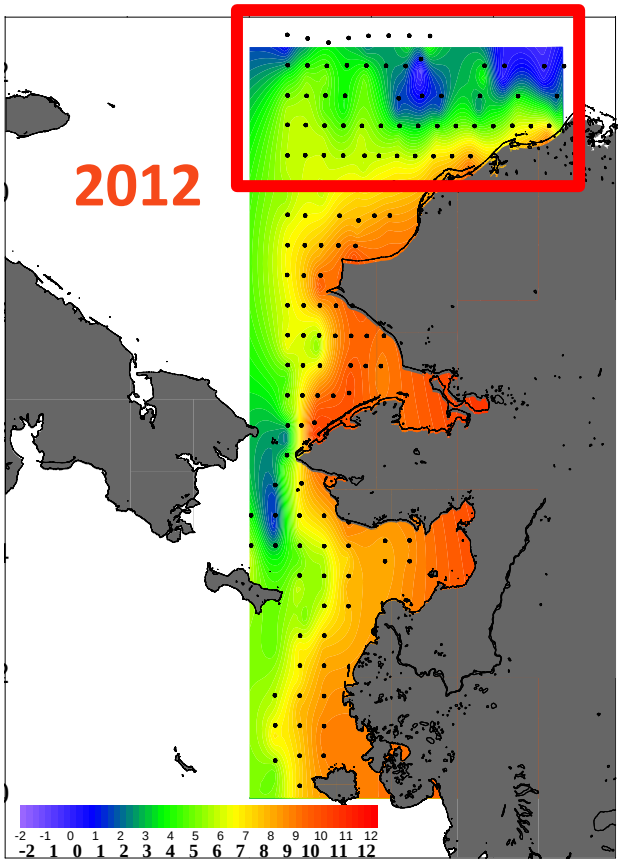
Influential environmental factors

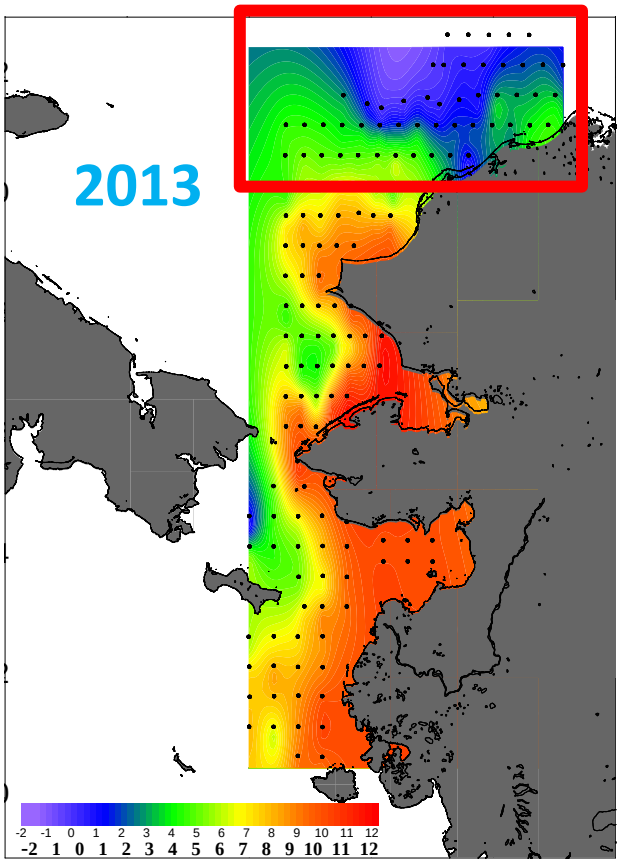


Sigler et al. 2016.

