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# Environmentally driven variability of zooplankton composition in the northwestern Bering Sea and its influence on the pollock fishery

# 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.
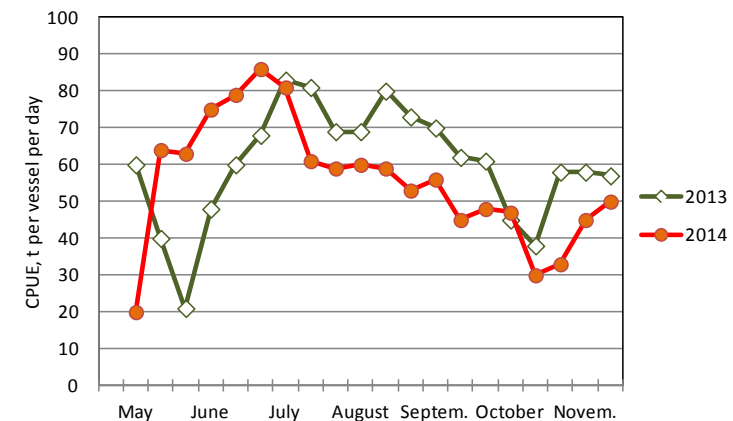




*Mean CPUE for the pollock fishery in the Navarin area in 2013 and 2014.*

*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 determine year-to-year variability of zooplankton abundance and species composition in the Navarin area;

- to understand its reasons and mechanisms, particularly for the autumn season;

- to estimate the zooplankton variations significance for the pollock fishery in this area.

# Data

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
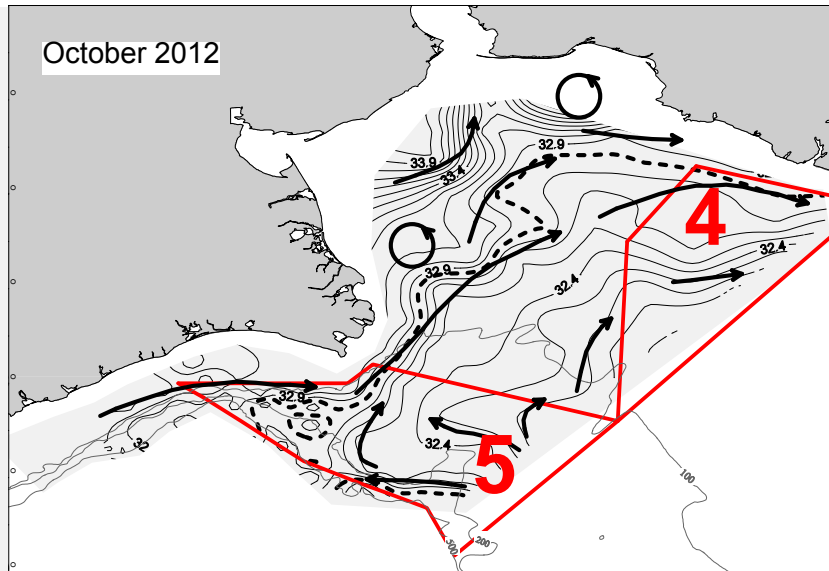


*Scheme of biostatistical areas location in the northern Bering Sea. Salinity and streams at 50 m depth in October 2012 are shown*

| 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/m³, by species)*

# Species composition of 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 %)
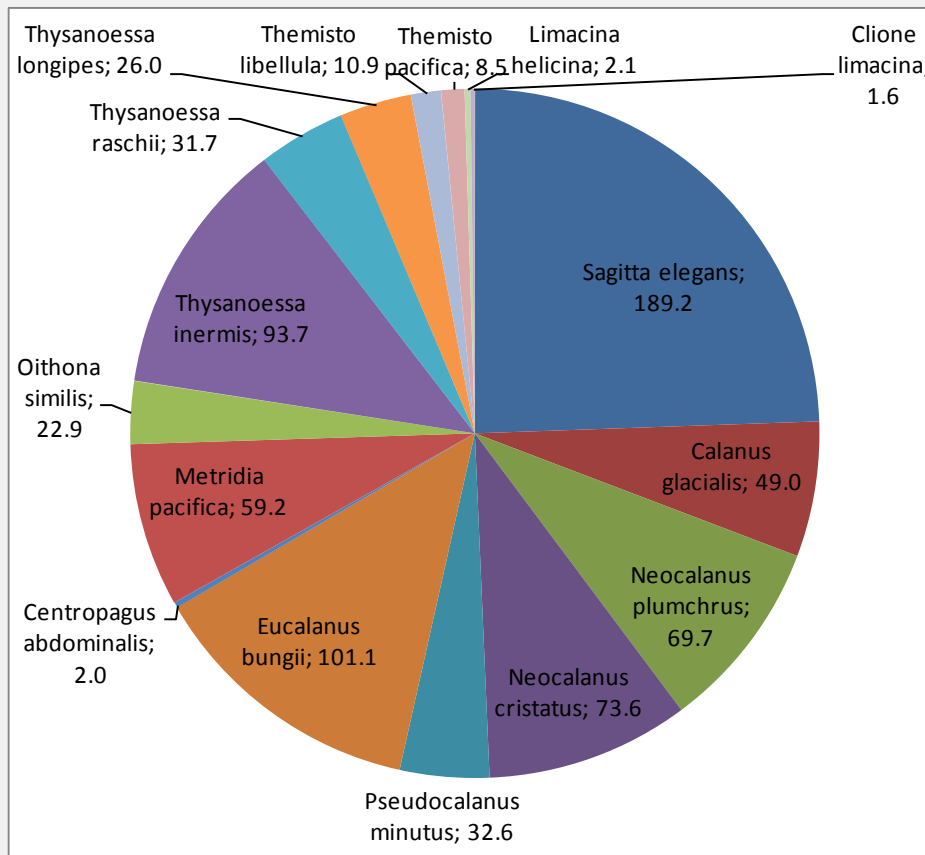


*Mean species composition of zooplankton within the biostatistical area № 5 in the Bering Sea*

# Seasonal dynamics

To consider year-to-year variations, seasonal variability should be removed from the time-series. For this purpose, monthly "norms" of biomass were calculated for each species
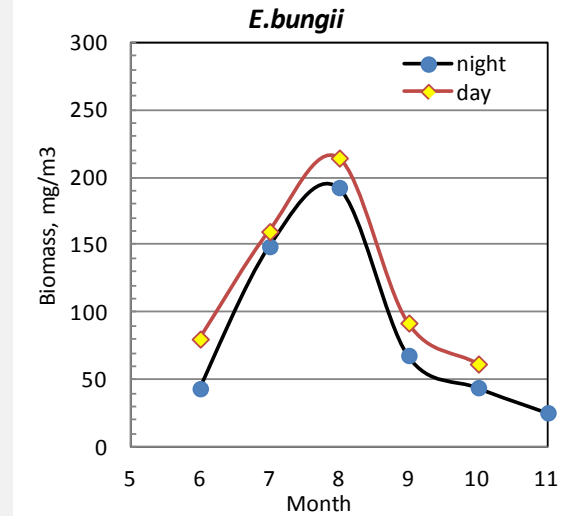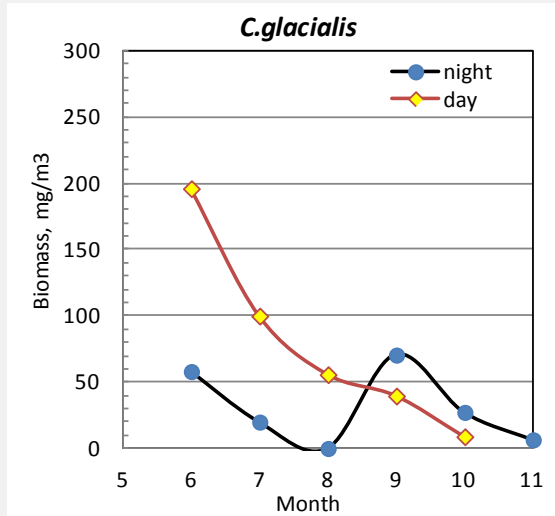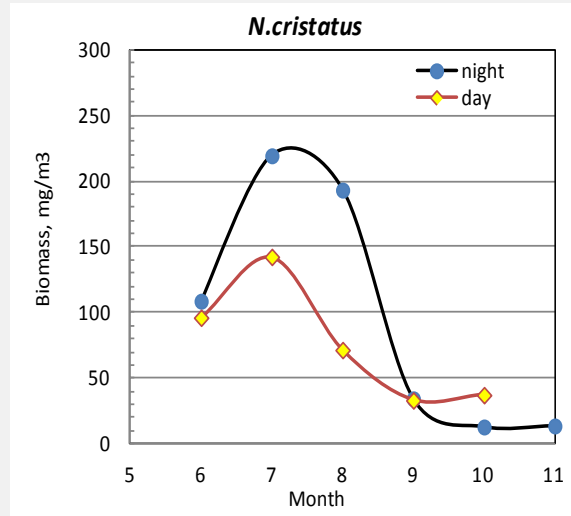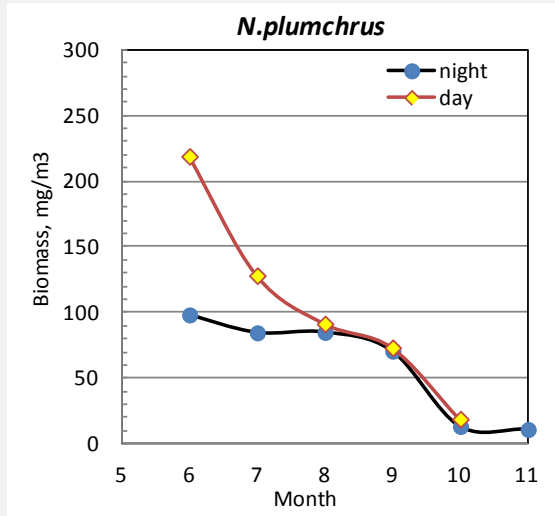


