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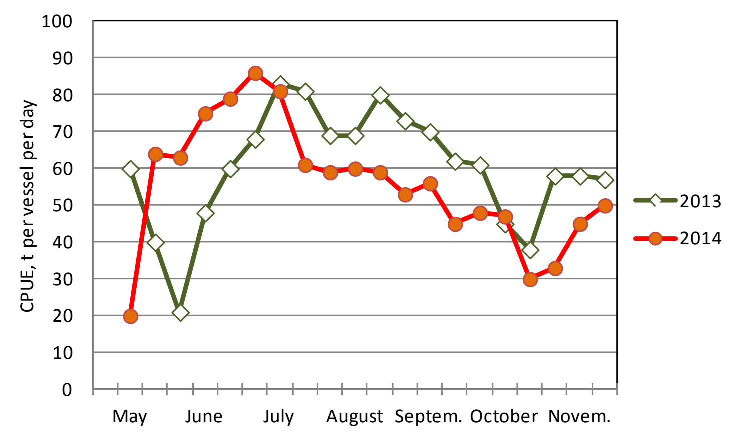
Environmental impacts on zooplankton and pollock fishery in the northern Bering Sea

Preface

Russian pollock fishery in the Bering Sea is based mainly on the feeding grounds at Cape Navarin where it feeds in summer-fall season. Dynamics of catch is determined here by zooplankton abundance and has considerable year-to-year variations. CPUE is usually high in summer then either decreases to moderate values or keeps high values until November.



Mean CPUE for the pollock fishery in the Navarin area in 2013 and 2014.

The CPUE lowering in August 2014 was the reason to stop the fishing operations by many vessels, therefore the total landing of pollock in the Bering Sea was only 330,600 t in 2014 instead of 358,900 t in 2013

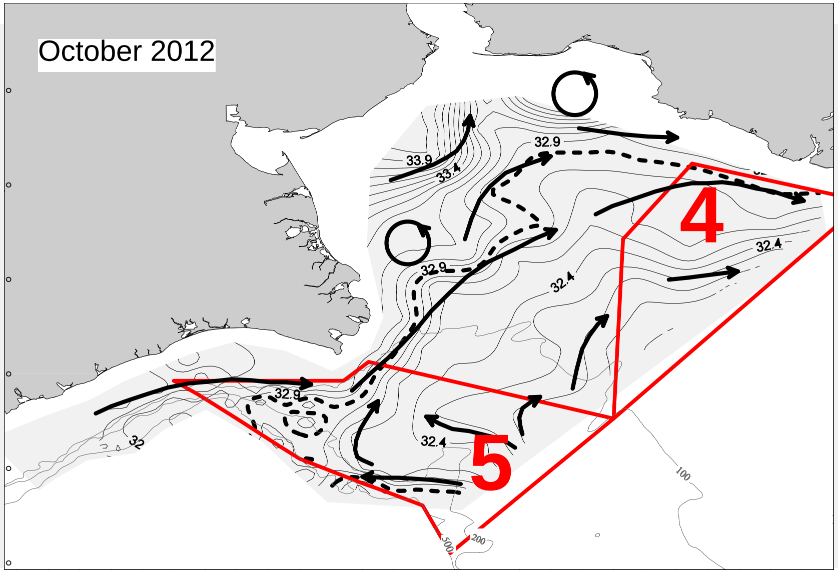
Goals

- to understand reasons and mechanisms of zooplankton variability in the area of Cape Navarin, particularly for the autumn season, and its influence on pollock fishery;

- to determine impacts of recent changes in marine environments (sea ice, water temperature, currents) on zooplankton, walleye pollock, and the Russian pollock fishery in this area.

Data

The less studied component of this system was the zooplankton. Time-series of zooplankton abundance, by species, were prepared by Dr. Anatoly Volkov for the 1986-2015 on the base of TINRO zooplankton data collection by averaging the data within biostatistical areas and by months, separately for day and night samples. The fishing grounds at Cape Navarin correspond to the biostatistical area № 5 that occupies the external shelf and slope beyond the Anadyr Bay



Scheme of biostatistical areas location in the northern Bering Sea. Salinity and streams at 50 m depth in October 2012 are shown

Day or Night	Year	Month	Sagitta elegans	Calanus glacialis	Neocalanus plumchrus	Neocalanus cristatus	Pseudocalanus minutus	Eucalanus bungii	Centropagus abdominalis	Metridia pacifica	Oithona similis	Thysanoessa inermis	Thysanoessa raschii	Thysanoessa longipes	Themisto libellula	Themisto pacifica	Limacina helicina	Clione limacina	Number of samples
д	1986	9	293	0	45	16	26	384	0	10	38	0	0	4	0	30	0	0	4
д	1987	8	482	3	3	0	130	830	0	106	нд	6	47	0	0	0	5	0	2
д	1987	9	264	0	8	1	22	313	0	21	нд	0	0	2	0	5	0	0	8
д	1988	10	24	10	0	0	16	9	0	10	нд	4	0	0	0	2	0	1	4
д	1989	7	48	5	117	204	55	49	0	22	240	15	11	0	0	6	4	0	7
д	1990	6	179	4	293	256	19	339	0	58	17	0	5	0	0	6	1	5	15
д	1990	10	269	0	31	147	4	256	39	20	нд	19	0	10	0	11	2	2	6
д	1992	1	149	1	6	3	17	60	0	3	15	32	0	0	0	51	0	1	1
д	1998	9	438	1	25	48	18	64	14	43	17	0	4	8	0	13	2	0	4
д	1998	10	825	21	30	271	5	61	0	26	3	81	0	3	0	45	1	1	3
д	1999	9	247	26	212	59	19	80	0	25	21	0	0	1	1	10	1	1	28
д	2000	9	425	34	206	40	17	144	1	24	38	1	0	13	0	6	0	0	7
д	2001	10	50	1	33	11	21	26	0	6	12	1	0	0	0	2	4	0	6
д	2003	8	75	11	76	3	29	187	0	6	27	16	13	0	0	6	1	0	3
д	2003	10	76	3	18	3	39	134	0	20	11	4	0	24	0	8	0	2	2
д	2004	10	108	0	14	83	64	24	23	5	0	0	1	81	0	11	2	0	2
д	2005	7	85	6	157	113	12	187	0	39	30	0	2	7	0	2	2	2	5
д	2005	9	175	6	45	25	21	199	0	41	27	4	0	2	0	4	43	9	32
д	2006	8	193	185	138	70	44	95	0	46	18	3	1	0	0	2	0	0	2
д	2006	9	238	0	98	0	9	88	0	24	37	0	1	91	0	9	0	0	1
д	2007	7	32	1	212	78	3	3	0	24	5	0	0	2	0	5	1	0	2
д	2007	9	128	4	28	16	54	155	1	18	37	1	8	0	9	3	1	1	4
д	2008	7	146	1	83	429	16	56	0	15	17	0	0	1	50	4	0	2	10
д	2008	8	107	22	187	85	7	22	0	59	11	46	26	2	35	2	0	2	19
д	2008	9	130	200	13	5	34	29	45	15	15	149	69	0	0	1	0	1	3
д	2009	7	78	13	272	36	8	20	0	11	11	0	69	4	277	0	0	0	4
д	2009	9	189	8	36	125	9	75	11	25	17	27	19	11	48	10	1	1	10
д	2010	7	3	1	22	0	21	106	3	35	24	0	0	0	186	0	0	0	2
д	2010	8	199	111	88	0	49	135	13	118	24	26	6	2	45	1	0	0	28
д	2010	9	89	81	9	0	185	16	0	183	17	0	1	3	0	1	1	0	5
д	2010	10	178	11	7	1	68	21	0	23	11	0	0	2	0	2	1	0	2
д	2011	6	123	409	218	117	161	156	0	46	26	0	1	0	0	2	3	0	3
д	2011	9	171	197	255	6	71	35	0	82	19	2	1	5	0	9	12	1	11
д	2012	7	142	0	35	137	5	45	0	5	18	0	0	0	0	7	1	1	12
д	2012	8	176	2	57	271	12	18	0	8	20	8	9	0	0	4	0	1	12
д	2012	9	227	0	11	6	35	34	3	7	25	0	76	0	0	7	0	1	3
д	2012	10	43	16	15	31	3	4	0	5	8	53	10	11	13	3	0	0	1
д	2013	6	105	176	146	75	22	5	0	8	13	0	39	13	0	2	1	2	4
д	2013	9	195	35	45	27	9	15	0	34	28	3	2	5	0	3	0	0	9
д	2014	9	177	3	64	125	25	44	1	78	24	0	29	84	0	7	1	0	2
д	2014	10	231	20	24	24	27	22	0	64	20	20	17	2	0	16	0	3	10

Example of the data set (biomass mg/m^3, by species)

Data

Oceanographic data (temperature and salinity profiles from the sea surface to the bottom) were obtained in almost annual expeditions of TINRO research vessels in this area.

Data on the ice cover were loaded from NOAA ftp-server: ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/shapefiles as shape-files of mean month ice edge, which were processed by QGIS software.

The currents in the upper 30 m layer were calculated for 1/3-degree grid by means of on-line re-analysis software OSCAR (version 2009.f): http://podaac.jpl.nasa.gov/dataset.

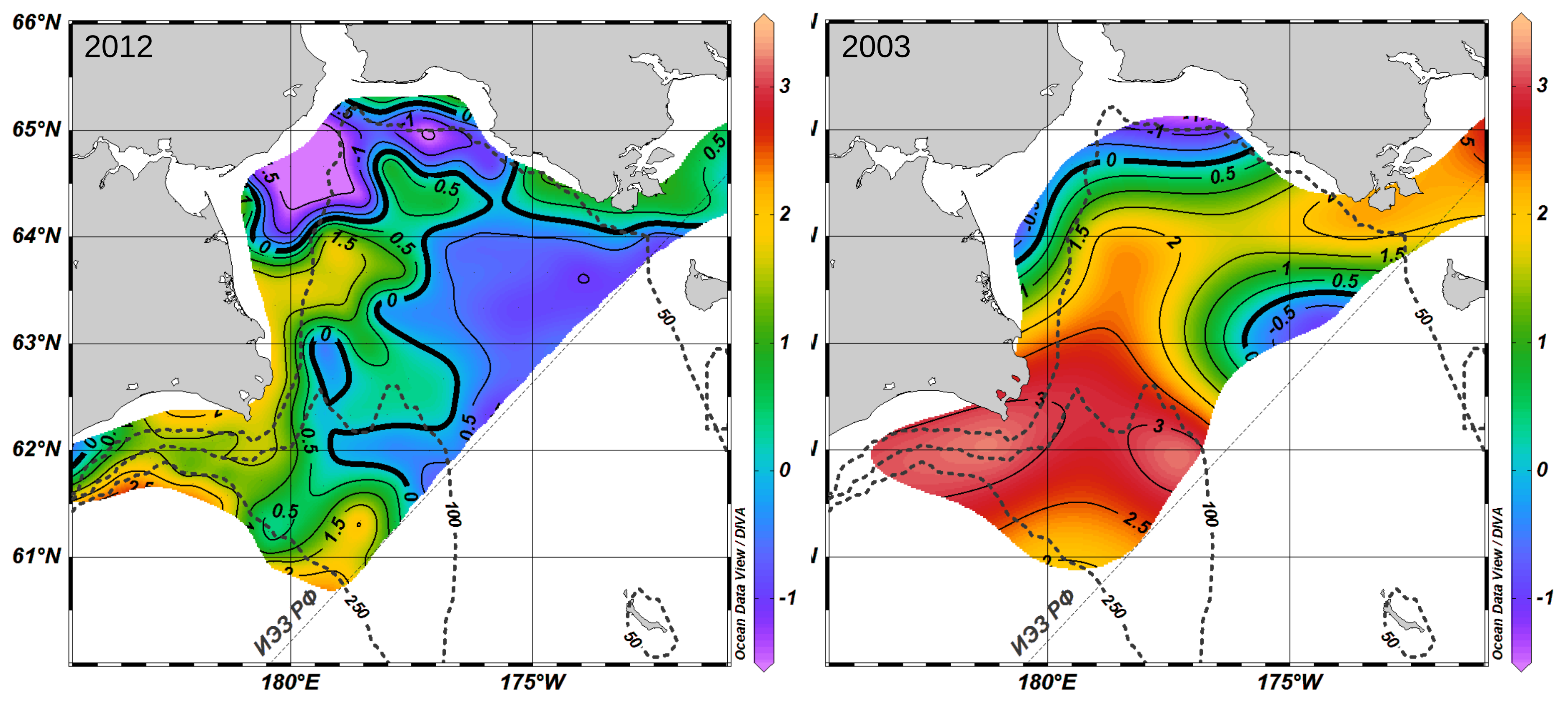
Data on pollock catch were found in materials of operative forecasting of fishing operations published in TINRO, prepared mainly by Mikhail Stepanenko and Elena Gritsay.