Arctic EIS: Temperature above pycnocline,

07Aug-24Sep



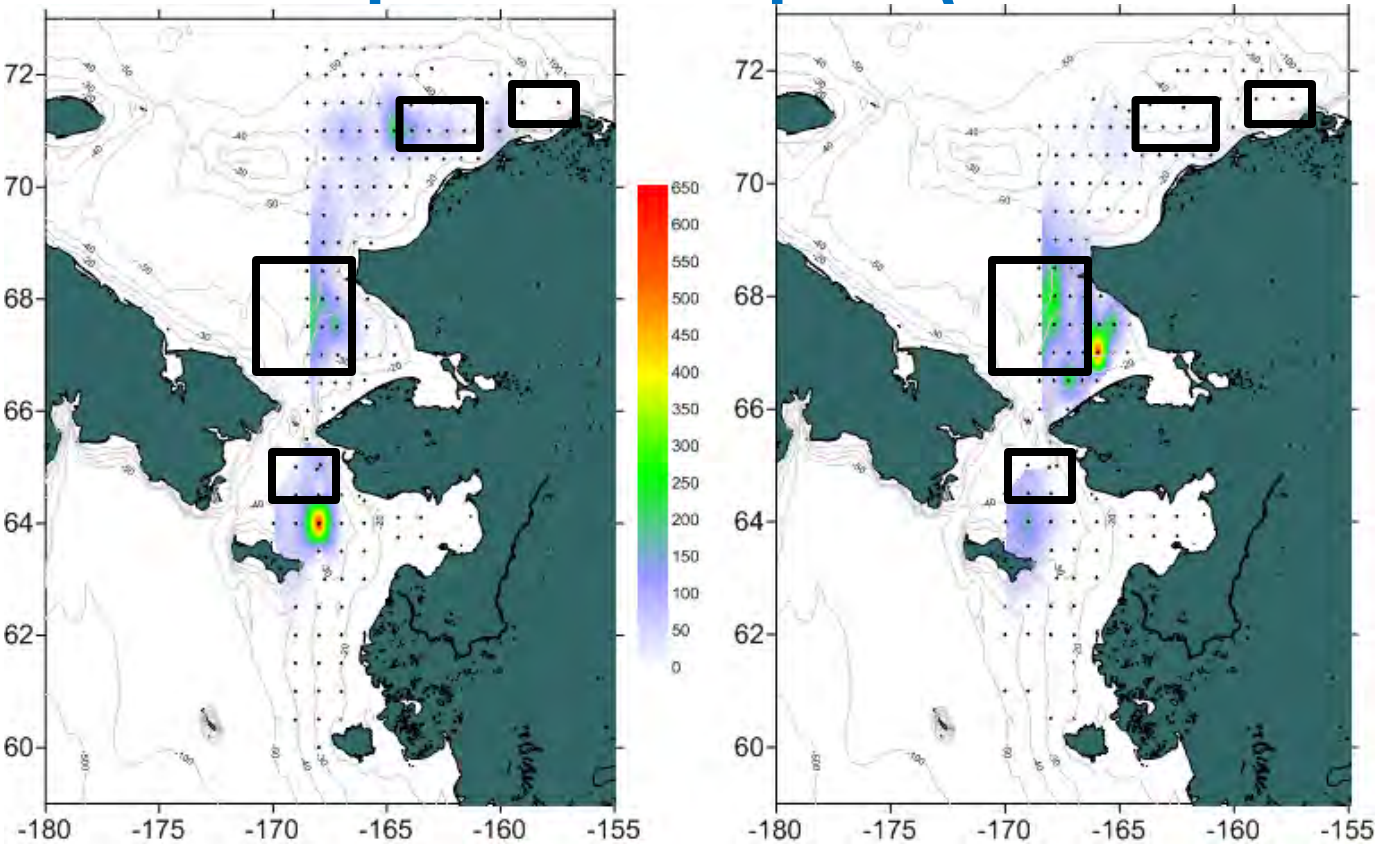


- **most differences occurring in the northeast**
- **ACC reduced in 2013**

Pinchuk & Eisner, Deep-Sea Research II, in press

Oceanic Pacific Species Complex (*Neocalanus* spp.)