*Seasonal dynamics of mean month biomass for the main species of large-sized copepods. Biomass of all species decreases in autumn*
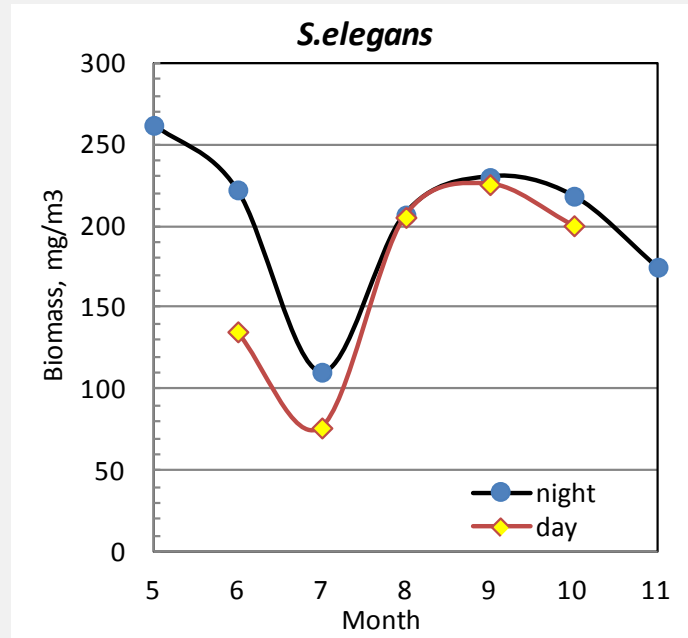
# Seasonal dynamics

To consider year-to-year variations, seasonal variability should be removed from the time-series. For this purpose, monthly "norms" of biomass were calculated for each species
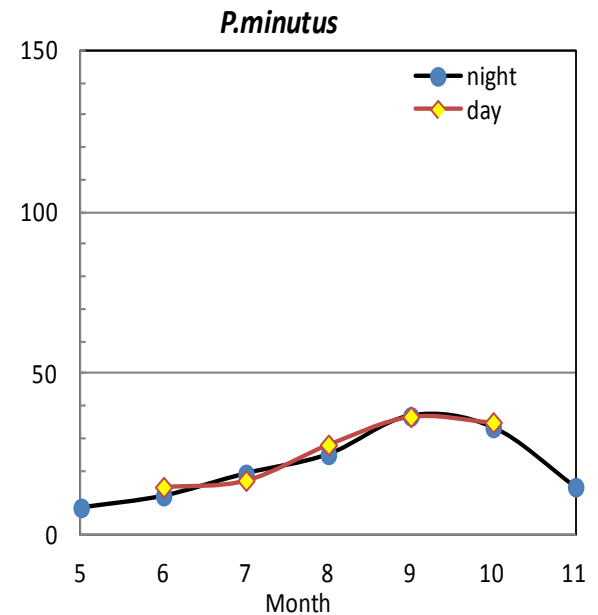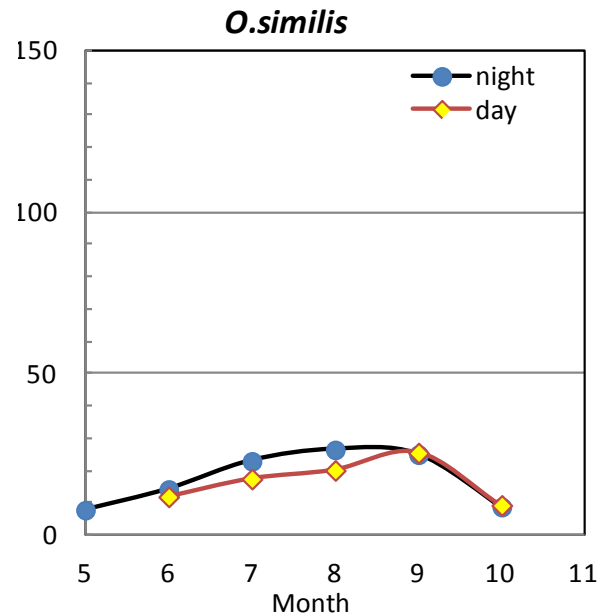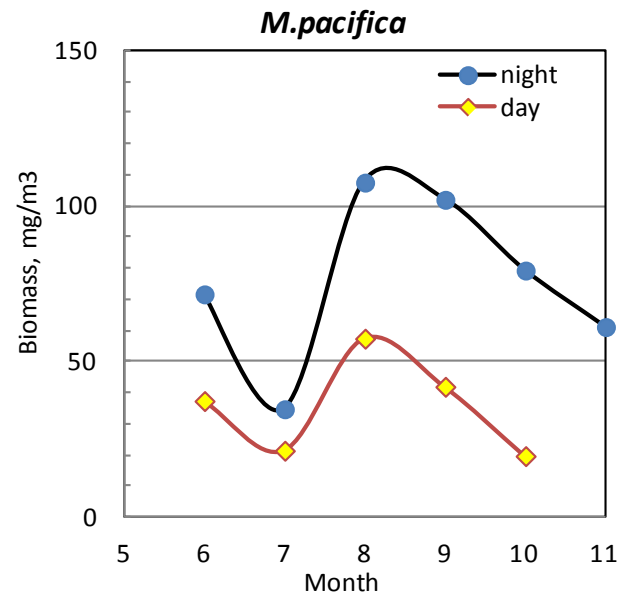


*Seasonal dynamics of mean month biomass for the main species of medium-sized and small-sized copepods. Seasonal changes are smaller in compare with the large-sized copepods*

# Seasonal dynamics

To consider year-to-year variations, seasonal variability should be removed from the time-series. For this purpose, monthly "norms" of biomass were calculated for each species
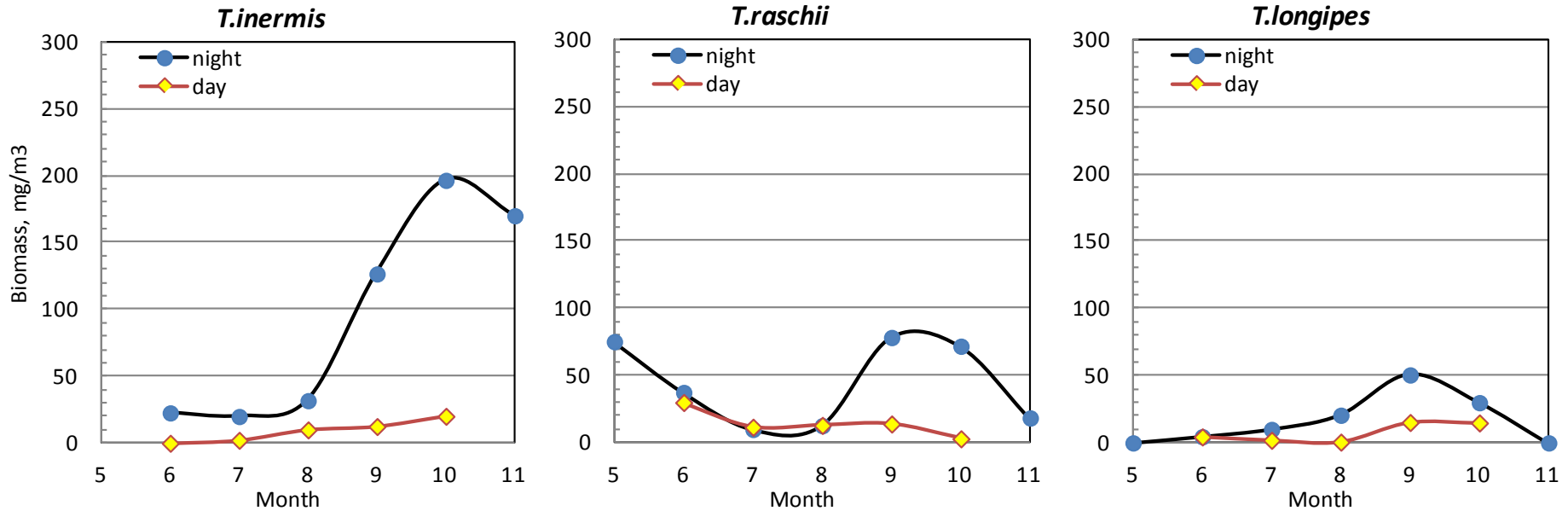