Scheme of RV Buhoro survey in the western Bering Sea (June –August 2017)

Oceanographic regime

The main feature of oceanographic regime in the area of Cape Navarin is the so called “Lawrence Cold Pool” at the bottom of the eastern shelf that forms in winter and remains along summer. However, the area of this cold water pool and its temperature have prominent year-to-year variations in dependence on winter severity.

The warm Navarin Current goes around the Lawrence Cold Pool from the west and further to the Bering Strait.



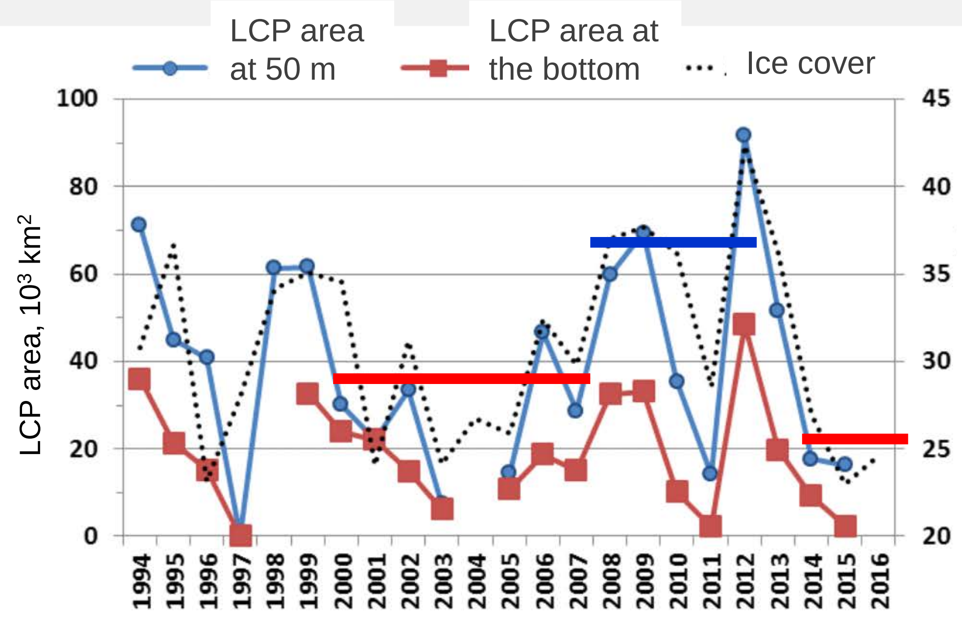
Examples of water temperature distribution at the bottom of the Anadyr Bay and adjacent areas in August after severe winter (2012, left panel) and relatively warm winter (2003, right panel)

Oceanographic regime

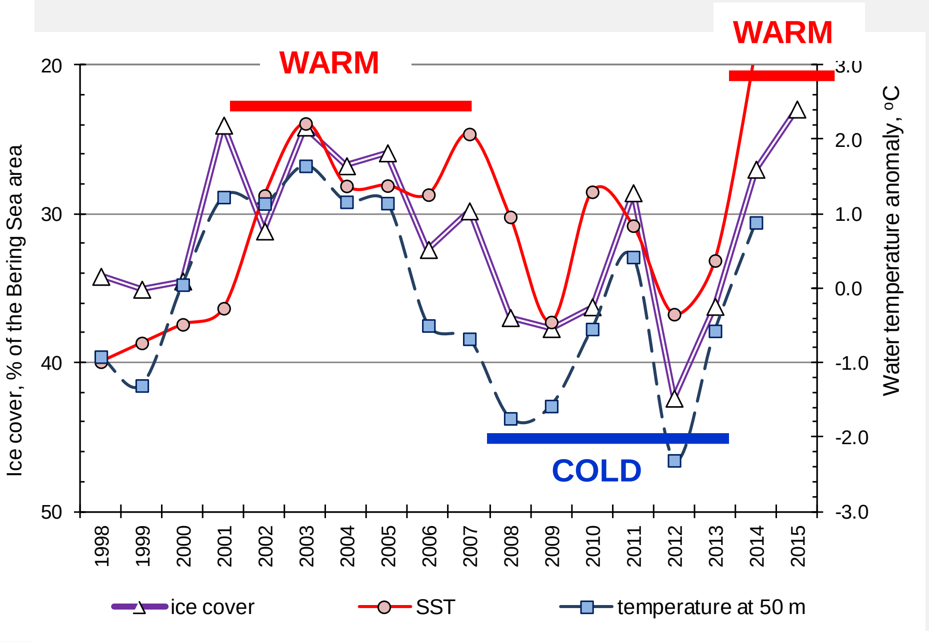
The Lawrence Cold Pool becomes wider and thicker after severe winters with the vast ice cover, and vice versa, that's why its area in summer correlates well with the mean ice cover in winter, in particular at 50 m depth.

The area at Cape Navarin could be occupied in summer either by cold waters of the Lawrence Cold Pool or by warmer and saltier waters of the Navarin Current, so its summer conditions depend on state of the Lawrence Cold Pool, i.e. on severity and ice cover in previous winter: the warmer the winter, the warmer and saltier water is observed at Cape Navarin, both in the upper and bottom layers.

The main pattern of long-term variability in the last decade are shifts to **cooling in 2008** and to **warming in 2014**



Year-to-year changes of the Bering Sea ice cover averaged for January-April and the cold pool area with the temperature below 0°C at 50 m depth and at the sea bottom in August-September

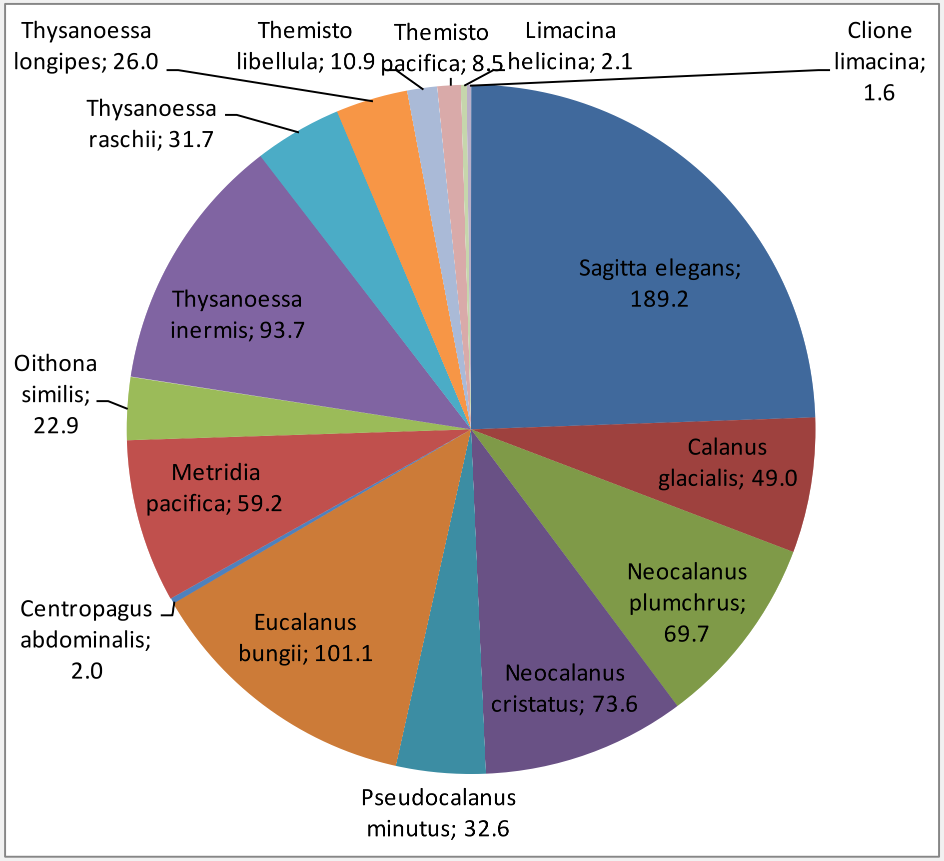


Year-to-year changes of water temperature anomaly at the sea surface and at 50 m depth averaged within the biostatistical area № 5 and the Bering Sea ice cover in January-April (inverted axis)

Zooplankton

The main groups of zooplankton in the Navarin area are (excluding jellyfish):

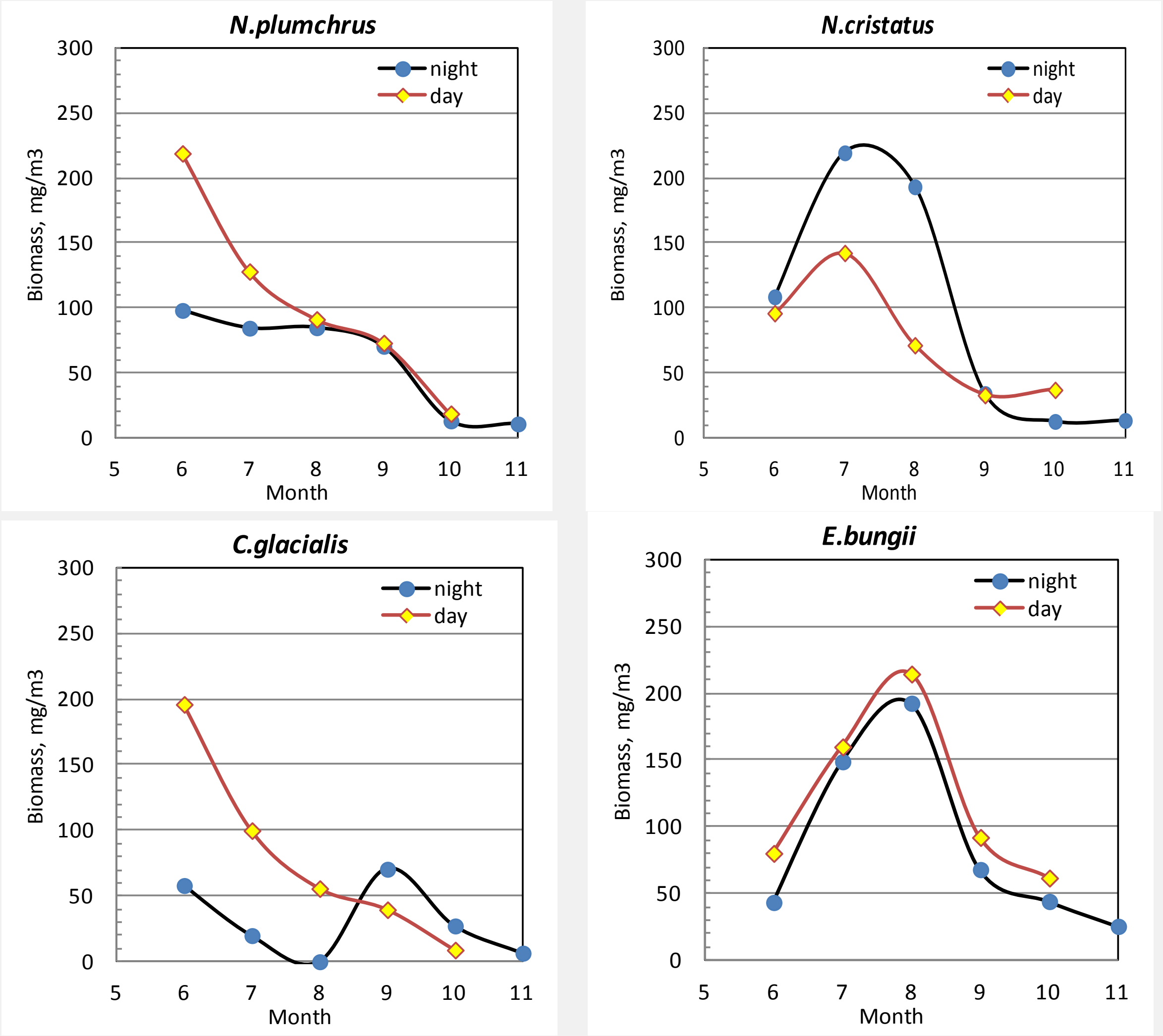
- arroworms (mainly *Sagitta elegans*, on average 24 % by biomass)
- large-sized copepods (main species *C.glacialis, N.plumchrus, N.cristatus, E.bungii* – summary 38 %)
- euphausiids (*T.inermis, T.raschii, T.longipes* – summary 19 %)
- small- and medium-sized copepods (main species *P.minutus, O.similis, M.pacifica* – summary 15 %)



