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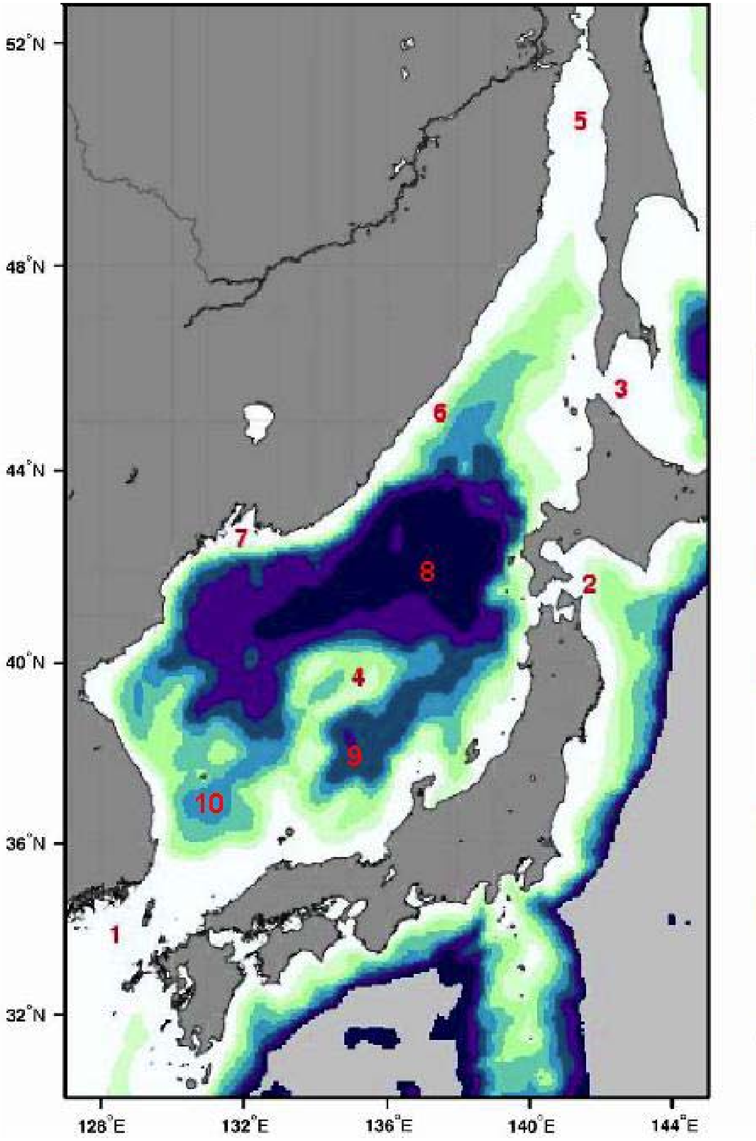
The Japan Sea hotspot: impacts of warming on bioproductivity and fisheries resources



Outline:

1. Long-term variation of oceanographic conditions

2. Possible effect of these variation to bioproductivity

3. Long-term variation of the main levels of trophic pyramid: phytoplankton, zooplankton, and nekton

Data sources:

Index	Period	Brief description	Source
SST in the northern and southern parts of JES	1950-2008	Mean seasonal SST anomalies in 40-46° N and 35-38° N, relative to the 1970-2000 mean	JODC
Intermediate Water temperature	1957-2008	Mean winter and summer modal temperature of the water mass at the section along 132° E Mean winter and summer temperature at 200 m depth at the section along 38° N	Author's data KODC
Bottom Water temperature	1932-1999	Potential temperature at 3000 m depth, in any site	Uda, 1934; Chen et al., 1999; Ponomarev et al., 2000; Kang et al., 2003
Salinity in surface, inter-mediate, and deep layers	1950-2005	Mean annual salinity in the layers 0-5, 350-1000, and 1000-2000 m	Rudykh, 2008
Ice cover	1953-2005	Mean percentage of ice cover for January-April	Khen et al., 2006
Polar Front position	1977-2007	Mean annual deflection (n. miles) of the Polar Front position from its climatic position	Author's data; Nikitin & Kharchenko, 2002
Mixed layer depth	1961-2008	NW part for June-July and October-November, SW part for April, SE part for February	Author's data; Kang et al., 2000; Chiba et al., 2008
Phytoplankton	1973-2002	Biomass at the PM-line (SE part of the Sea) in February and April	Chiba et al., 2008
Chl *a*	1961-1990	For S. Korean EEZ in April	Kang et al., 2000
Zooplankton	1985-2007	Total biomass in the area southward from Vladivostok in May-June. Total annual biomass in S. Korean EEZ. Annual anomaly of total biomass at PM-line	Zuenko, Dolganova, 2009; Minami et al., 1999; Chiba et al., 2008; Rebstock, Kang, 2003
Sardine, pollock, japanese common squid	1918-2005	Total annual catch of these species; number of generations for pollock	Davidova, Zuenko, 2004; Zuenko et al., 2008; Mokrin, Khen, 2004
Tunas, mackerels, yellowtail	1964-2004	Annual Japanese catch	Tian et al., 2008