*Seasonal dynamics of mean month biomass for the main species of euphausiids.*
*Biomass of the main species (Thysanoessa inermis) increases in autumn.*
*Day samples don't represent the real abundance for all Euphausia species*

# Seasonal dynamics

To consider year-to-year variations, seasonal variability should be removed from the time-series. For this purpose, monthly "norms" of biomass were calculated for each species



*Seasonal dynamics of mean month biomass for Sagitta.*

# Year-to-year dynamics

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
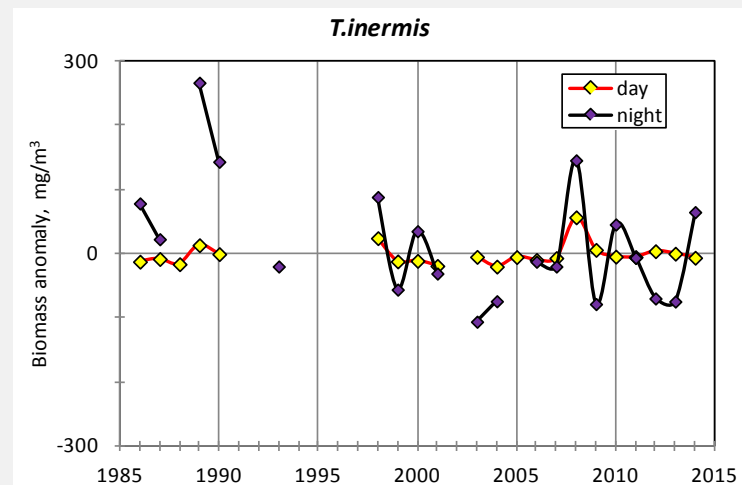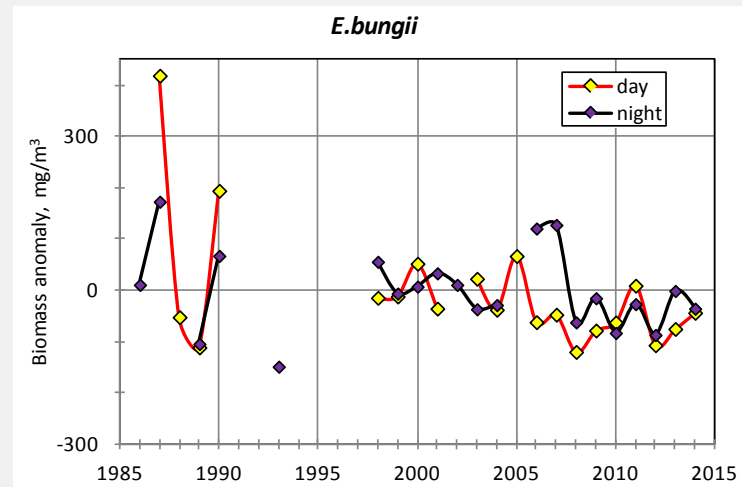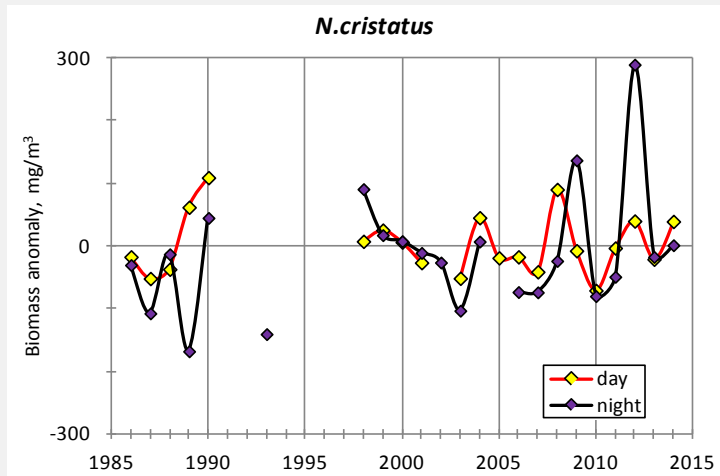


*Examples of year-to-year dynamics for some mass species of zooplankton in the Navarin area.*

# Year-to-year dynamics

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
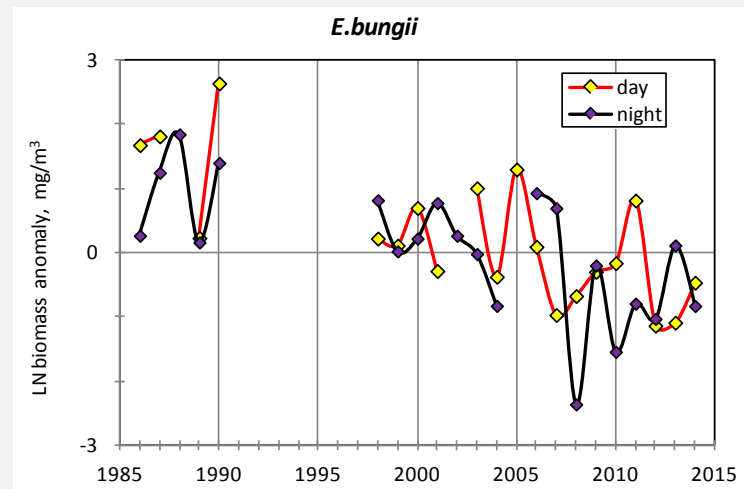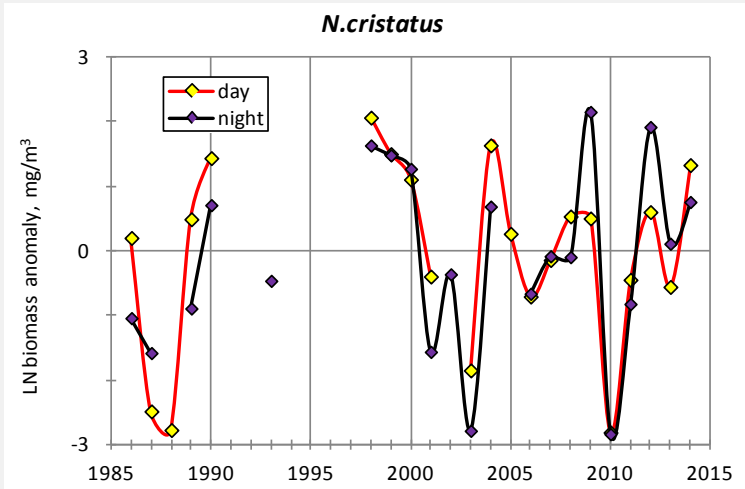