Mean species composition of zooplankton within the biostatistical area № 5 in the Bering Sea

Zooplankton

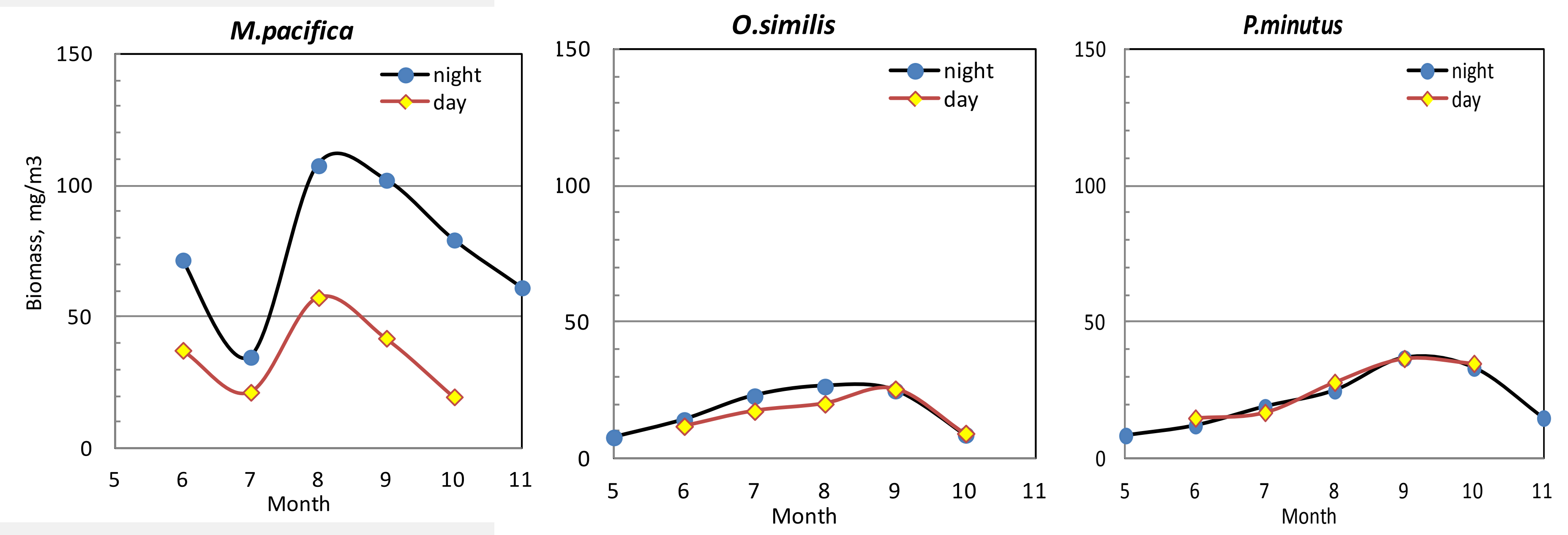
Seasonal variability is determined for each mass species. Biomass of large copepods decreases in autumn.



Seasonal dynamics of mean month biomass for the main species of large-sized copepods

Zooplankton

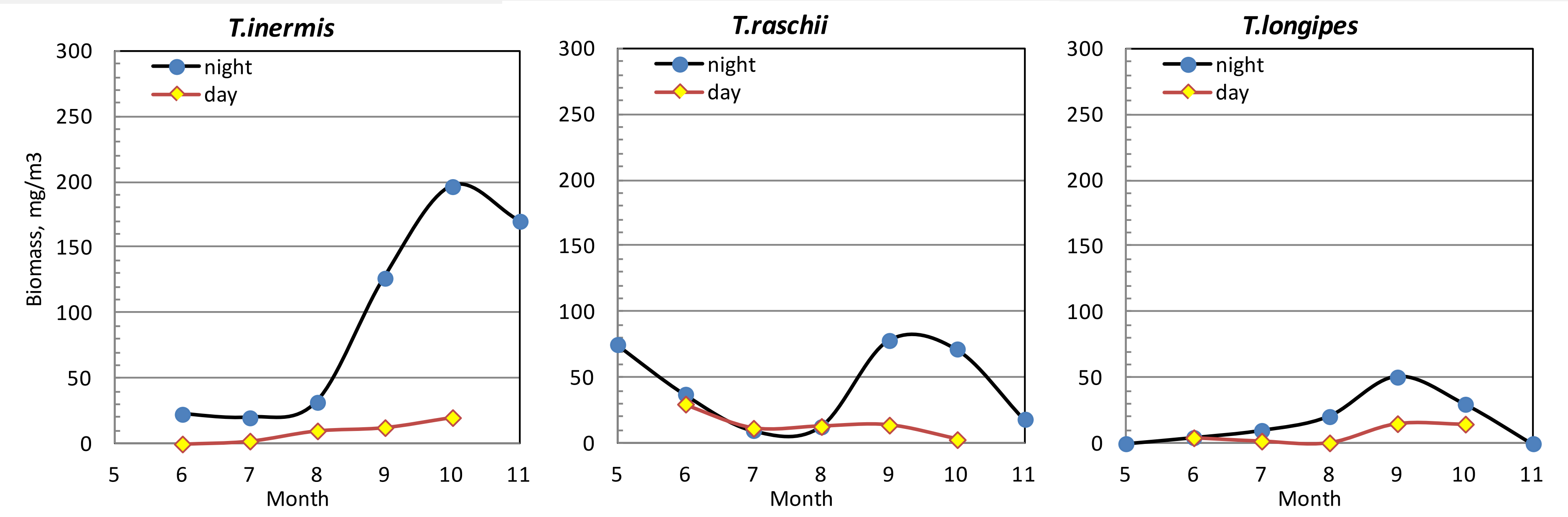
Seasonal variability is determined for each mass species. Biomass of small and medium-sized copepods is rather stable



Seasonal dynamics of mean month biomass for the main species of medium-sized and small-sized copepods

Zooplankton

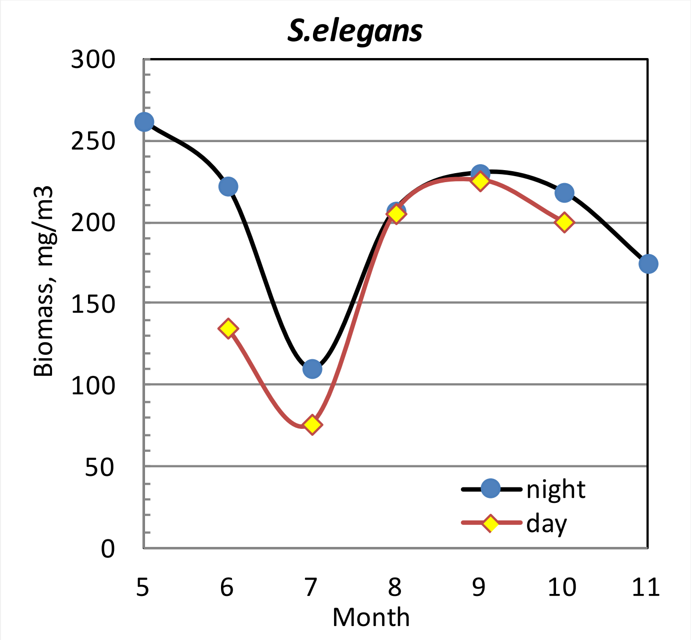
Seasonal variability is determined for each mass species. Biomass of euphausiids (*Thysanoessa inermis*) increases in autumn.



Seasonal dynamics of mean month biomass for the main species of euphausiids.
Day samples don’t represent the real abundance for all Euphausia species

Zooplankton

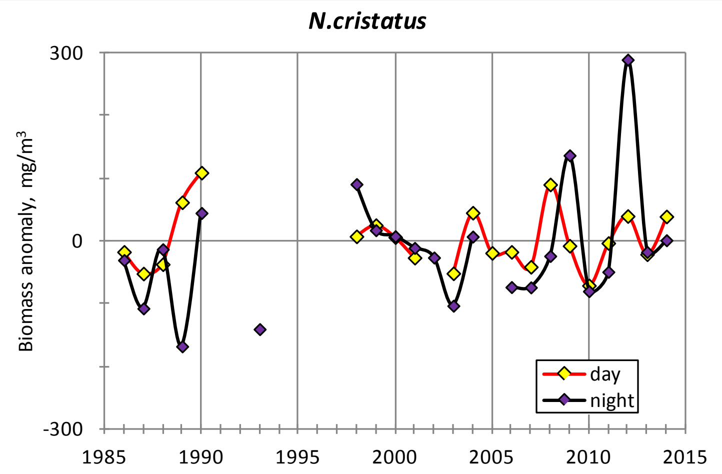
Seasonal variability is determined for each mass species. Arrowworms have two peaks of biomass annually

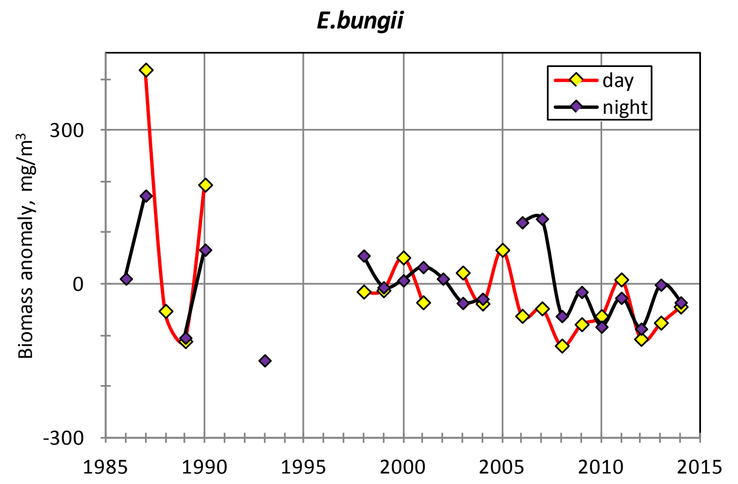


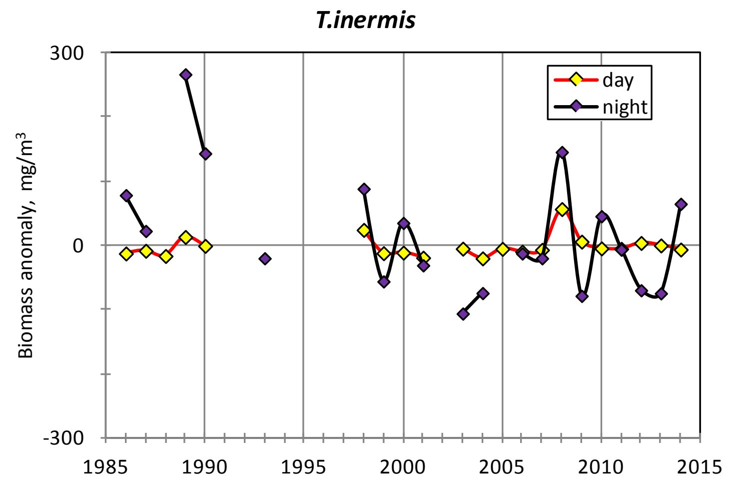
Seasonal dynamics of mean month biomass for Sagitta.