Results: **trends of oceanographic parameters in the last 3 decades**

Parameter	Trend, year^{-1}	Significance (95% level)
SST in the northern JES (winter)	+0.026 deg.C	significant
SST in the northern JES (summer)	+0.028 deg.C	significant
SST in the southern JES (winter)	+0.021 deg.C	significant
SST in the southern JES (summer)	+0.013 deg.C	insignificant
SST at the coast of Primorye	+0.040 deg.C	significant
Intermediate Water temperature (winter)	+0.017 deg.C	significant
Intermediate Water temperature (summer)	+0.025 deg.C	significant
Bottom Water temperature	+0.001 deg.C	significant
Intermediate Water salinity	+0.001 ‰	significant
Deep Water salinity	-0.0003 ‰	significant
Ice cover in the Tatar Strait	+0.0015 %	insignificant
Polar Front position	0.7-0.9 n.miles	insignificant
Mixed layer depth in the northern JES	+0.16 m	insignificant
Dissolved oxygen content at the sea bottom	-0.018 ml/l	significant

Results: **trends of biological parameters in the last 3 decades**

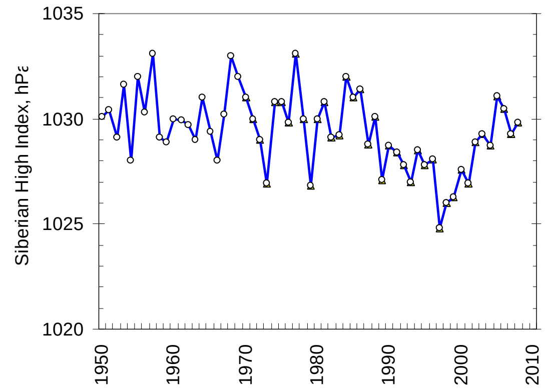
Parameter	Trend, $year^{-1}$	Significance (95% level)
Phytoplankton abundance in the southeastern Japan/East Sea	-0.3 mg/m^3	insignificant
Chl *a* concentration in the southwestern Japan/East Sea	-0.004 mg/m^3	insignificant
Zooplankton biomass in the northwestern Japan/East Sea	-1.5 mg/m^3	insignificant
Zooplankton biomass in the southeastern Japan/East Sea	+0.1 mg/m^3	insignificant
Zooplankton biomass in the southwestern Japan/East Sea	+6.0 mg/m^3	significant
Annual catch of sardine	$+3.78 * 10^3$ t	insignificant
Number of generations for pollock	$-3.64 * 10^6$ sp.	significant
Annual catch of japanese common squid	$+4.18 * 10^3$ t	significant

Results: **sea surface warming**

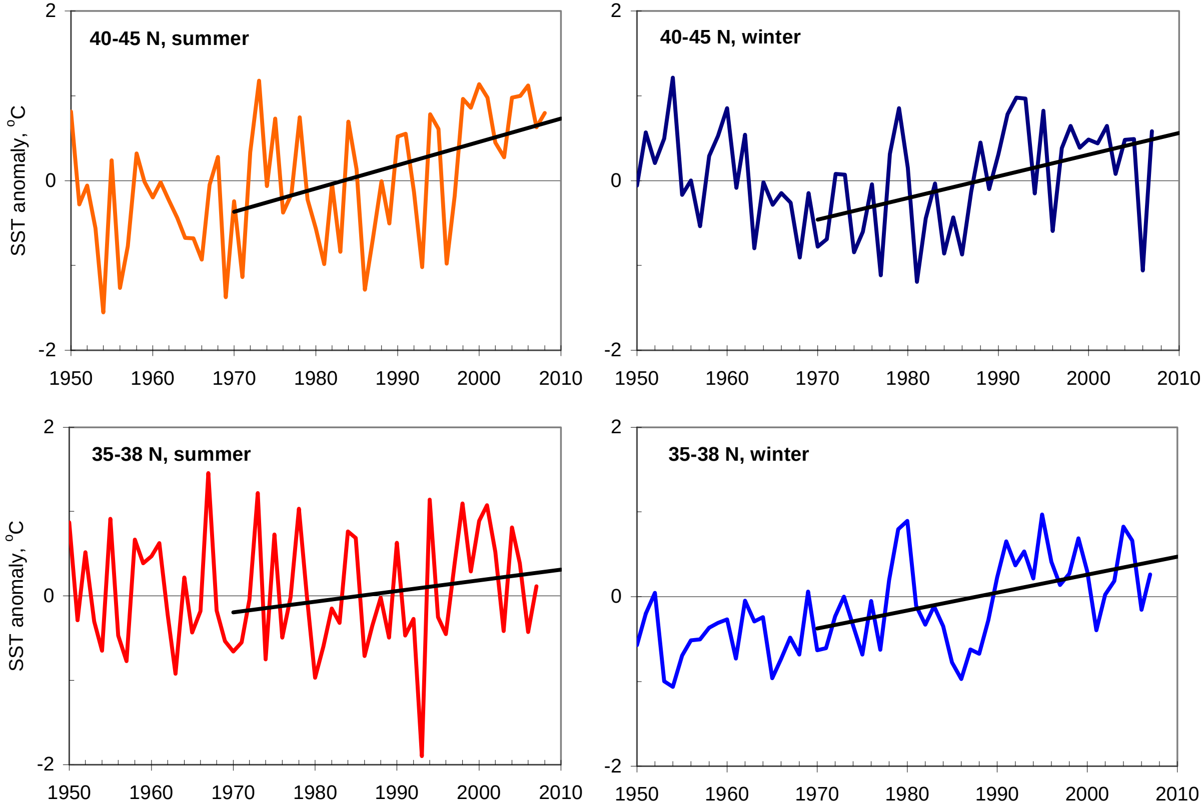
Climatic trend of SST for the last 3 decades is positive over the whole Sea, in all seasons.