*Examples of year-to-year dynamics for some mass species of zooplankton in the Navarin area (logarithms of the biomass anomalies)*
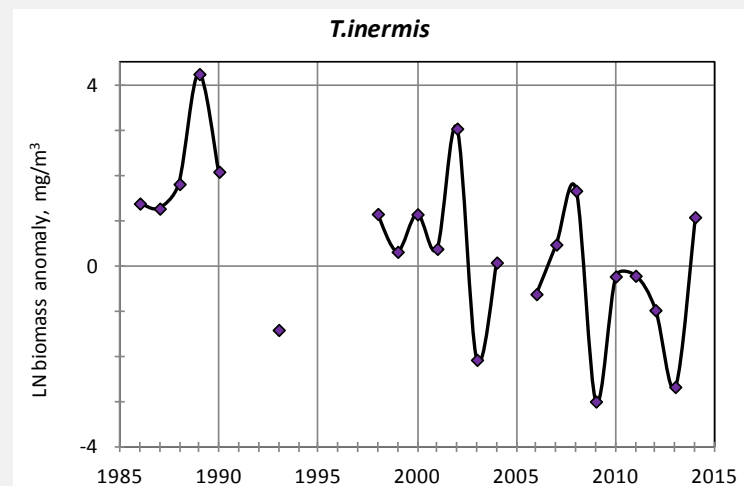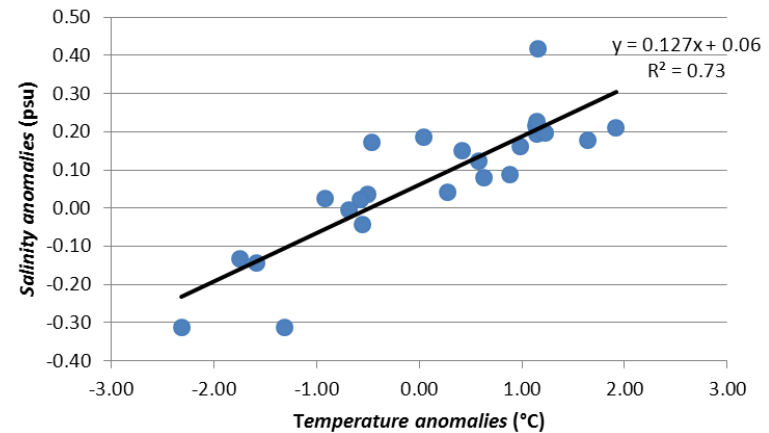
# Year-to-year dynamics

Meanwhile, water environments in the Navarin area had distinctive regime shifts in the same period: after the relatively cold conditions in the 1990s, there was a warming in the 2001-2007, then a cooling in the 2008-2013, and a new relatively warm period nowadays. Salinity has similar changes, so far as the salinity is correlated significantly with the water temperature.
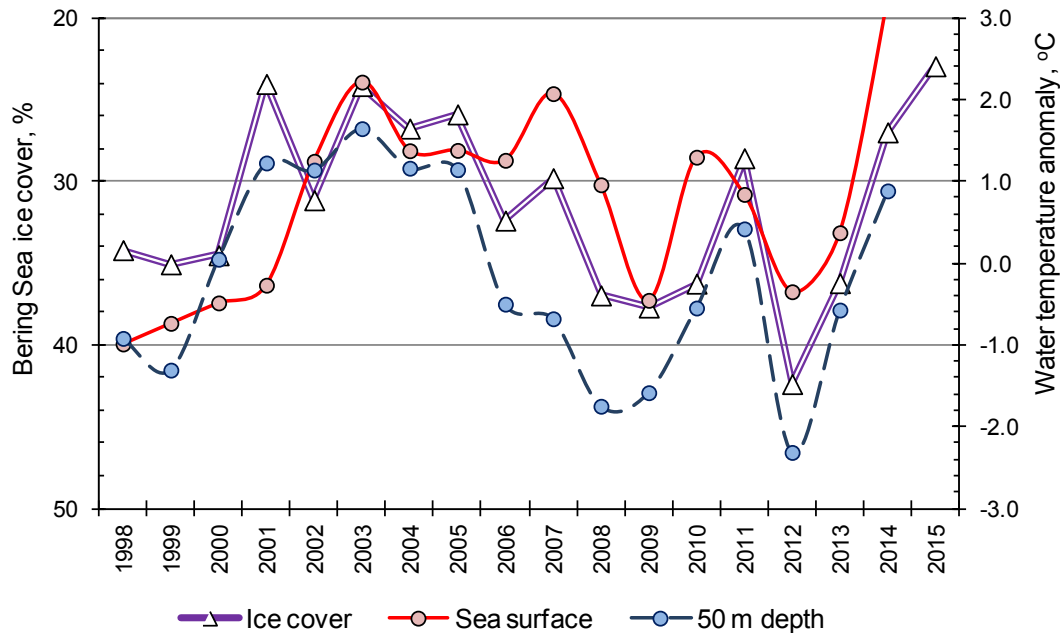


*Year-to-year changes of the ice cover in the Bering Sea and mean temperature anomalies in the Navarin area for summer season (data of TINRO shipboard measurements)*
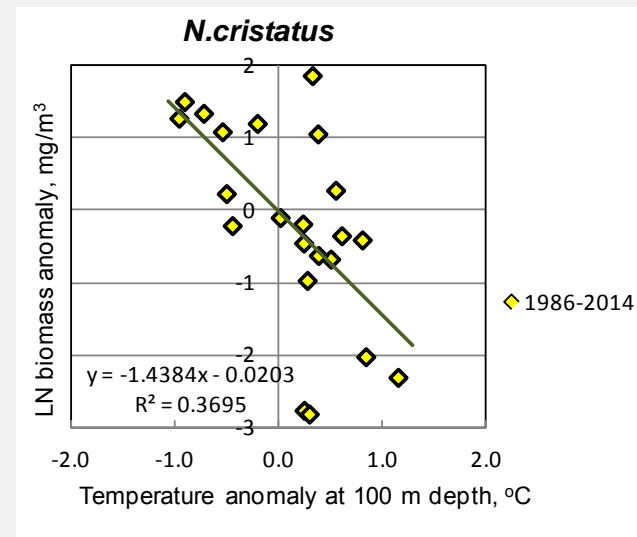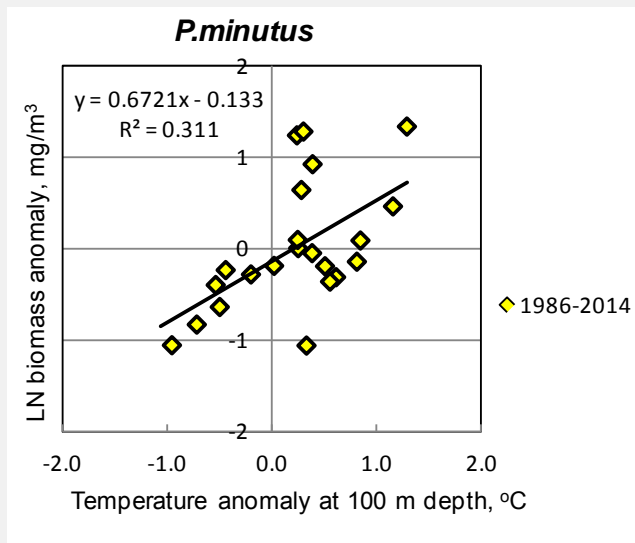
*Linear dependence between mean salinity and temperature anomalies at 50 m depth in the Navarin area in summer of different years*

# Year-to-year dynamics

Two mass species only has significant  linear correlation with the
environments:
*Neocalanus cristatus* that is more abundant in cold conditions
and *Pseudicalanus minutus* that 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*

# Year-to-year dynamics

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.
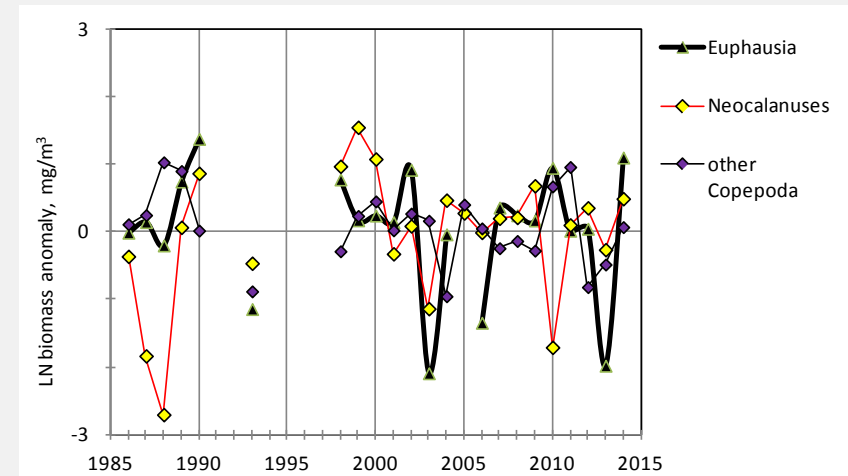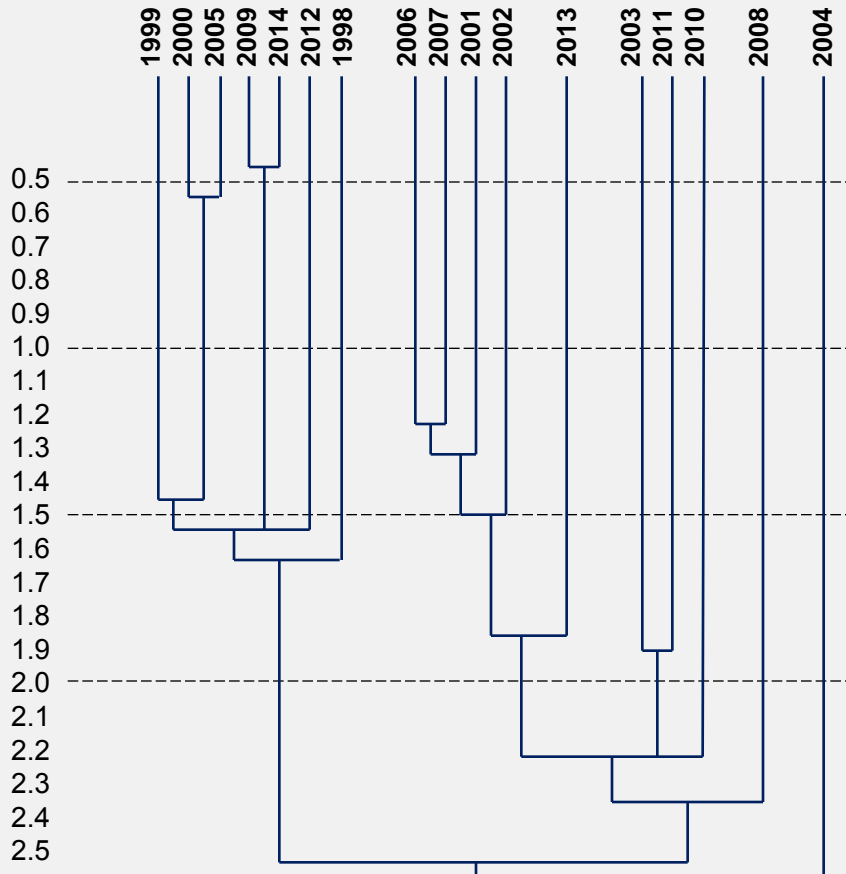