Zooplankton

Although year-to-year changes of mean annual anomalies of the species biomass have some prominent patterns, their time-series are not comparable with any environmental factor because of multiplicative nature of the biomass



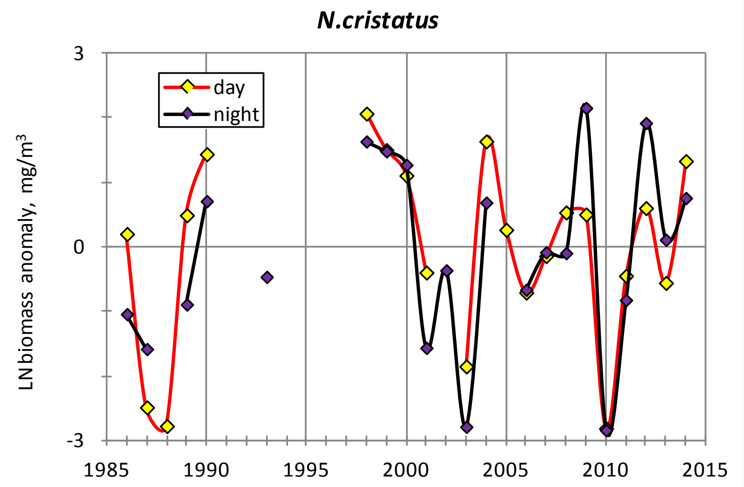


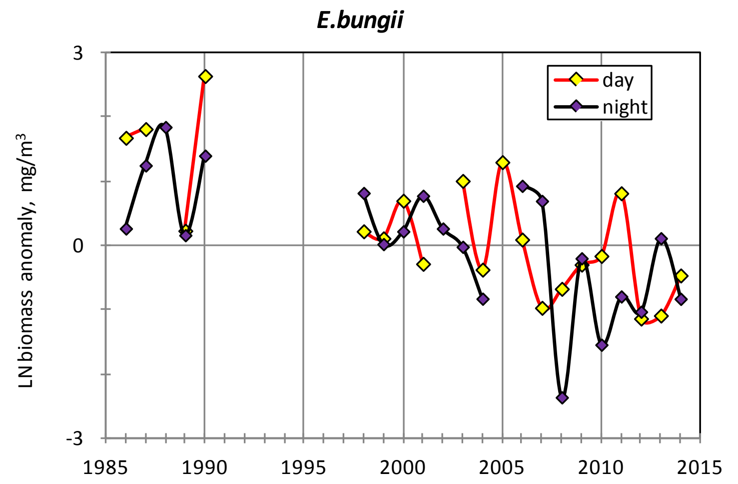


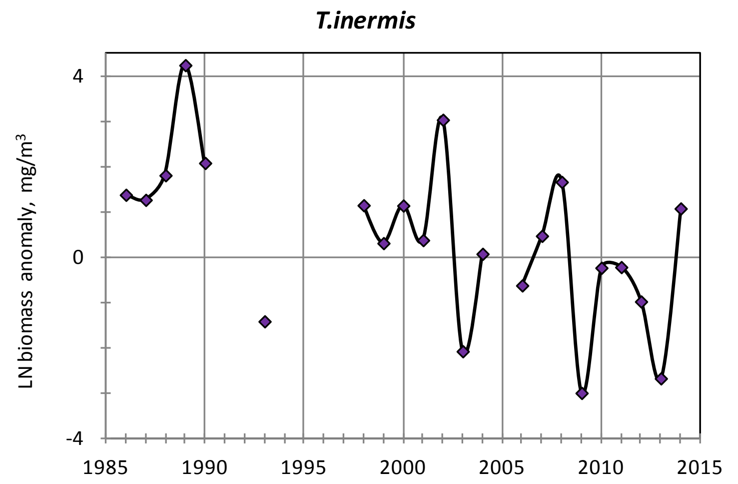
Examples of year-to-year dynamics for some mass species of zooplankton in the Navarin area.

Zooplankton

Although year-to-year changes of mean annual anomalies of the species biomass have some prominent patterns, their time-series are not comparable with any environmental factor because of multiplicative nature of the biomass. To avoid this problem, the anomalies were logarithmed







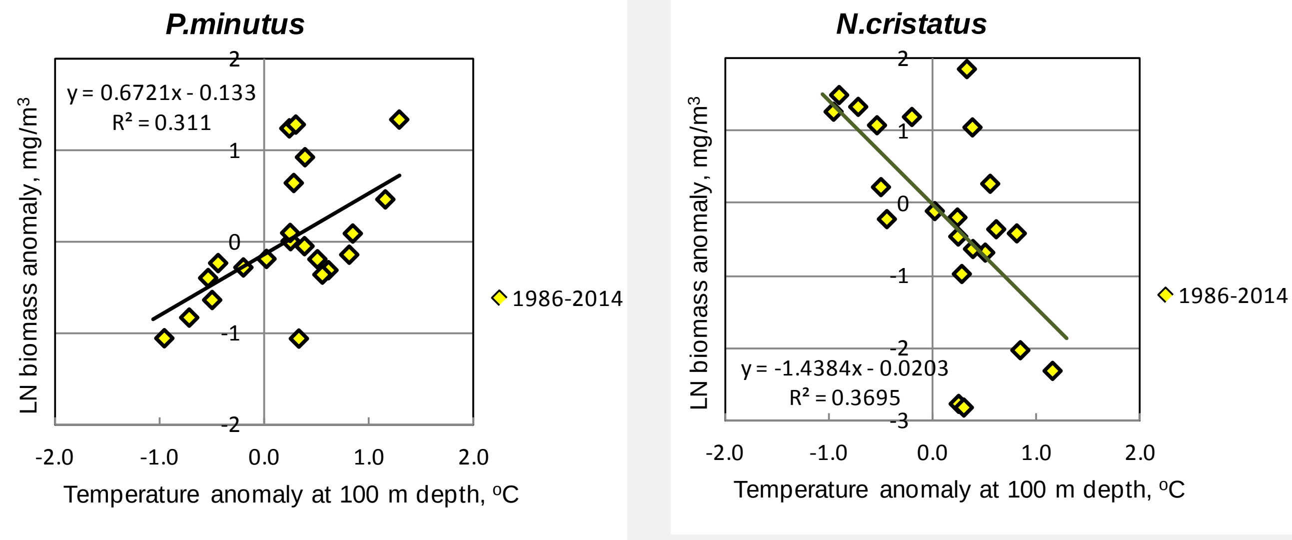
Examples of year-to-year dynamics for some mass species of zooplankton in the Navarin area (logarithms of the biomass anomalies)

Environmental influence on zooplankton

Two mass species only has significant linear correlation with the environments:

Neocalanus cristatus is more abundant in cold conditions and

Pseudicalanus minutus prefers warm environments.

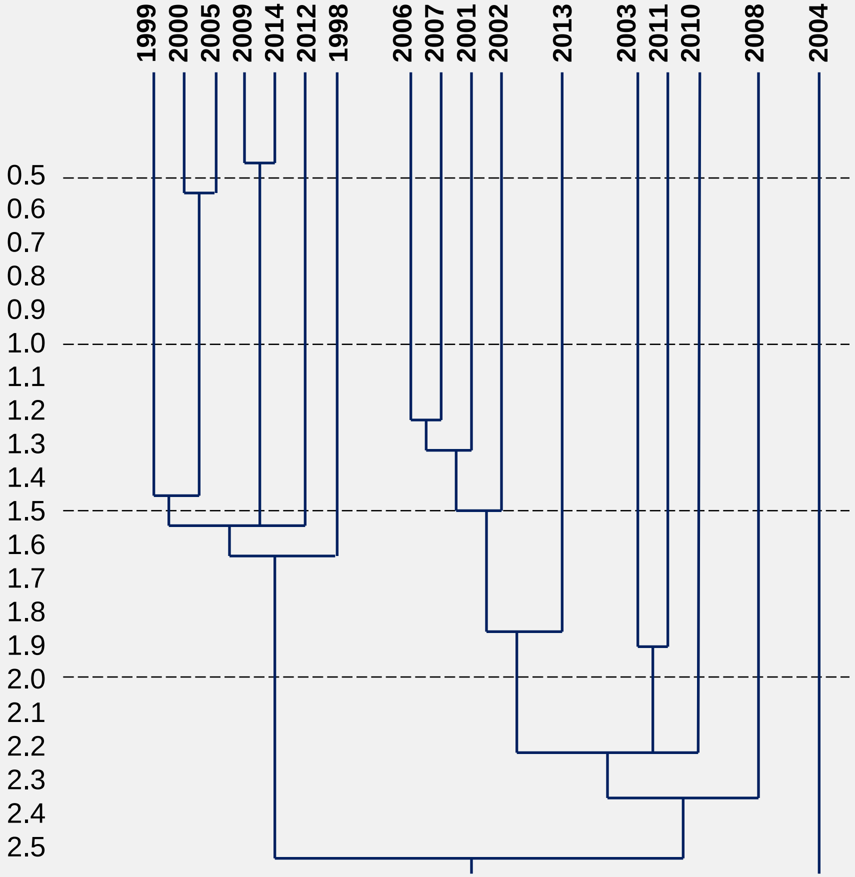


Dependence of P.minutus and N,cristatus abundance in the Navarin area (logarithmed anomalies of annual biomass) on water temperature in the layer 100 m in the same area

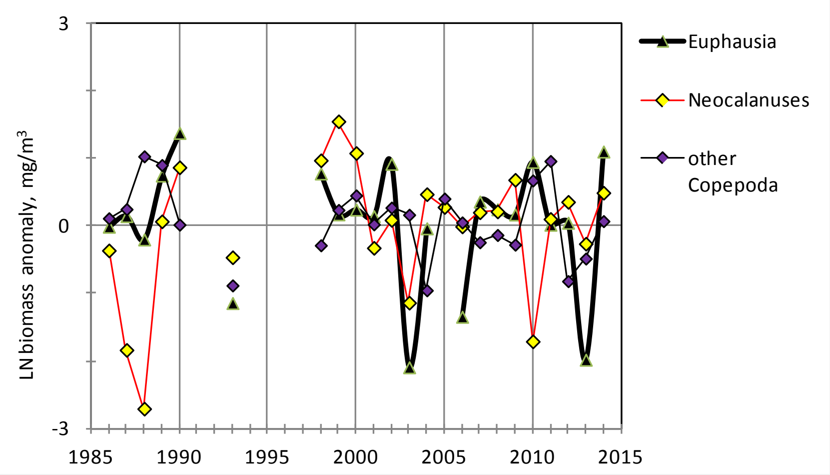
Environmental influence on zooplankton

Some species, as neocalanuses *N.plumchrus* and *N.cristatus* have similar year-to-year changes, but majority of species have their unique variability. Although some years have similar species composition, the year-to-year variability of the whole zooplankton community looks chaotic.