Besides, interdecadal changes could be seen, which are stronger than year-to-year fluctuations: SST grew until late 1990s and is decreasing recently.

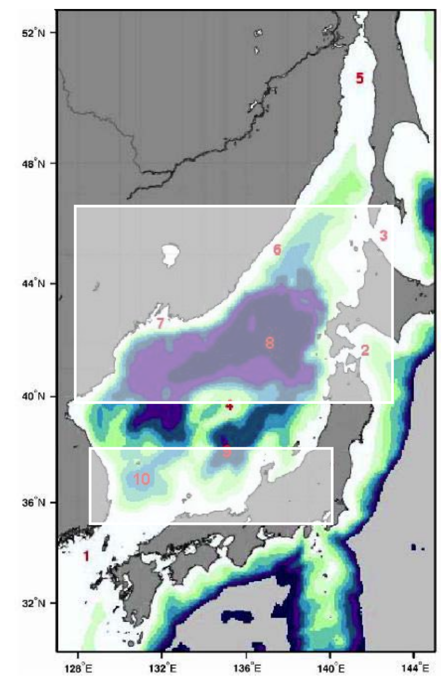
Both trends and interdecadal changes are stronger in the northern part of the Sea in winter. Obviously, they are caused by latent heat flux decreasing in conditions of wind weakening because of weakening of the Siberian High.



SHI (Siberian High Index)

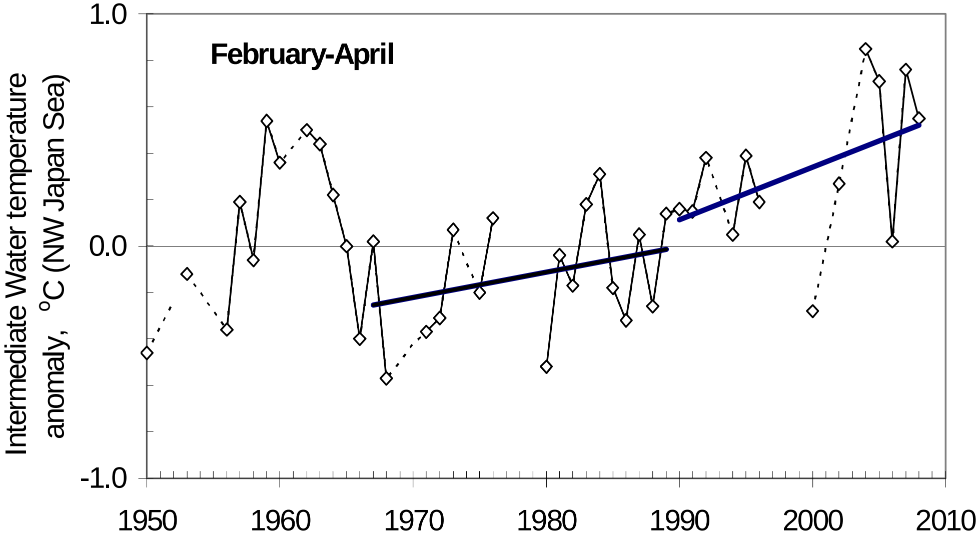


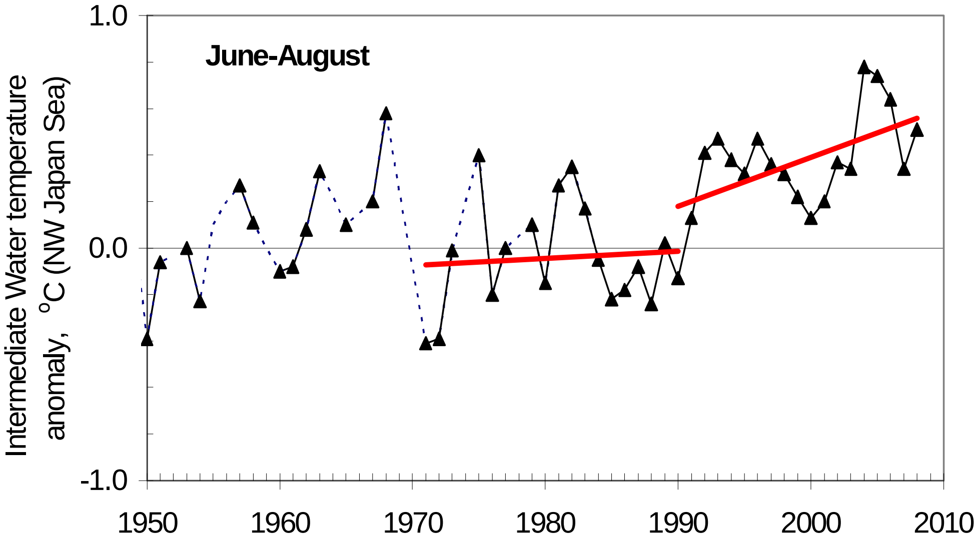
SST anomalies for certain areas and seasons (JMA data)