*Year-to-year dynamics of the main taxonomic groups of zooplankton in the Navarin area (logarithms of the biomass anomalies)*

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

# Year-to-year dynamics

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*)
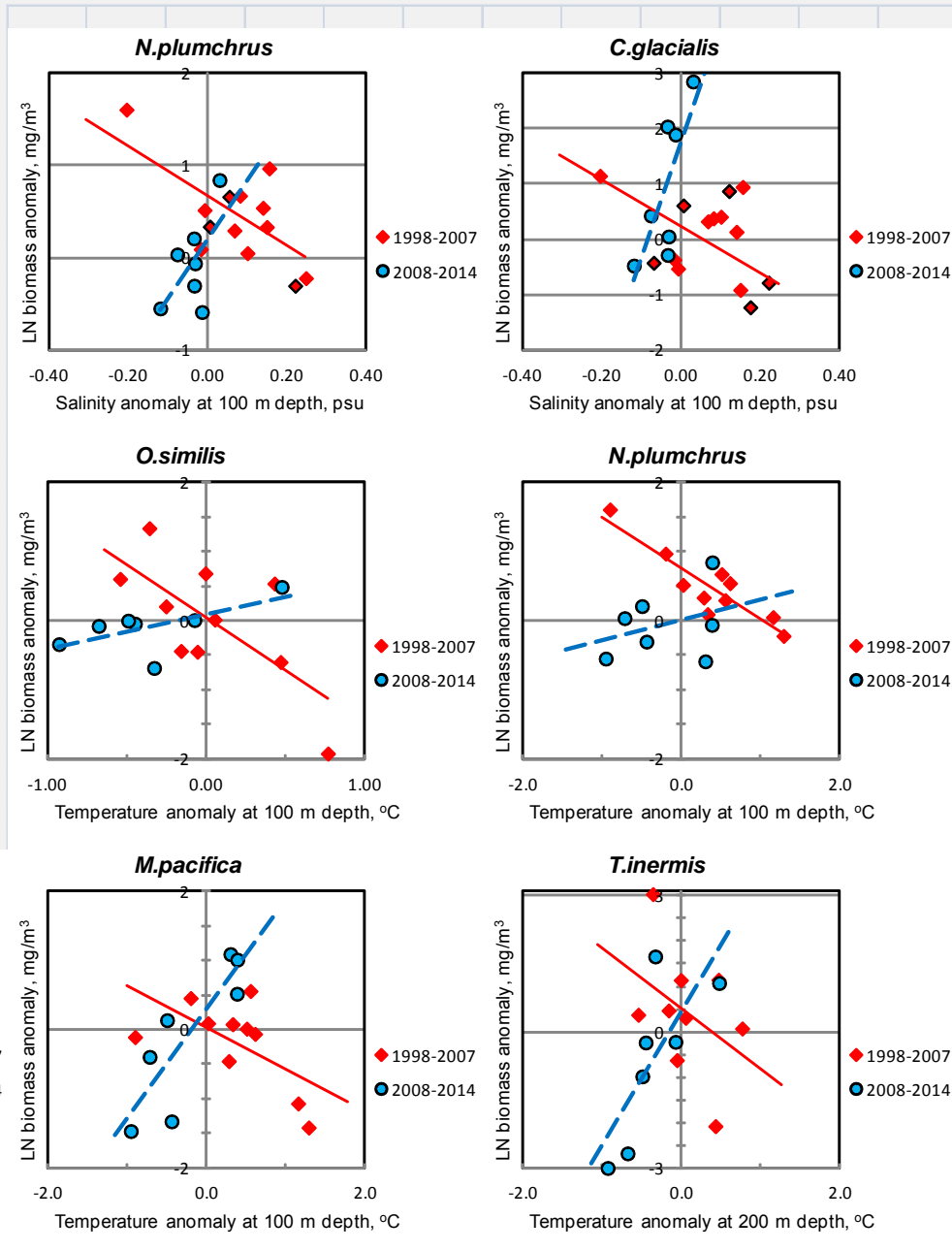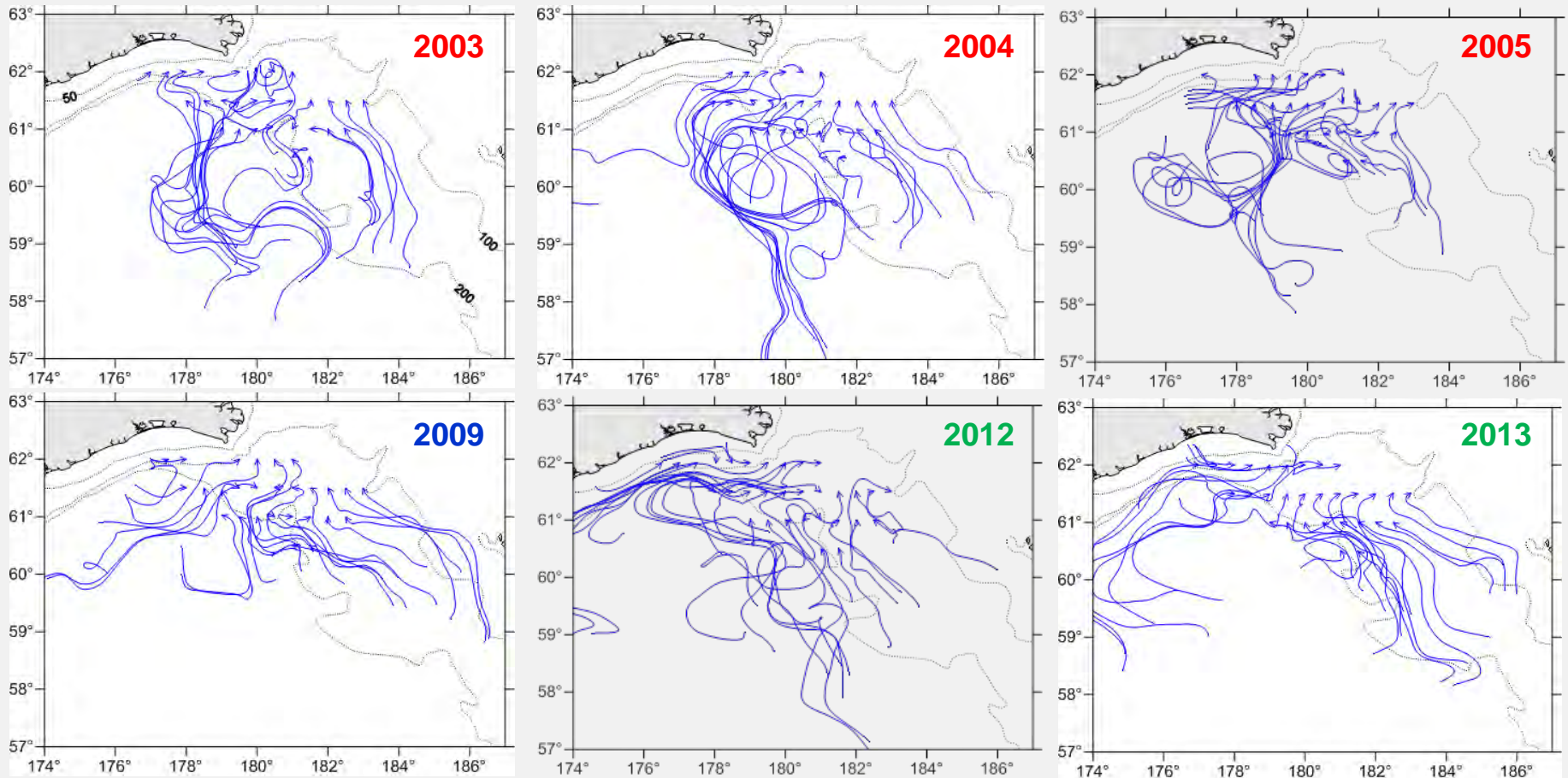