Why the regime changes don't affect visibly on many species of zooplankton community? We suppose, that the environmental influence could be non-linear.



Dendrogram of similarity for Copepoda species composition in the Navarin area (Euclidean distances for biomass anomalies)

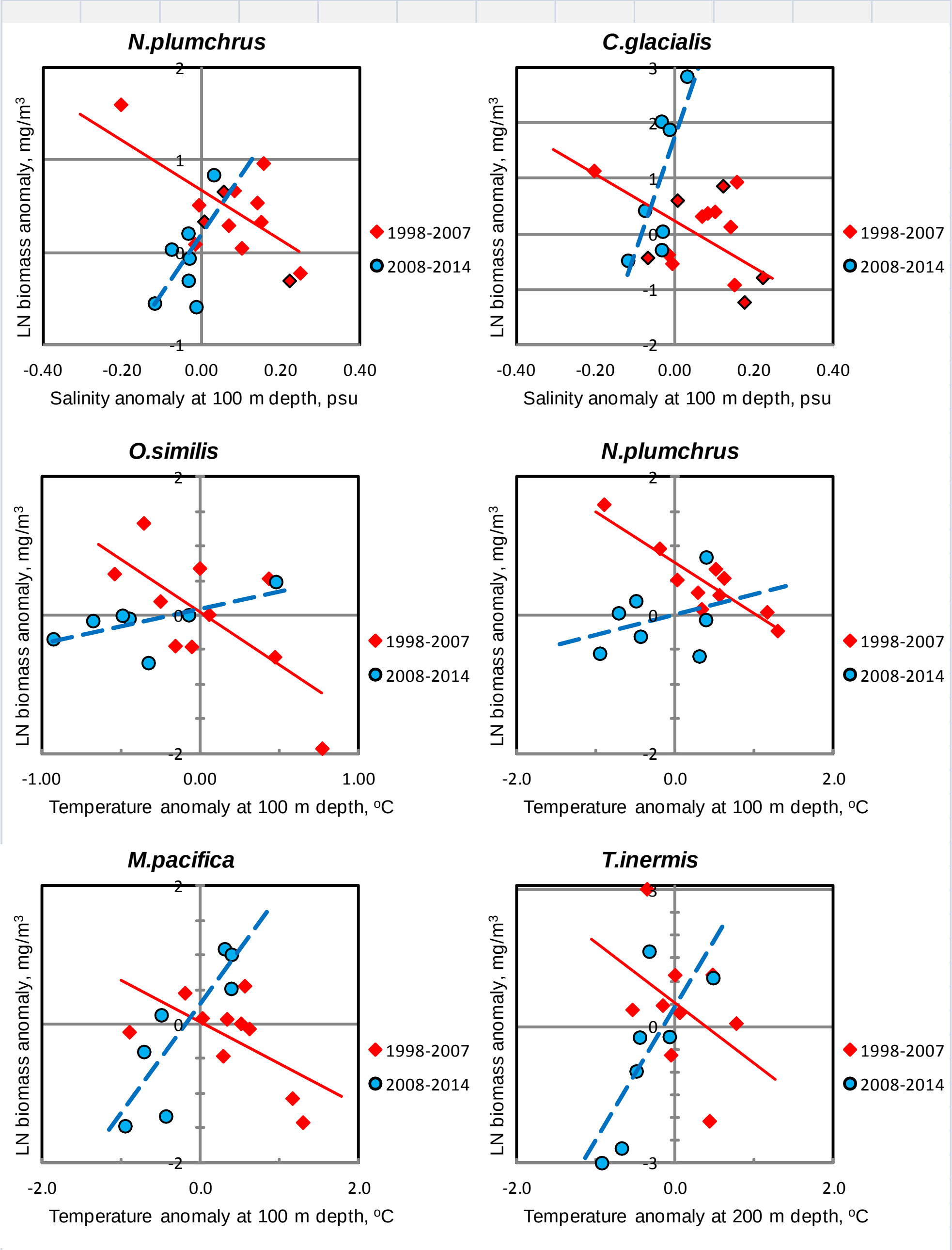


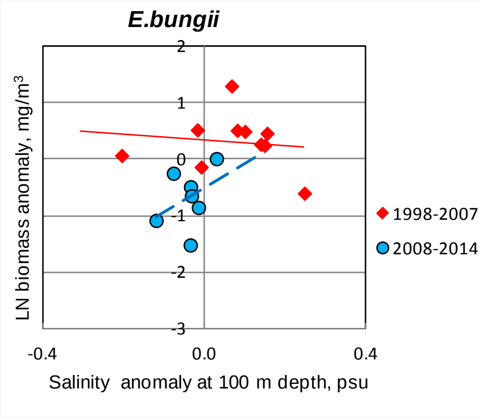
Year-to-year dynamics of the main taxonomic groups of zooplankton in the Navarin area (logarithms of the biomass anomalies)

Environmental influence

To reveal the non-linear effect of environments, the influence of water temperature on plankton species is analyzed separately for the “warm” (2001-2007) and “cold” (2008-2013) periods. The result is surprising: abundance of the species depends significantly on the water temperature or salinity in the layer 100-200 m in both periods, but these relationships have opposite signs!

So, the species abundance dependence on environmental conditions is usually U-shaped: the medium conditions are favorable for but cold conditions in the cold period and warm conditions in the warm period are not favorable for many (with exclusion of *N.cristatus* and *P.minutus*)

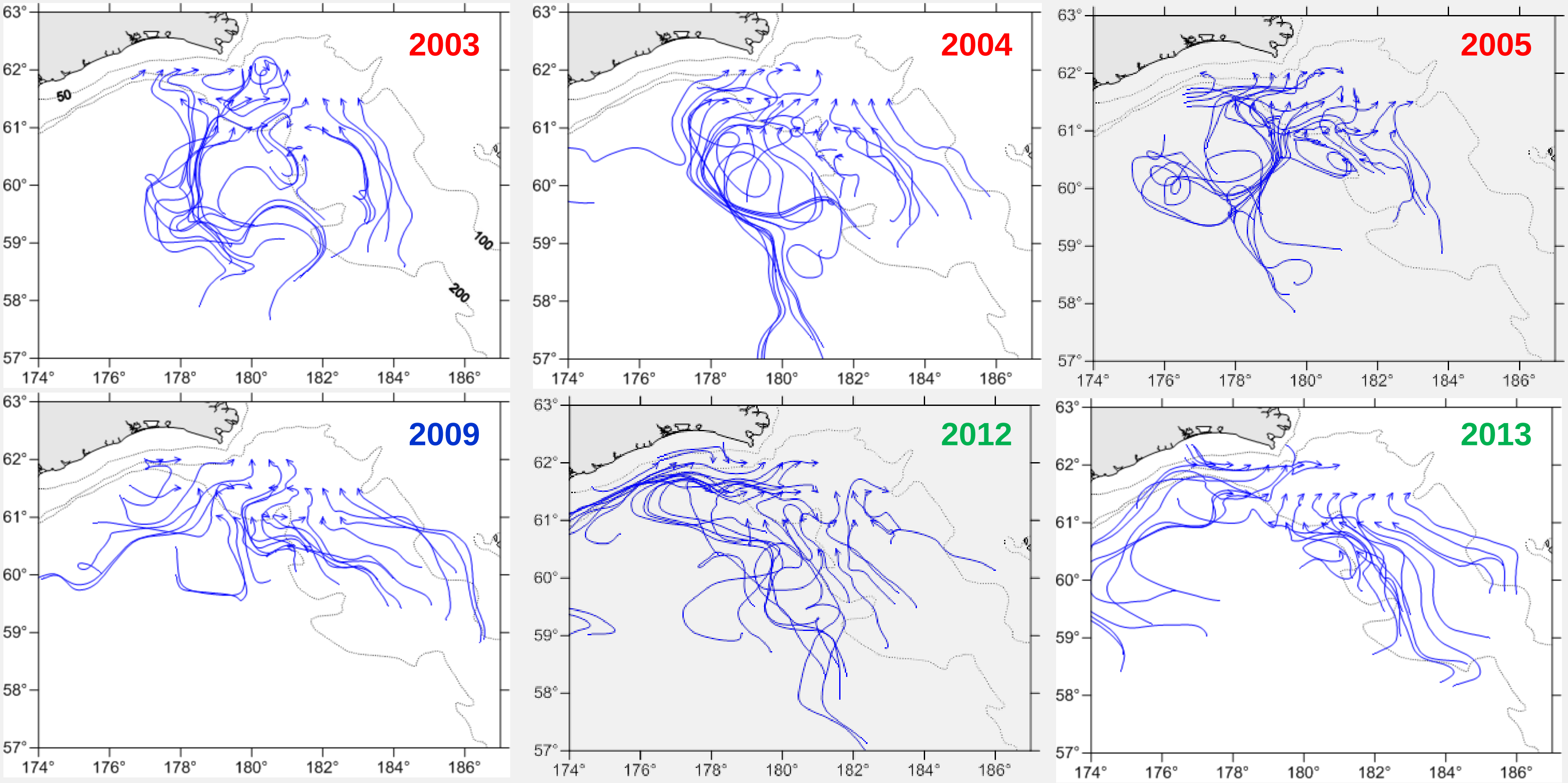




Dependence of zooplankton species abundance in the Navarin area (logarithmed anomalies of annual biomass) on water temperature or salinity in the layer 100-200 m in the same area

Mechanism of environmental influence on zooplankton

The “warm” and “cold” periods correspond to different types of water circulation in the northern Bering Sea.