2012



2013

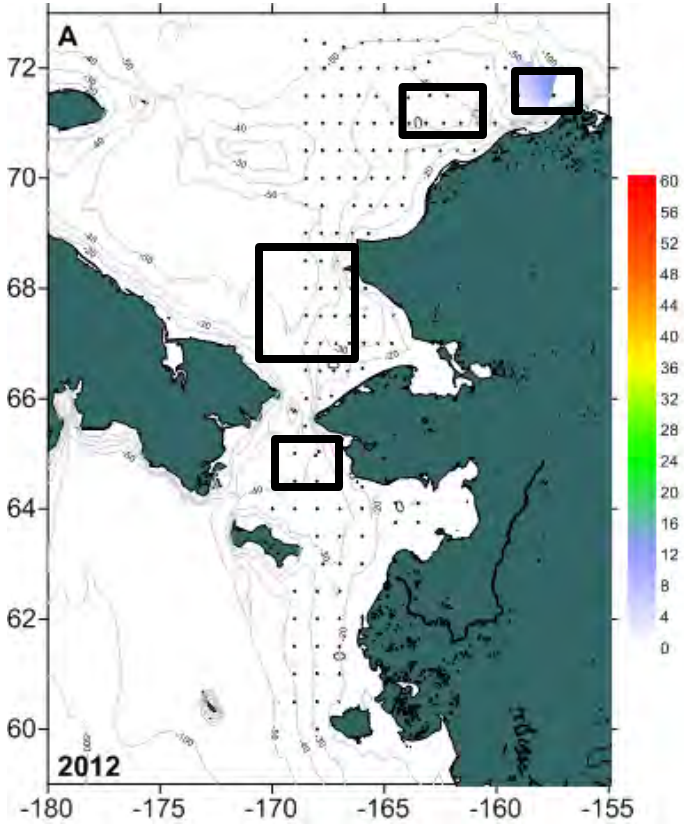
	T_{above}	T_{below}	S_{above}	S_{below}
Correlation (p<0.05)	-0.041	-0.092	**0.510**	**0.439**

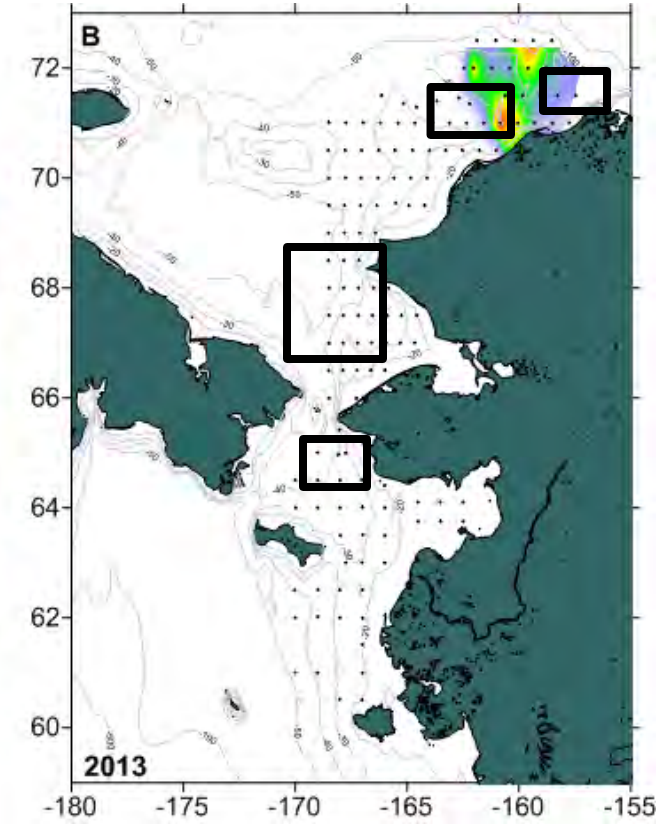
- **strong positive correlations to salinity indicate a link to the Bering/Chukchi Summer Water**
- **occur over the Central Channel and in northeast in 2012, but restricted to southern shelf in 2013**

Pinchuk & Eisner, in press

Arctic Species Complex (*Calanus hyperboreus*)