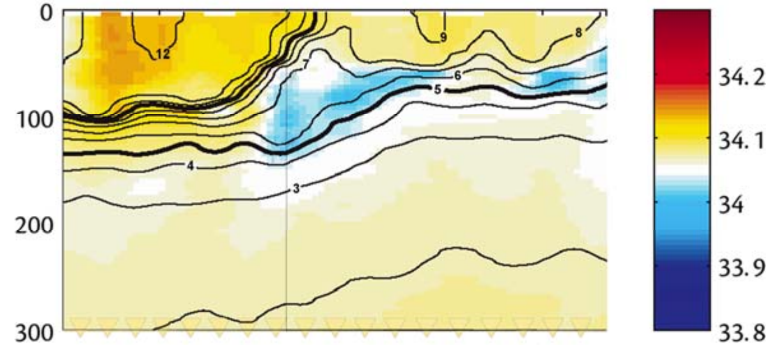
Results: **Intermediate Water warming**

Temperature of the Intermediate Water has positive trend in the last 3 decades



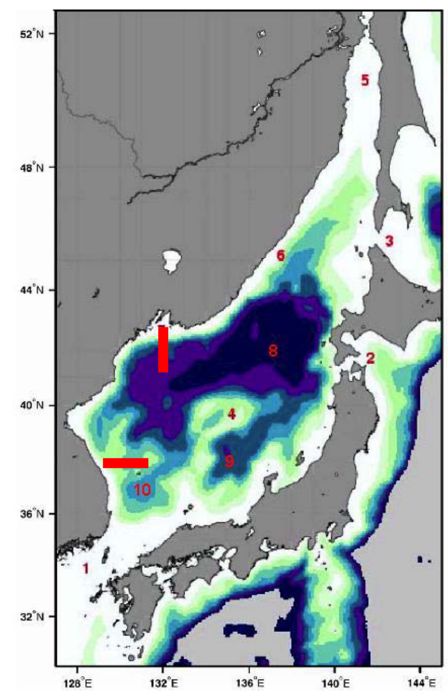


Temperature anomalies in the layer from thermocline to 200 m at the standard section along 132° E.



Scheme of the Intermediate Water formation in the process of subduction at the Polar Front (from Lee et al., 2006)

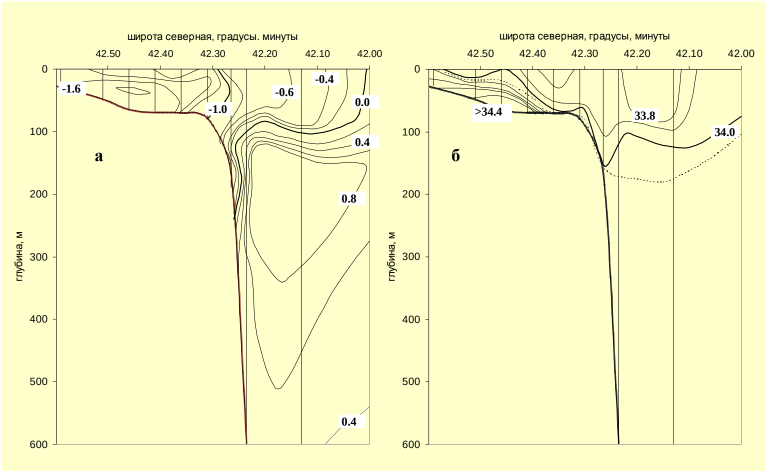
Taking into account the mechanism of the Intermediate Water formation (subduction), the main reason of warming is winter SST heightening southward from the Polar Front



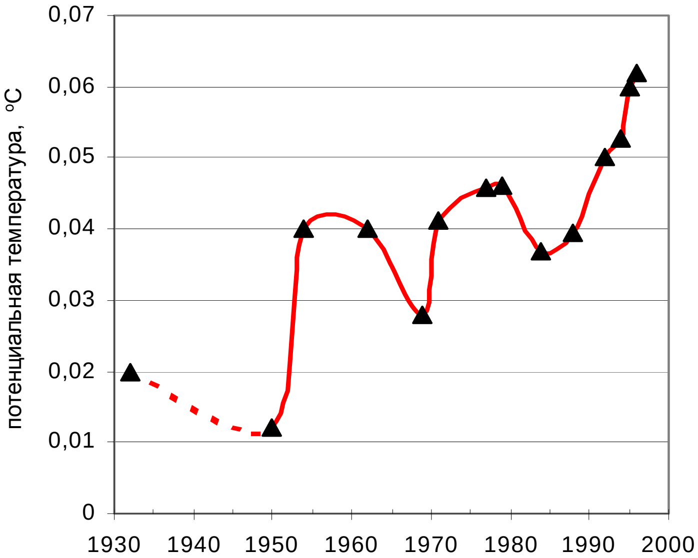
Results: **Deep and Bottom Waters - warming and oxygen depletion**

Temperature in deep and bottom layers has positive trend in the last 3 decades that coincides with the tendency for dissolved oxygen depletion in these layers.

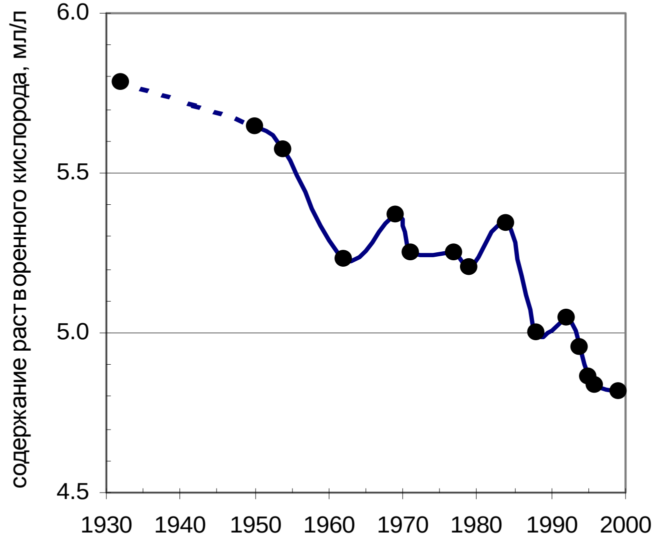
The tendencies are caused by convection weakening because of winter SST warming. Relatively strong convection in the beginning of the last decade was episodic event.