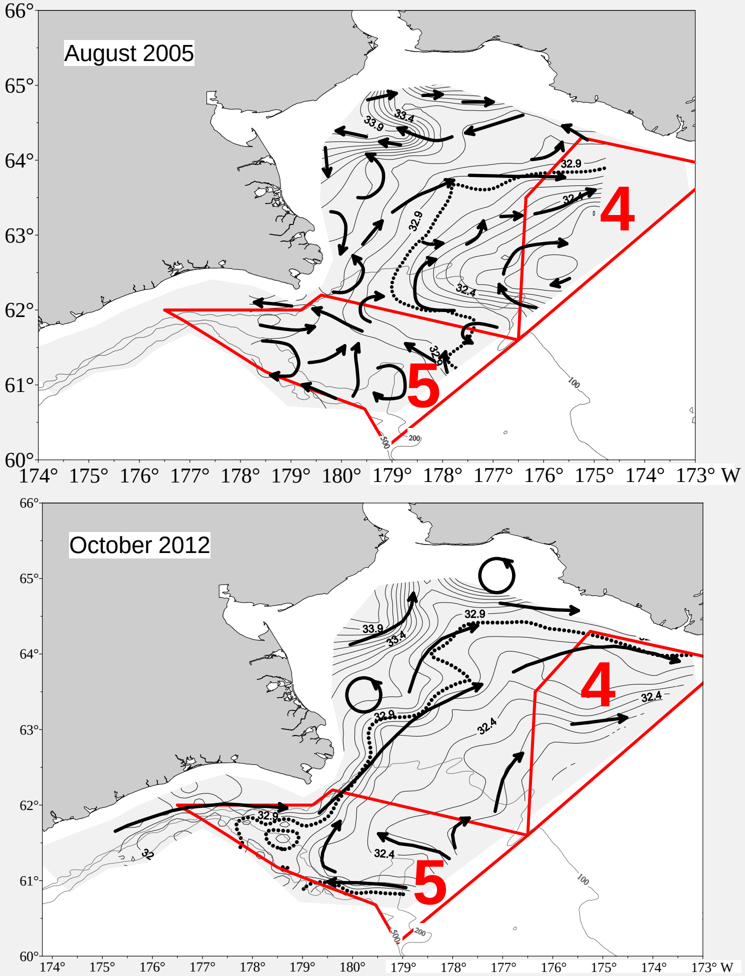
Water transport pathways into the Navarin area by September 1 of certain years, determined by OSCAR re-analysis (http://podaac.jpl.nasa.gov/dataset/OSCAR_L4_OC_third-deg)

[ESR. 2009. OSCAR third degree resolution ocean surface currents. Ver. 1. PO.DAAC, CA, USA]

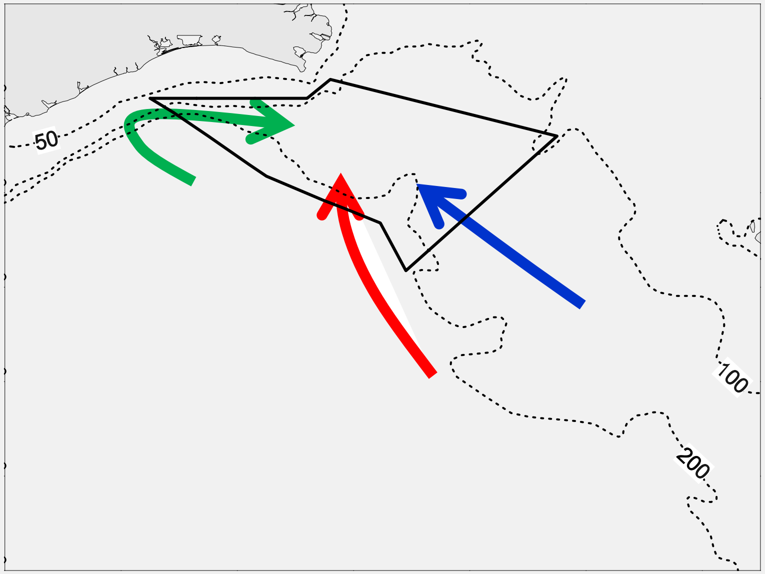
The Group for High Resolution Sea Surface Temperature (GHRSST) Multi-scale Ultra-high Resolution (MUR) SST data were obtained from the NASA EOSDIS Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the Jet Propulsion Laboratory, Pasadena, CA (http://dx.doi.org/10.5067/GHGMR-4FJ01)

Mechanism of environmental influence on zooplankton

Pathways of the water advection into the Navarin Area are determined by position of the shelf front around the so called Lawrence Cold Pool. In dependence on the Cold Pool size, the streams enter the Navarin area (№ 5) from the east, south or west



Examples of the shelf front position (in the subsurface salinity field) in the Navarin area and Anadyr Bay

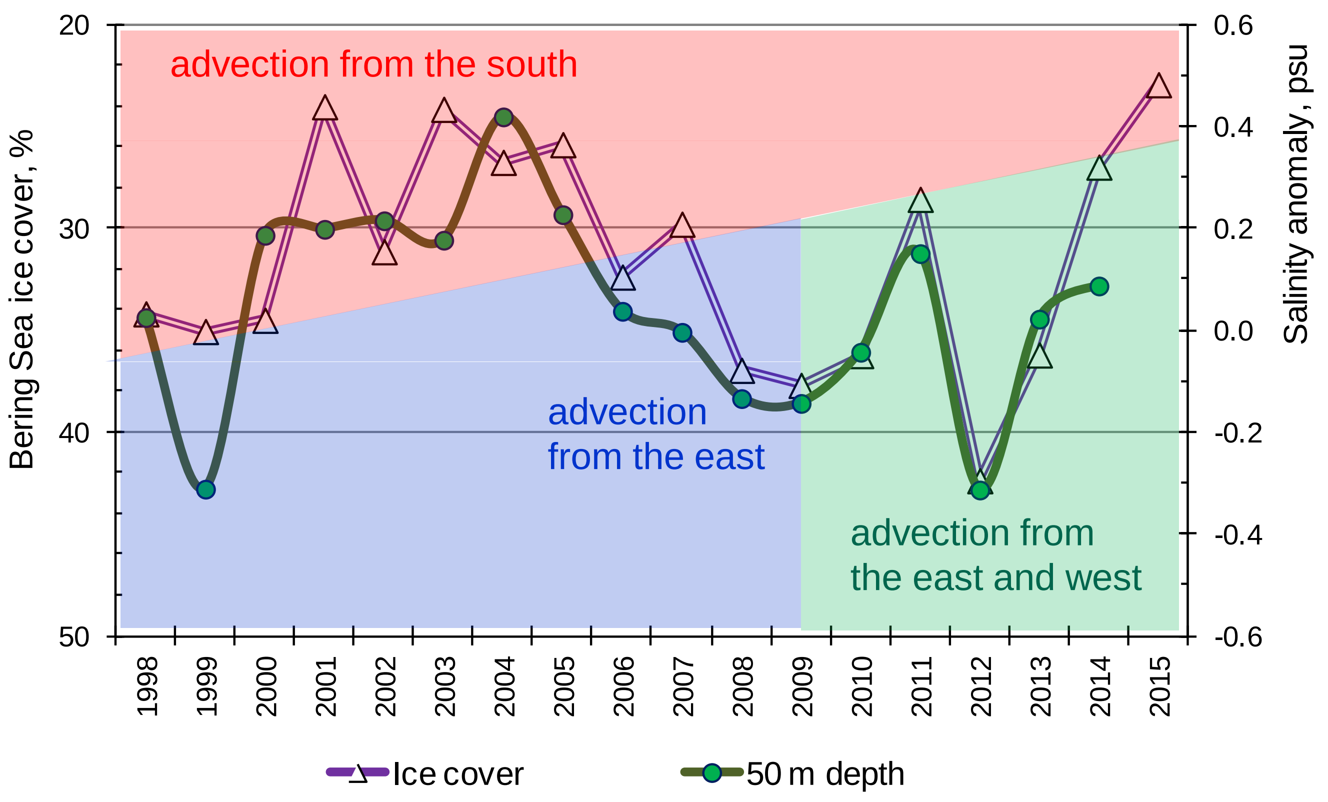


Possible pathways of water transport into the Navarin area determined by OSCAR re-analysis

Mechanism of environmental influence on zooplankton

Water temperature and salinity in the Navarin area correspond to the water transport pathways:

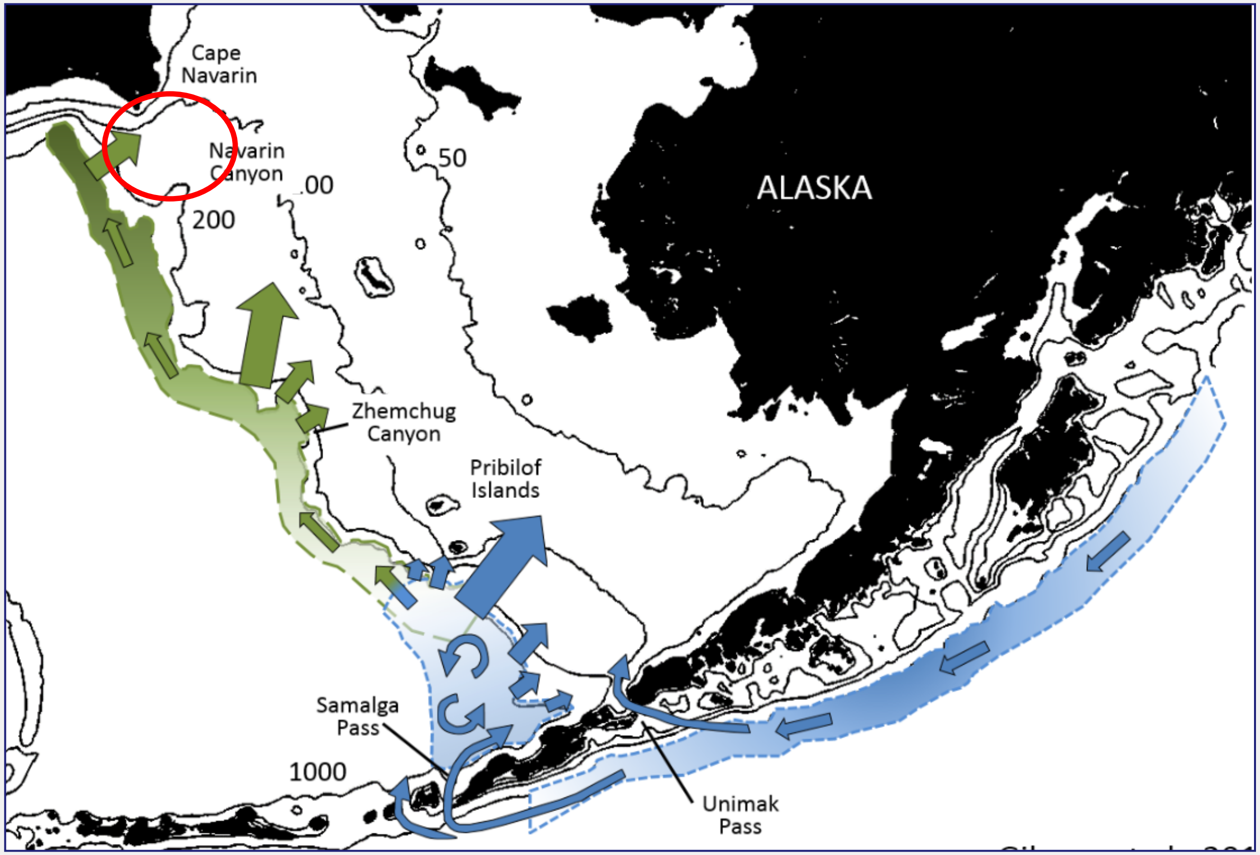
- when the Lawrence Cold Pool is small – the area is occupied by relatively warm and salt water transported here from the south with the Bering Slope Current;
- when the Lawrence Cold Pool is big – the area is occupied mostly by cold and low-saline shelf water



Correspondence of the water transport pathways with winter ice cover in the Bering Sea (axis inverted !) and summer salinity in the Navarin area

Mechanism of environmental influence on zooplankton

The Bering Slope Current transports toward Cape Navarin euphausiids and large copepods from the high-productive areas of the Green Belt