*Dependence of zooplankton species abundance in the Navarin area (logarithmed anomalies of annual biomass) on water temperature or salinity in the layer 100-200 m in the same area*

# Year-to-year dynamics - interpretation

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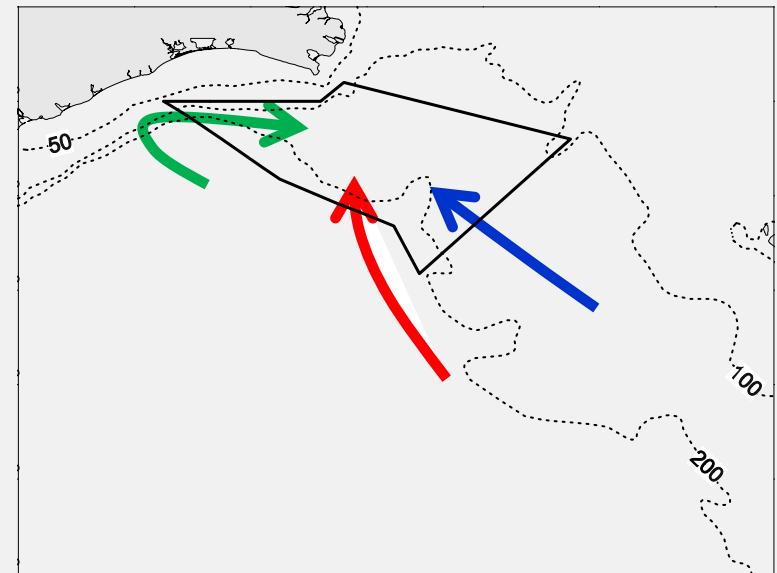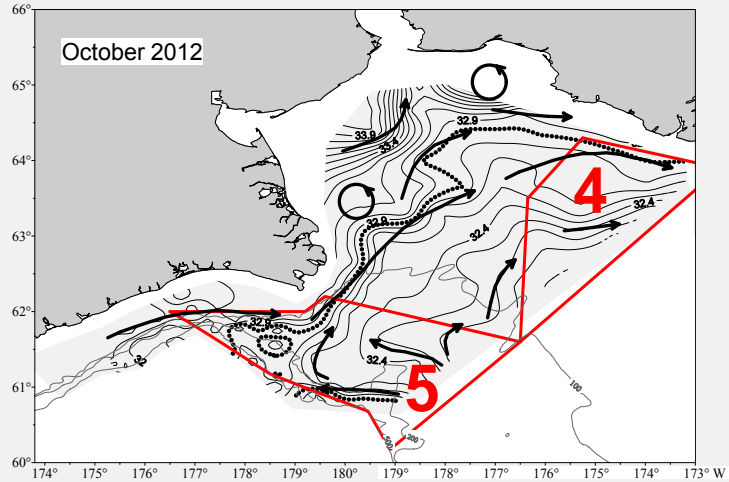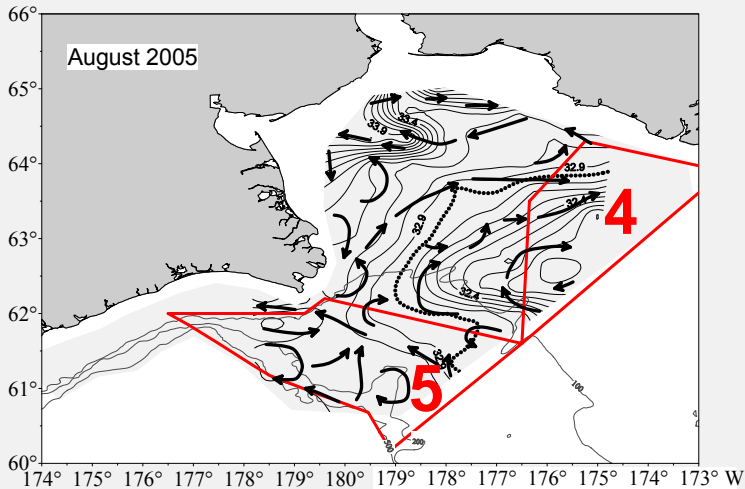


*Water transport pathways into the Navarin area by September 1 of certain years, determined by OSCAR re-analysis* (http://podaac.jpl.nasa.gov/dataset/OSCAR_L4_OC_third-deg)

[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)

# Year-to-year dynamics - interpretation

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

# Year-to-year dynamics - interpretation

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
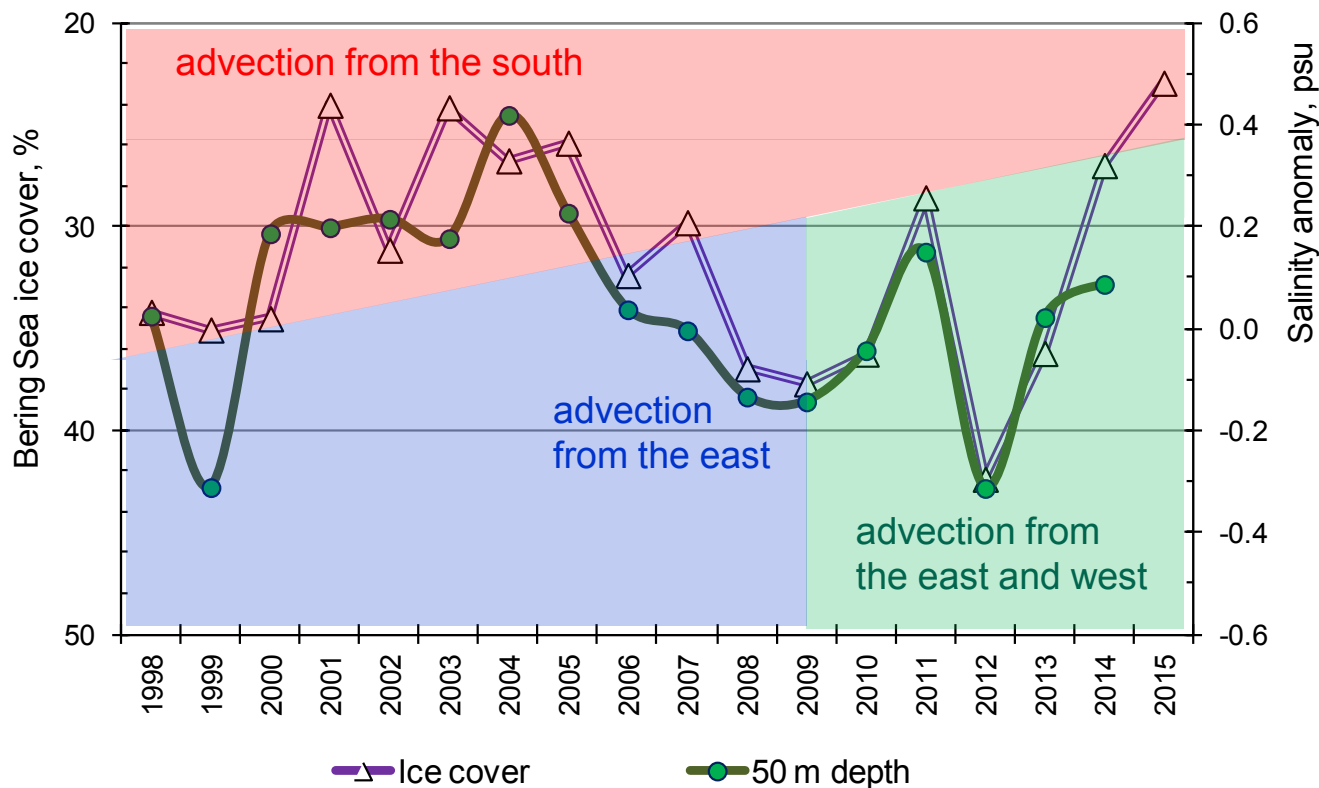