2012





2013

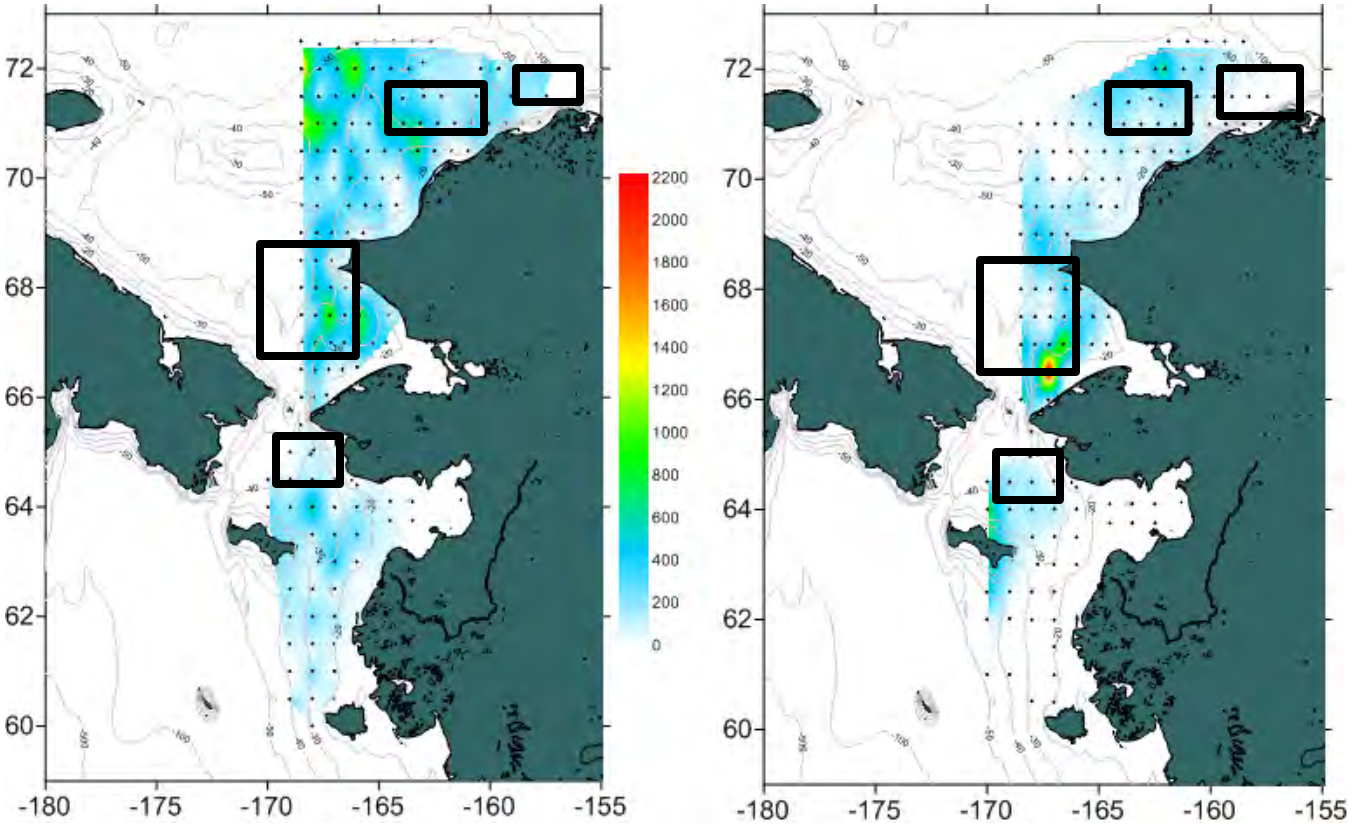
	T_{above}	T_{below}	S_{above}	S_{below}
Correlation (p<0.05)	-0.541	-0.468	-0.440	0.080

- **strong negative correlations to temperature and salinity above the pycnocline, indicate a link to Melt Water**
- **virtually absent in 2012, but expanded in the northeast in 2013**

Pinchuk & Eisner, in press

Calanus glacialis

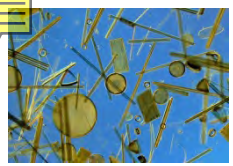
2012



2013

- occur over the Central Channel and in the northeast in 2012
- two centers of distribution in 2013: south and northeast

Pinchuk & Eisner, in press



Conclusions

- Changes in temperature, ice, Chla and zooplankton composition are greater in S than N, but still see changes in N (in some regions).
- Lower Chla, lower zooplankton biomass and more gelatinous zooplankton in N than S.
- High Chla and high abundance of large zooplankton in South Bering Strait. Negative relationship of Chla to T (unlike in S Bering).
- Abrupt gradients in zooplankton composition from north Bering to Chukchi, related to water mass, latitude (northward transport important).
- See only half the picture, need to look at western side of north Bering and Chukchi seas.