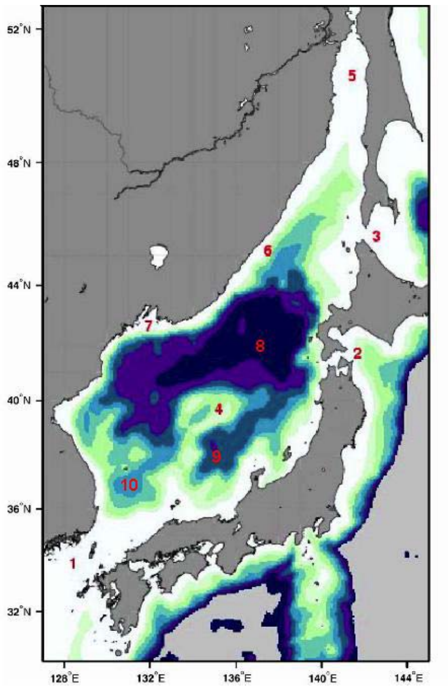
Bottom Water formation in the process of cascading in Peter the Great Bay (March 2000)



Potential temperature at 3000 m depth



Dissolved oxygen content at 3000 m depth

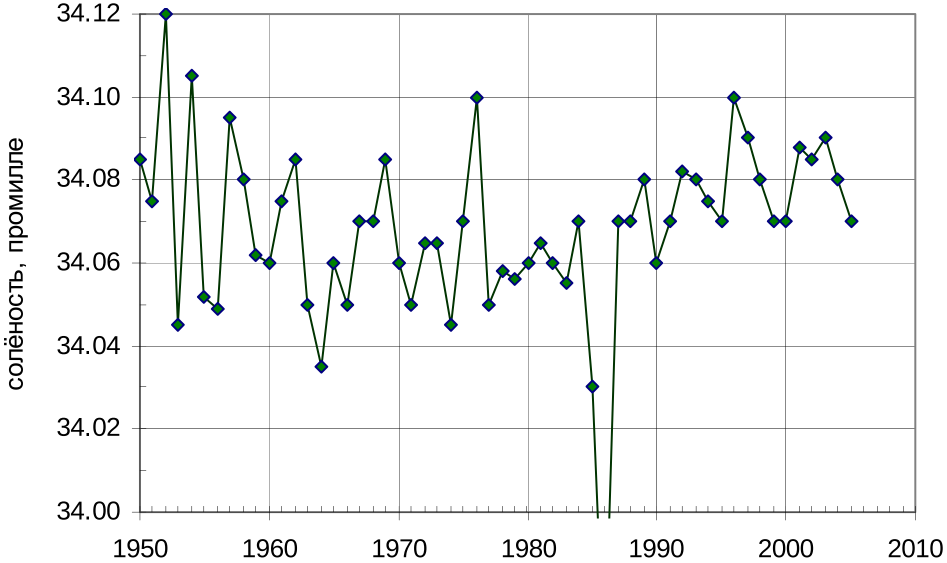


(data from Uda, 1934; Chen et al., 1999; Ponomarev et al.,2000; Kang et al., 2003)

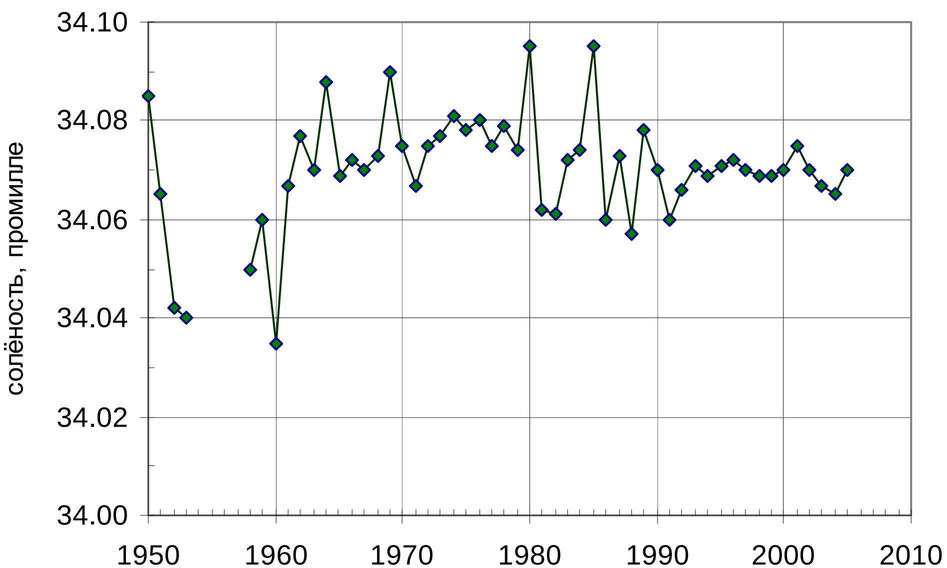
Results: **salinity - stabilization**

Salinity in the intermediate and deep layers had opposite trends until the late 1980s: positive for the intermediate layer and negative for the deep layer that was caused by strengthening of convection which smoothed the difference between these layers