*Correspondence of the water transport pathways with winter ice cover in the Bering Sea (axis overturned !) and summer salinity in the Navarin area*

# Year-to-year dynamics - interpretation

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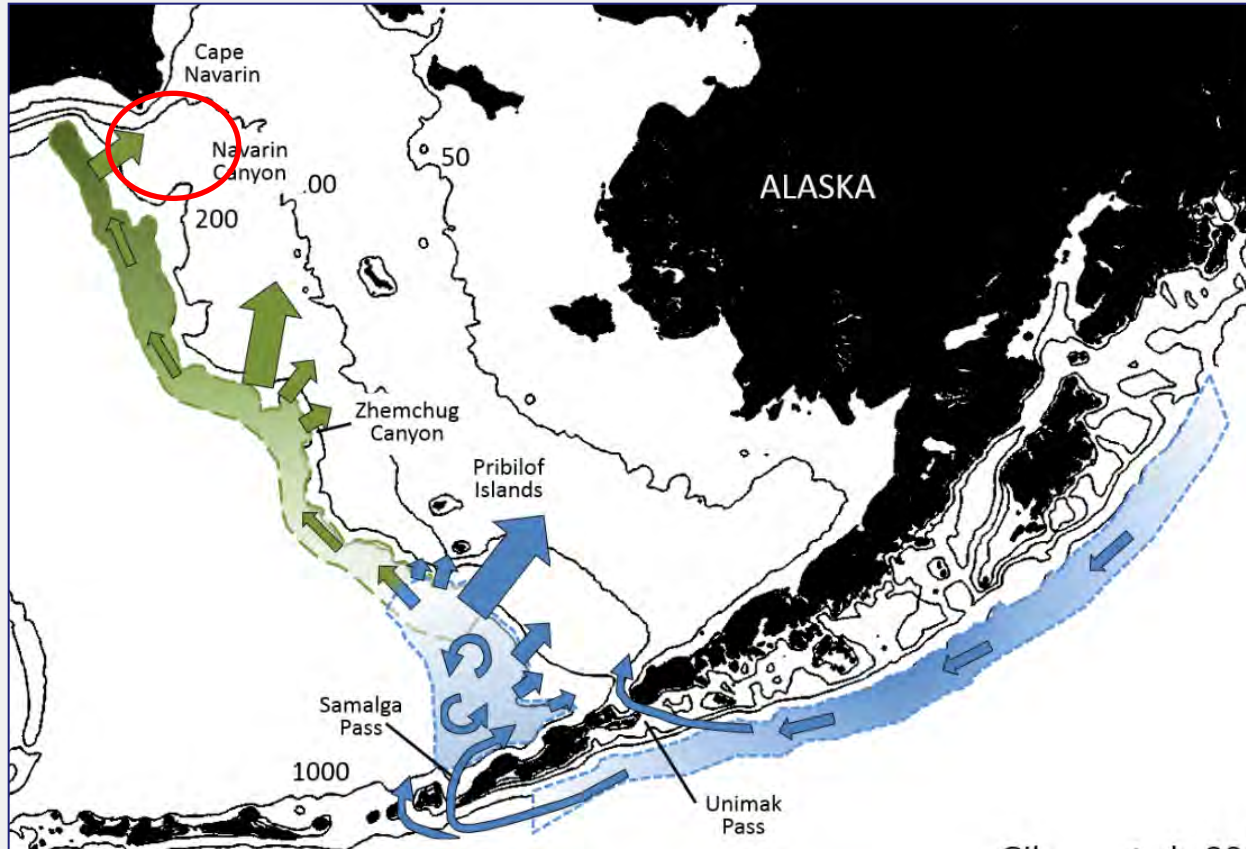


*Scheme of zooplankton transport by the Bering Slope Current (from: Gibson et al., 2012)*

# Year-to-year dynamics - interpretation

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.
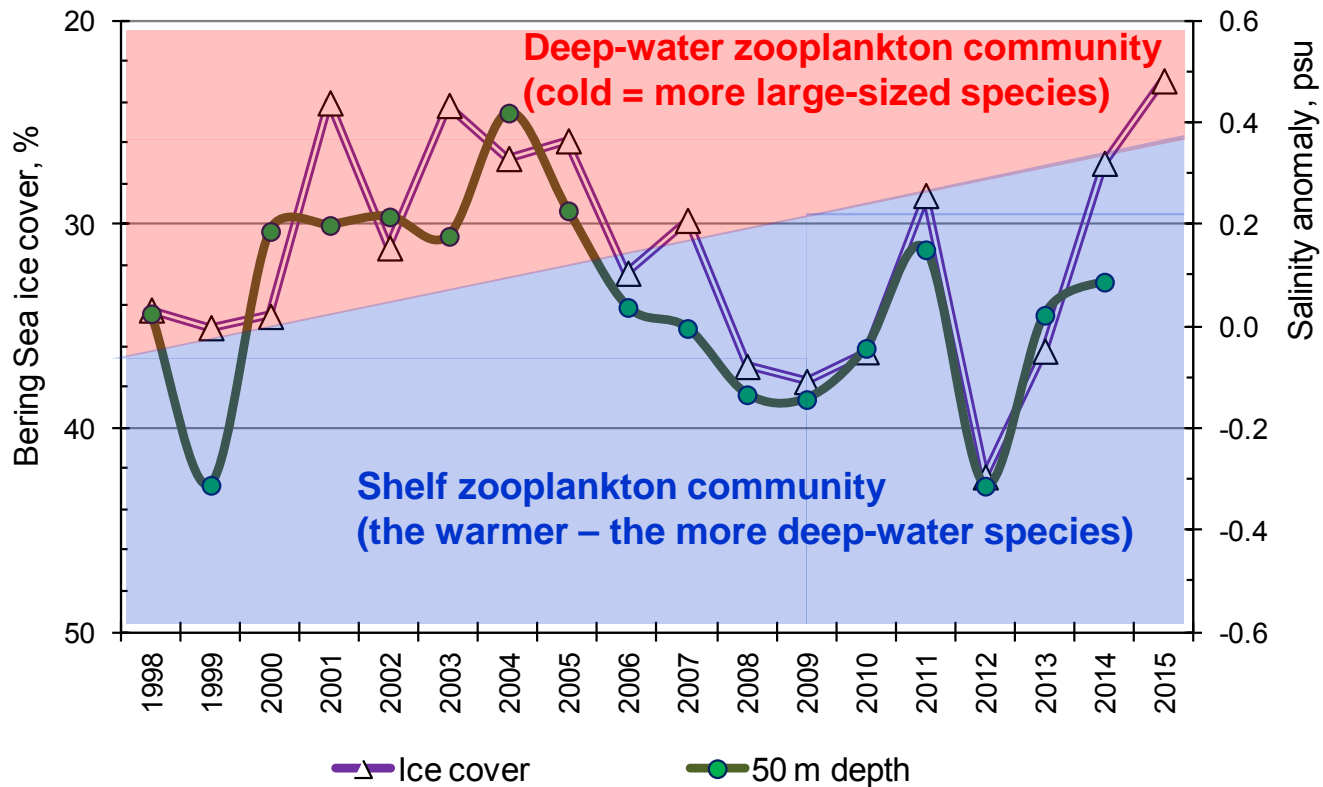


*Correspondence of the water transport pathways (background color) with types of plankton community in the Navarin area on the background of salinity and ice cover variations*