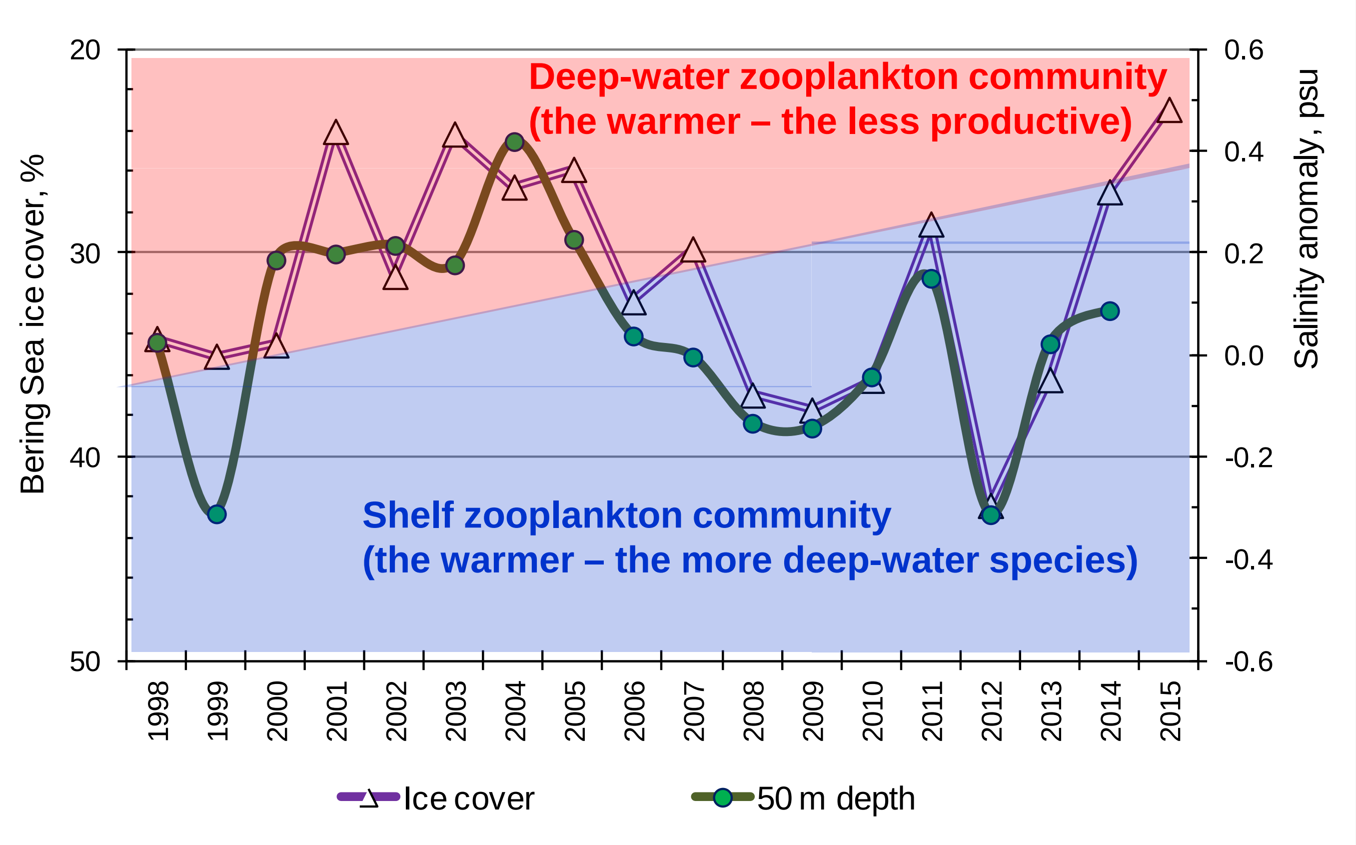


Scheme of zooplankton transport by the Bering Slope Current (from: Gibson et al., 2012)

Mechanism of environmental influence on zooplankton

In the terms of zooplankton community, two modes are possible in the Navarin area:

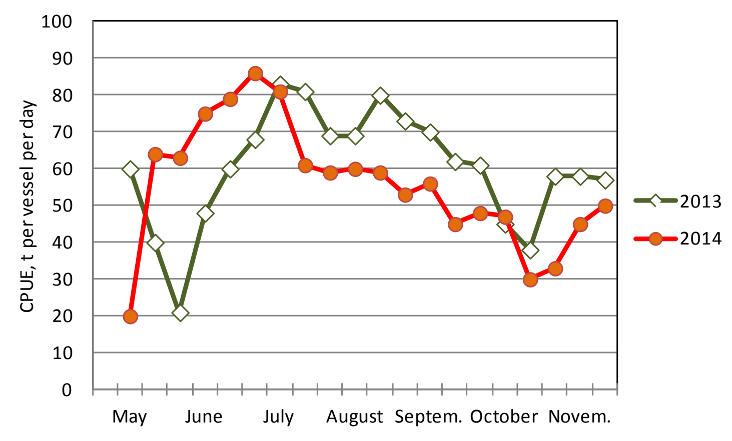
1) if the Lawrence Cold Pool is small – the area is occupied mostly by allochtonous deep-water zooplankton transported here from the Green Belt area, that is more abundant in colder conditions;
2) if the Lawrence Cold Pool is big – the area is occupied mostly by poor local community (mainly *N.cristatus*) with some allochtonous species which contribution is higher under warmer conditions.



Correspondence of the water transport pathways (background color) with types of plankton community in the Navarin area on the background of salinity and ice cover variations

Environmental influence on walleye pollock fishery

Walleye pollock starts its back migration from the feeding area at Cape Navarin in August (as in 2014) or continues its feeding here till November (as in 2013) in dependence on zooplankton abundance.

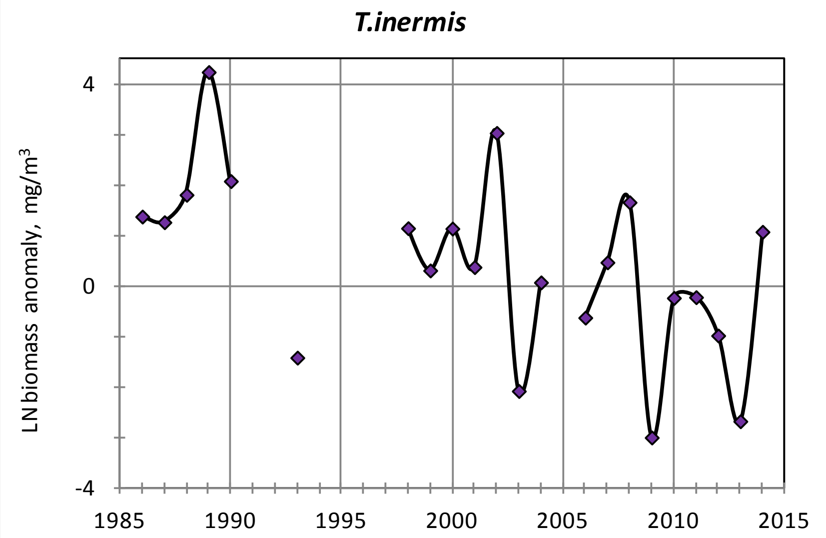


Mean CPUE for the pollock fishery in the Navarin area in 2013 and 2014.

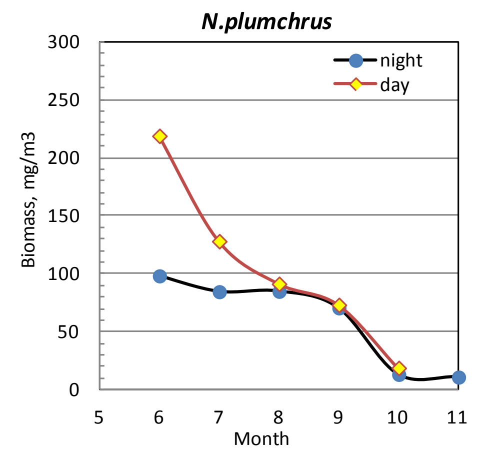
The CPUE lowering in August 2014 was the reason to stop the fishing operations by many vessels, therefore the total landing of pollock in the Bering Sea was only 330,600 t in 2014 instead of 358,900 t in 2013

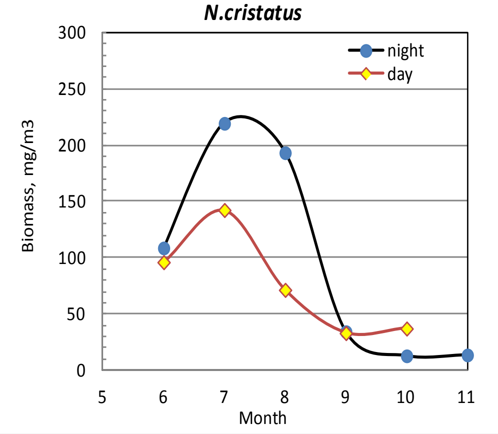
Environmental influence on walleye pollock fishery

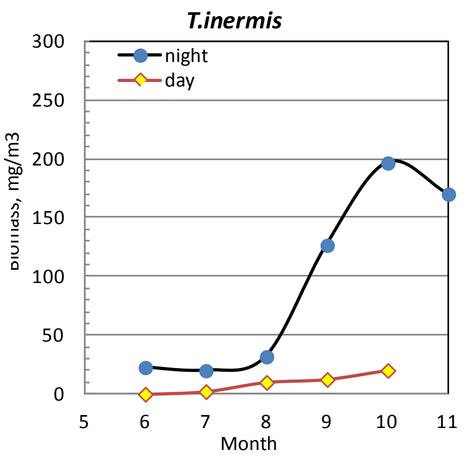
Meanwhile, all Copepoda species decrease their abundance in the Navarin area in autumn, so Euphausia abundance becomes crucial. The main Euphausia species, *Thysanoessa inermis* has allochtonous origin and increase its abundance in the Navarin area in the "warm" periods (water advection from the south) or in "warm" years of "cold" periods.



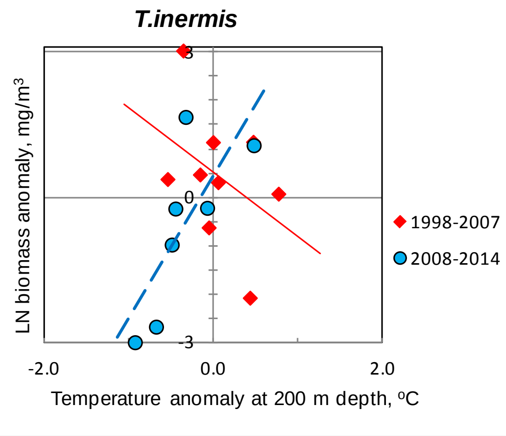
Year-to-year changes of biomass anomaly for the main Euphausia species in the Navarin area







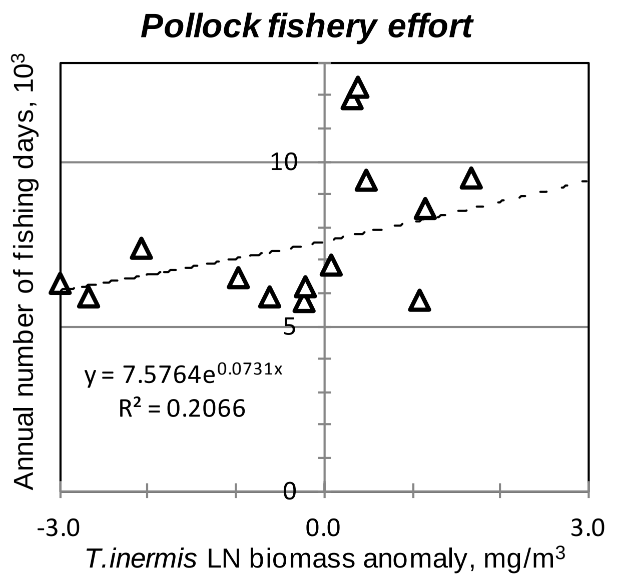
Mean seasonal changes of biomass for the main Copepoda and Euphausia species in the Navarin area