Recently salinity has unilateral tendencies (insignificant lowering) in both these layers because of deep convection cessation and separation between the intermediate and deep water masses which interact between each other in the process of turbulent mixing



Annual mean salinity in the layer 350-1000 m in the central JES (Rudykh, 2008)



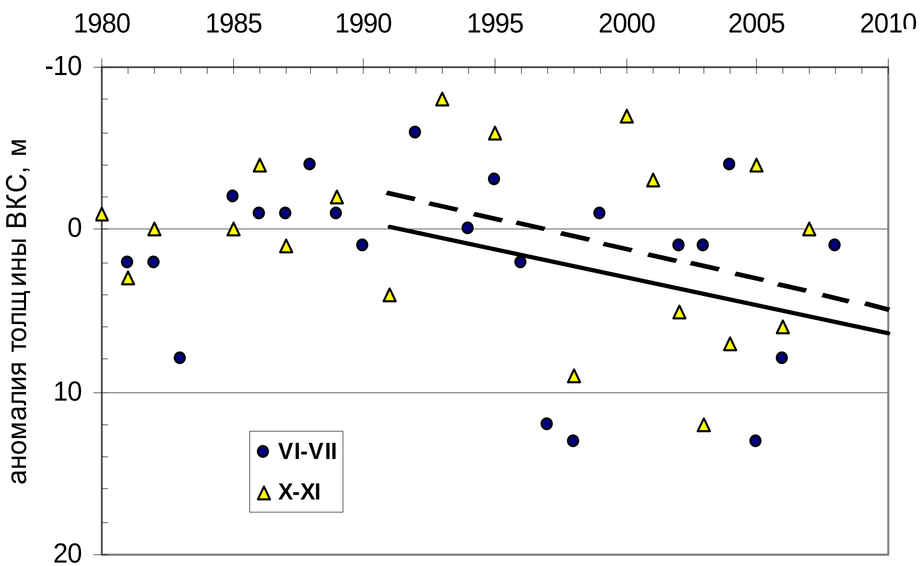
Annual mean salinity in the layer 1000-2000 m averaged for the whole JES (Rudykh, 2008)

Results: **mixed layer depth – insignificant change**

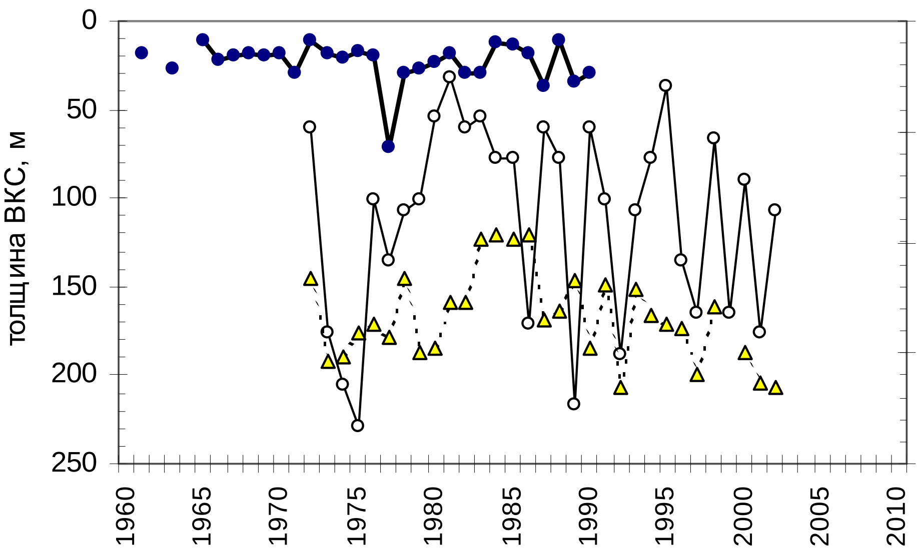
MLD has no significant trend in the last 3 decades

MLD became thicker in the last decade both in winter and summer

The MLD depends on wind rate, but this dependence is smoothed by opposite influence of water stability



MLD anomaly in Subarctic zone of the Japan Sea (relative to 1986-1996)