# Significance for 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.
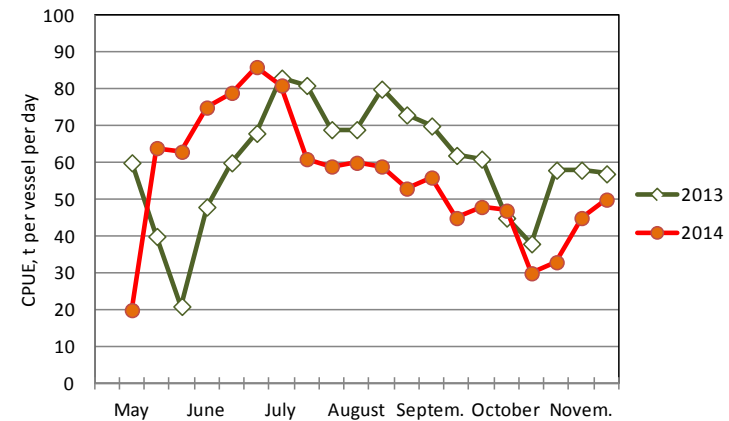


*Mean CPUE for the pollock fishery in the Navarin area in 2013 and 2014.*

*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*

# Significance for 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 (cold = more krill).
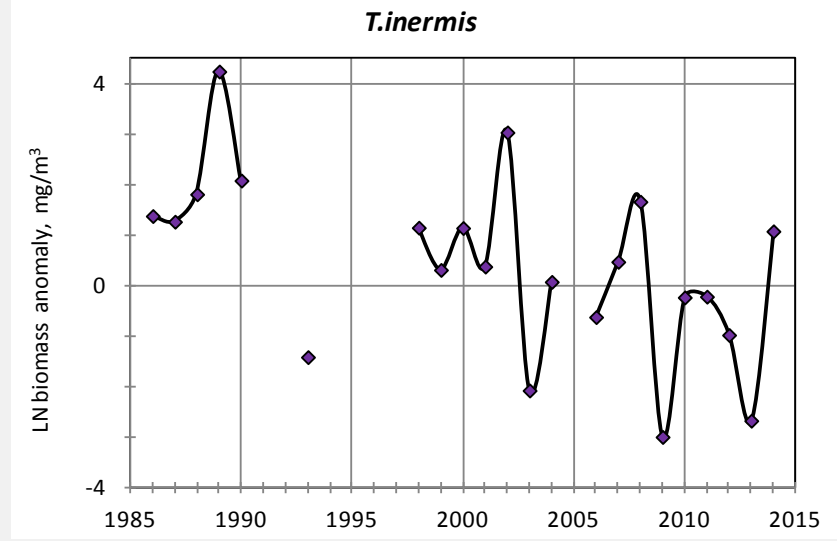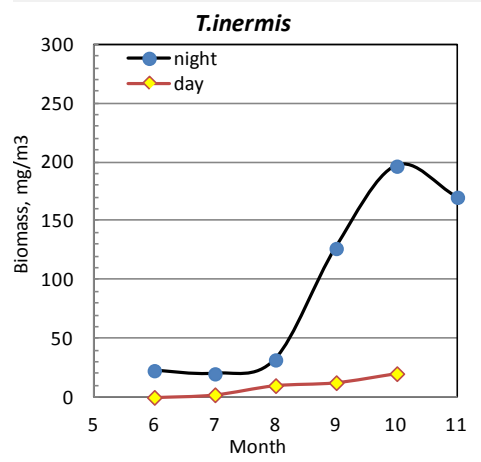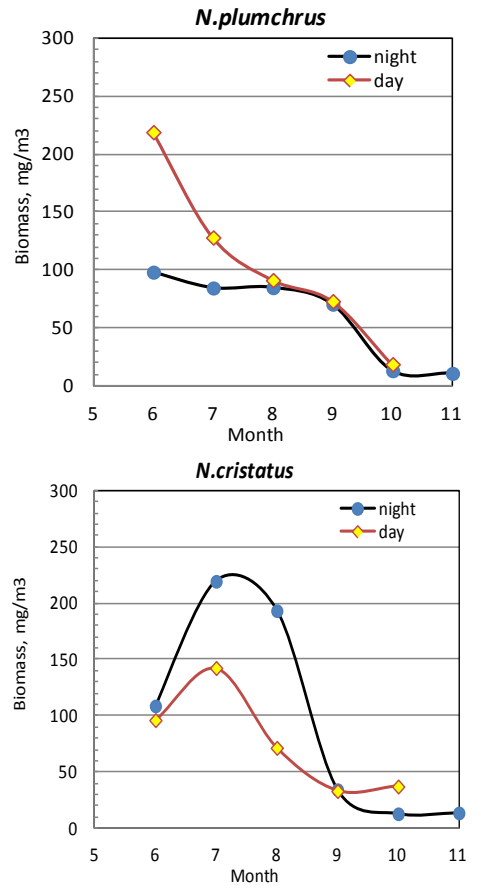


*Year-to-year changes of biomass anomaly for the main Euphausia species in the Navarin area*



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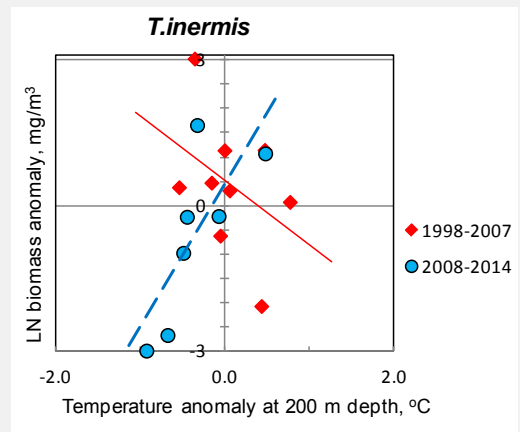


*Dependence of T.inermis biomass on water temperature at 200 m depth in the Navarin area, separately for the "warm" and "cold" periods*

# Significance for 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*).
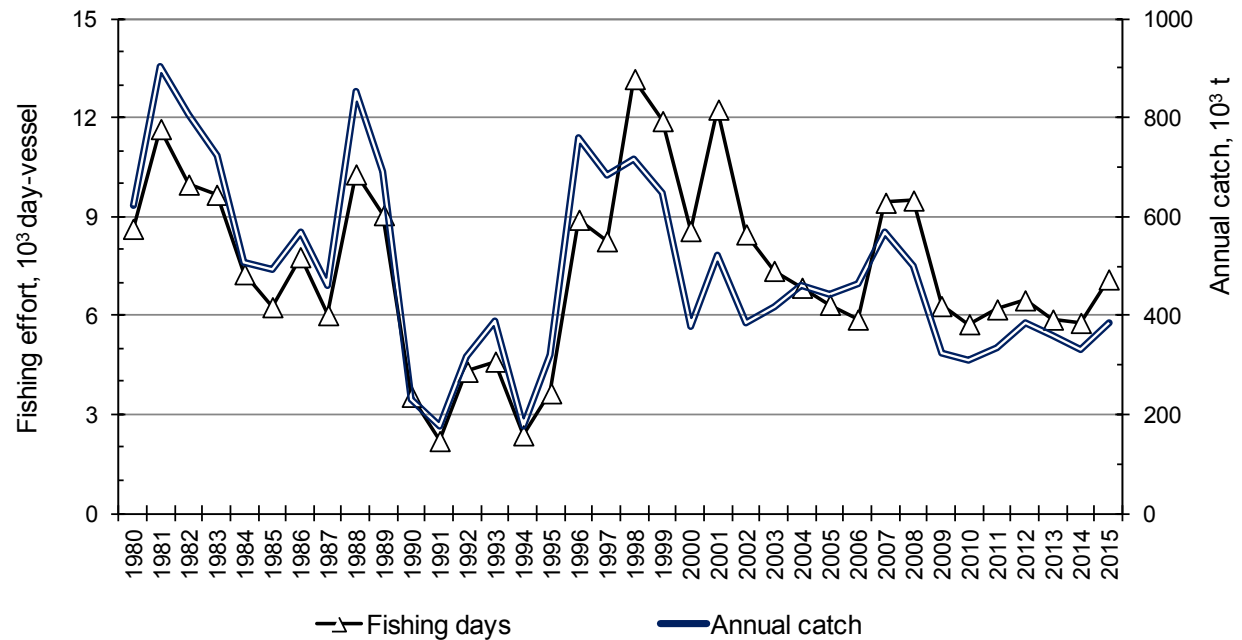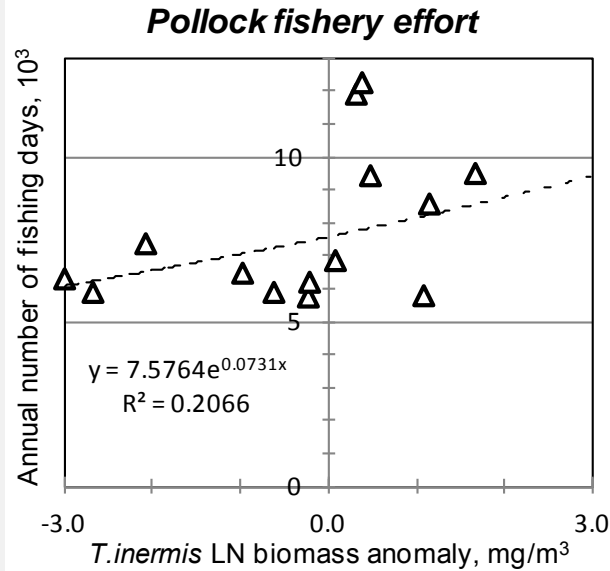


*Dependence of the Russian pollock fishery effort in the western Bering Sea (10³ days) on T.inermis abundance in the Navarin area*

*Dynamics of the Russian pollock fishery effort (10³ days) and annual catch (10³ 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 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**