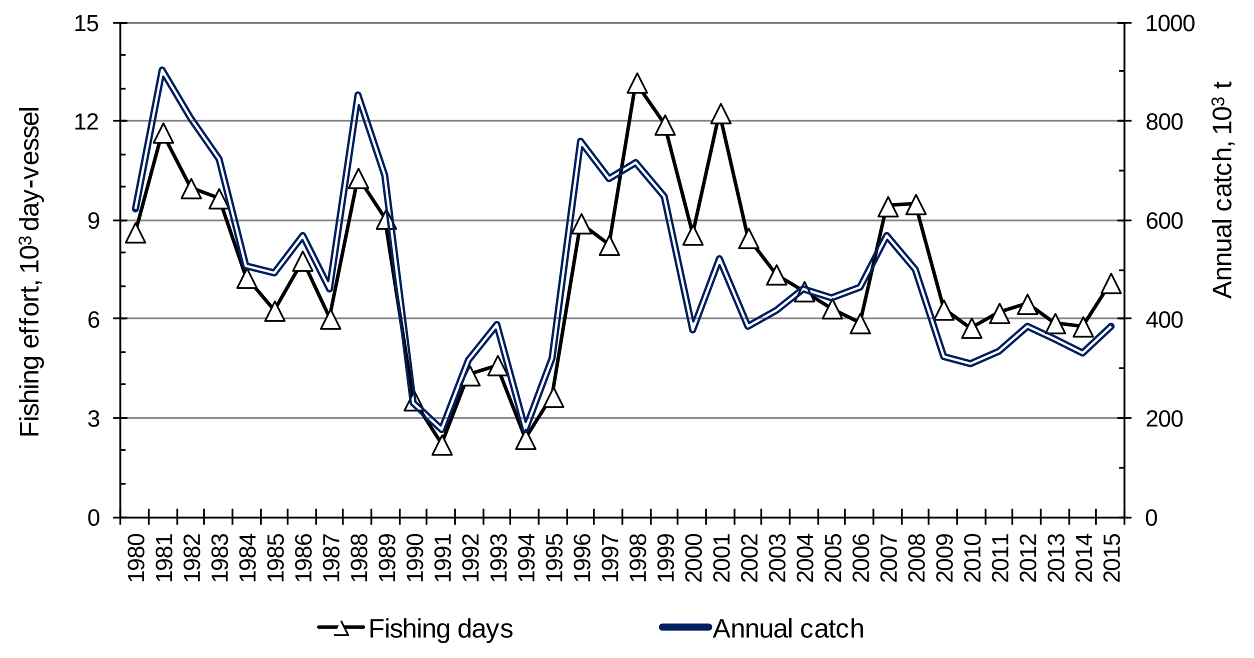
Dependence of T.inermis biomass on water temperature at 200 m depth in the Navarin area, separately for the "warm" and "cold" periods

Environmental influence on walleye pollock fishery

Russian walleye pollock fishery in the Bering Sea (mainly in the Navarin area) continues longer in the years when *T.inermis* is more abundant in this area. Annual catch of pollock is absolutely determined here by fishing effort: the longer the fishing – the higher the landing (*D = 0.68*).



Dependence of the Russian pollock fishery effort in the western Bering Sea (10^3 days) on T.inermis abundance in the Navarin area



Dynamics of the Russian pollock fishery effort (10^3 days) and annual catch (10^3 t) in the western Bering Sea (the main fishing grounds in the Navarin area)

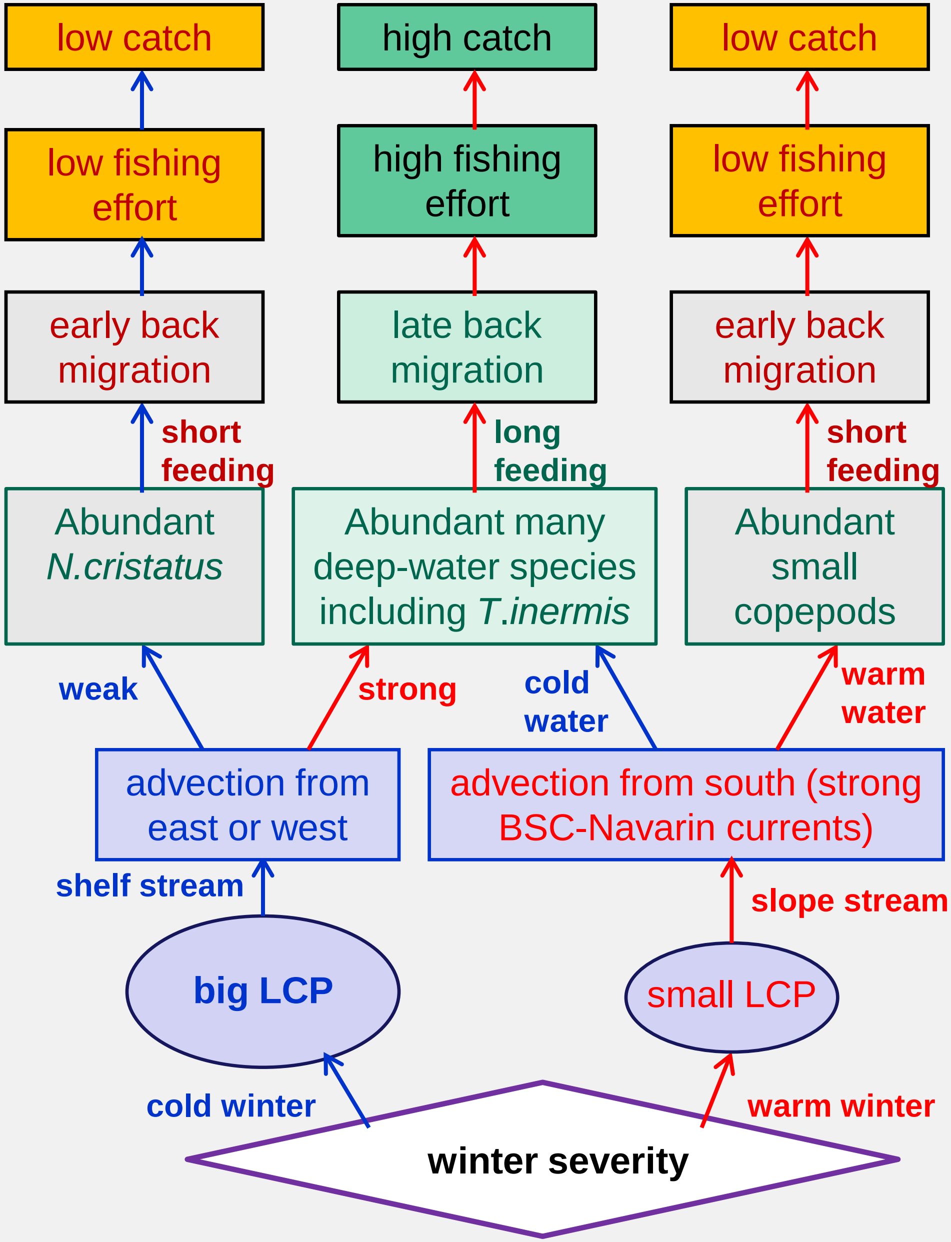
Conclusions

1. Temperature and salinity conditions in the Navarin area in summer-fall depend on direction of water advection controlled by size and position of the Lawrence Cold Pool, which are determined by severity of preceding winter: strong alongslope current is formed after relatively warm winter and provides heightened temperature and salinity.

2. Environmental conditions favorable for high abundance of zooplankton in the Navarin area can be formed after both cold and warm winters, following to the U-shaped dependence of many species on temperature or salinity: they are abundant in relatively cold years within warm periods or in relatively warm years within cold periods.

4. Transport of euphasiids (mostly *T.inermis*) by currents from the Green Belt to the Navarin area is crucially important for pollock feeding in this area and the fishery. High annual landings of pollock in the Navarin area are possible only in the years with long feeding of pollock preying there mostly on euphaiisiids in autumn, independently on its stock or on general state of food base in the Bering Sea.

Scheme of pollock fishery conditions development in the Navarin area, Bering Sea



low catch

high catch

low catch

low fishing effort

high fishing effort

low fishing effort

early back migration

late back migration

early back migration

short feeding

long feeding

short feeding

Abundant *N.cristatus*

Abundant many deep-water species including *T.inermis*

Abundant small copepods

weak

strong

cold water

warm water

advection from east or west

advection from south (strong BSC-Navarin currents)

shelf stream

slope stream

big LCP

small LCP

cold winter

warm winter

winter severity

Conclusions

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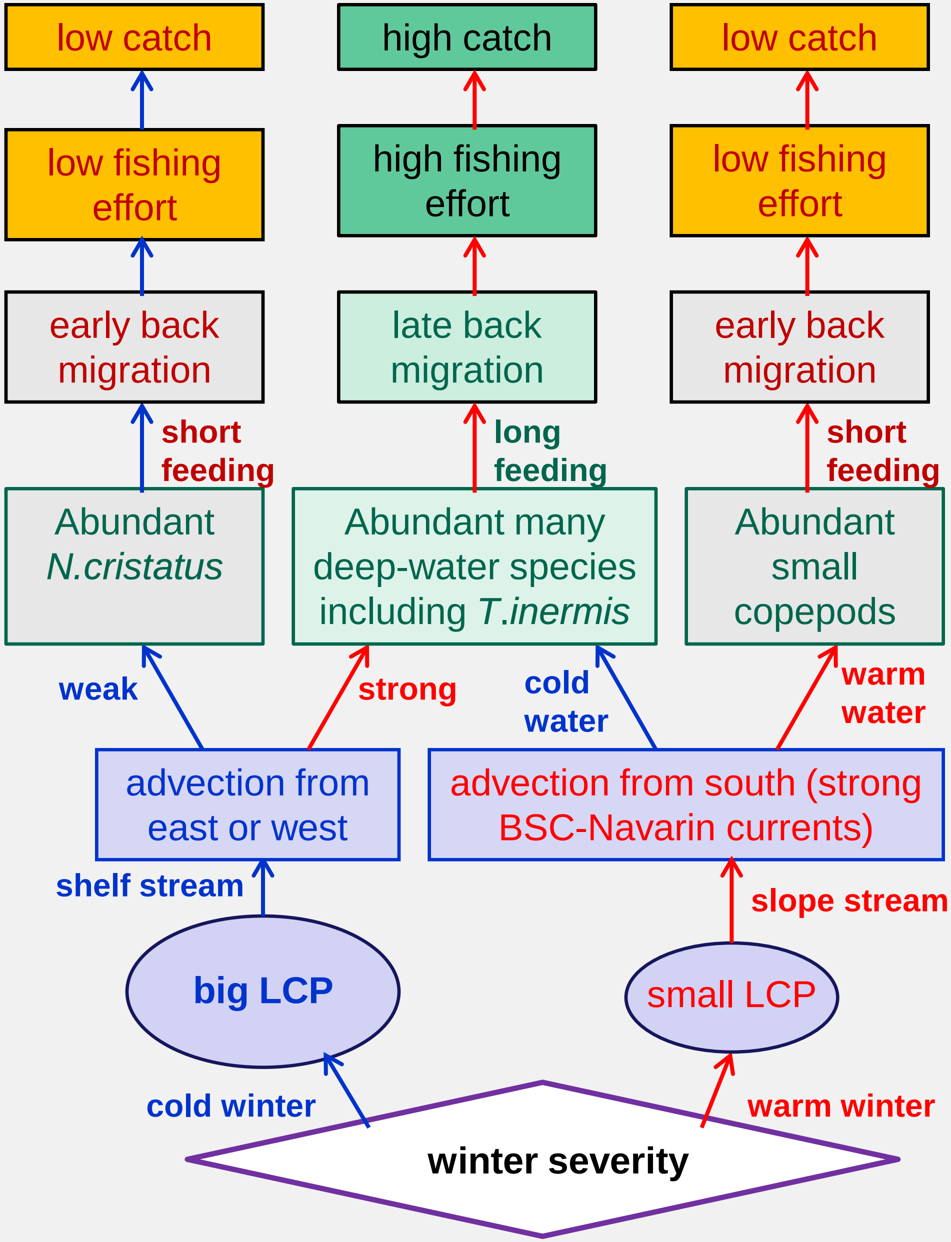

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