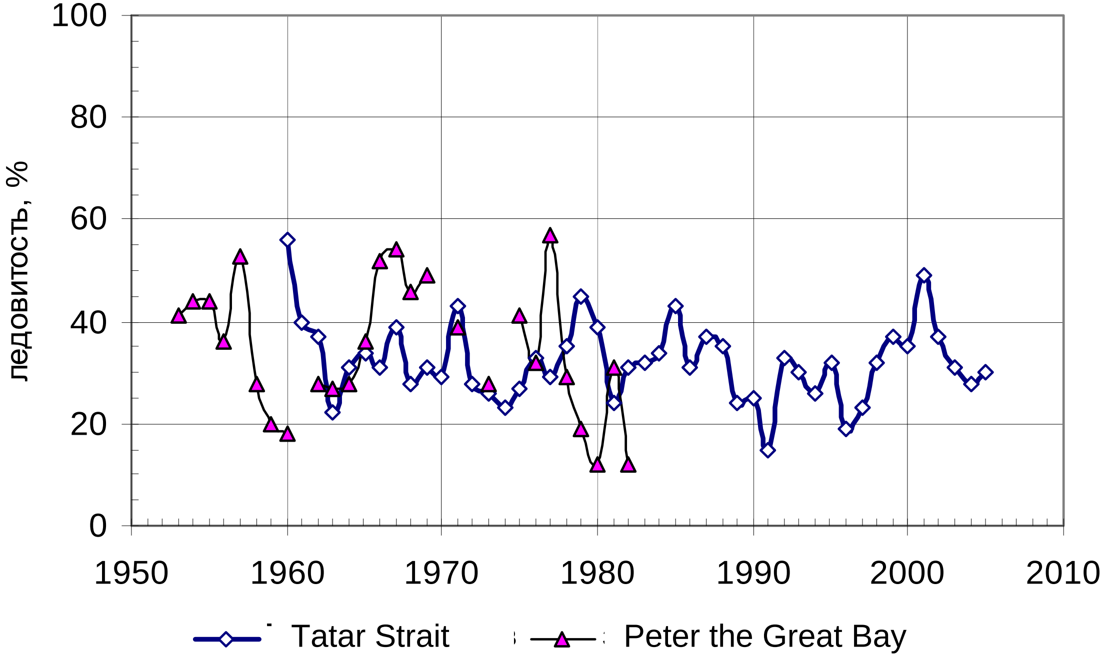


- *Year-to-year fluctuations of MLD in the southern Japan Sea*
- *in winter (blue circles) and spring (white circles)*
  (Kang et al., 2000; Chiba et al., 2008)

Results: **ice cover – no tendency**

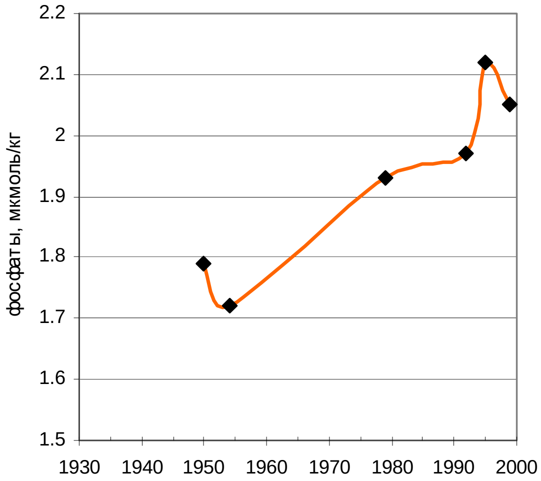
Ice cover fluctuation has no significant trend, although both air temperature and SST have those ones

Possibly, the reason is a strong influence of warm currents on the ice cover in the JES; the currents activity has no evident trend



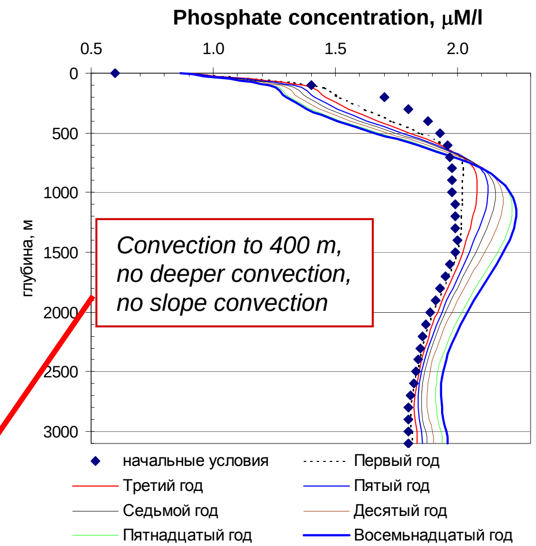
Year-to-year fluctuations of ice cover in the Tatar Strait and Peter the Great Bay averaged for January-April (Khen et al., 2002)

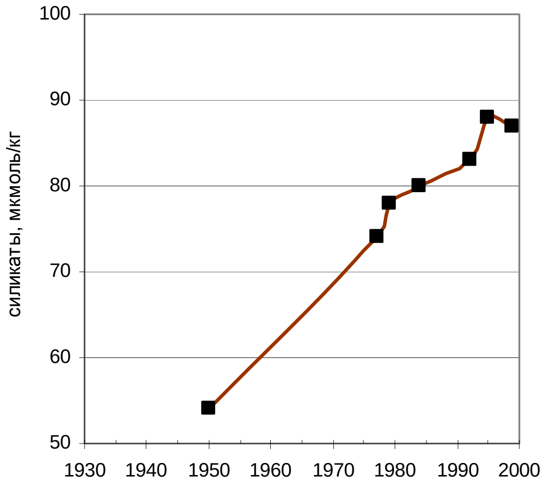
Results: **convection weakening prevents vertical exchange with dissolved oxygen and nutrients and reduces productivity**



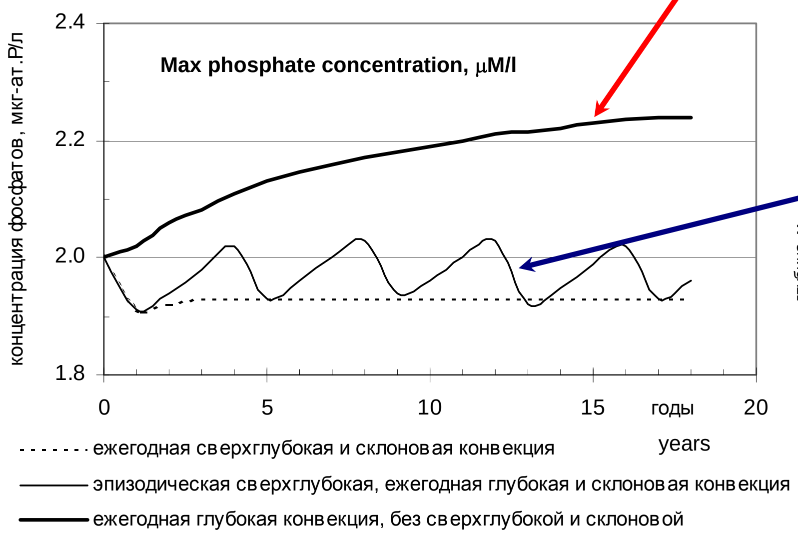
Shallowing of the deep convection and cessation of the slope convection weaken ventilation of the deep and bottom layers, so the oxygen content decreases and the nutrients concentrations increase within these layers

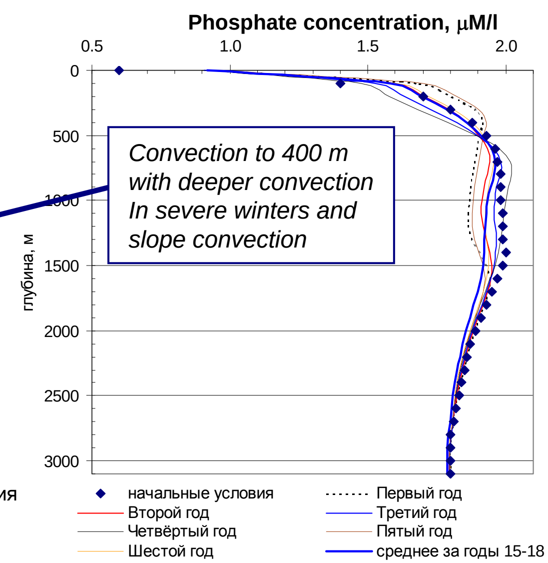
Because of convection weakening, convective influx of nutrients into euphotic layer weakens, and spring **"new production" decreases**





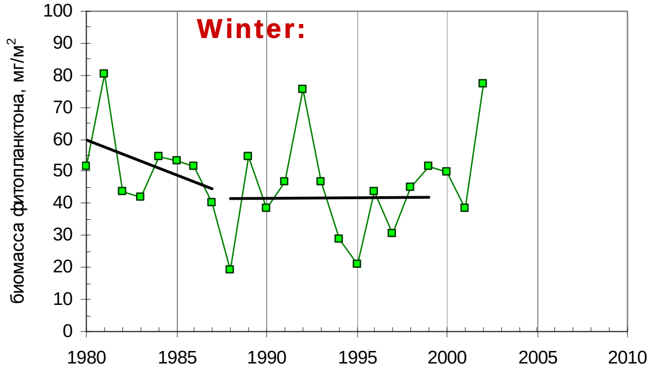
Change of phosphate and silicate concentrations at 3000 m depth





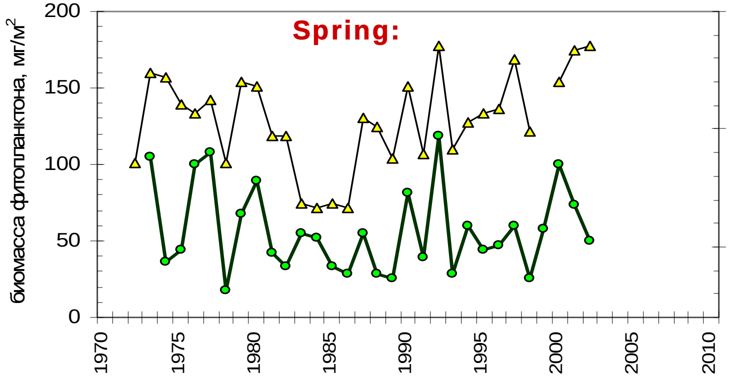
Modeling of phosphate concentration in conditions of strong (down) and weak (up) convection

Results: **however, no evident tendencies of phytoplankton abundance**



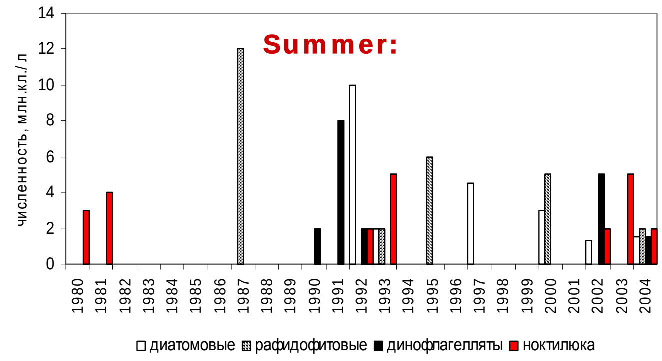
Phytoplankton biomass in the layer 0-150 m in in the SE JES in February (Chiba et al., 2008)

Winter: winter monsoon weakening causes MLD shallowing, so this tendency is favorable for the phytoplankton growth; however, in real the phytoplankton biomass has no positive trend, possibly because of warm currents strengthening in 1990s



Phytoplankton biomass (green) in the layer 0-150 m in the SE JES in April-May (Chiba et al., 2008)

Spring: according to modeling results, warming is not favorable for phytoplankton growth in spring, but observations do not show any significant trend



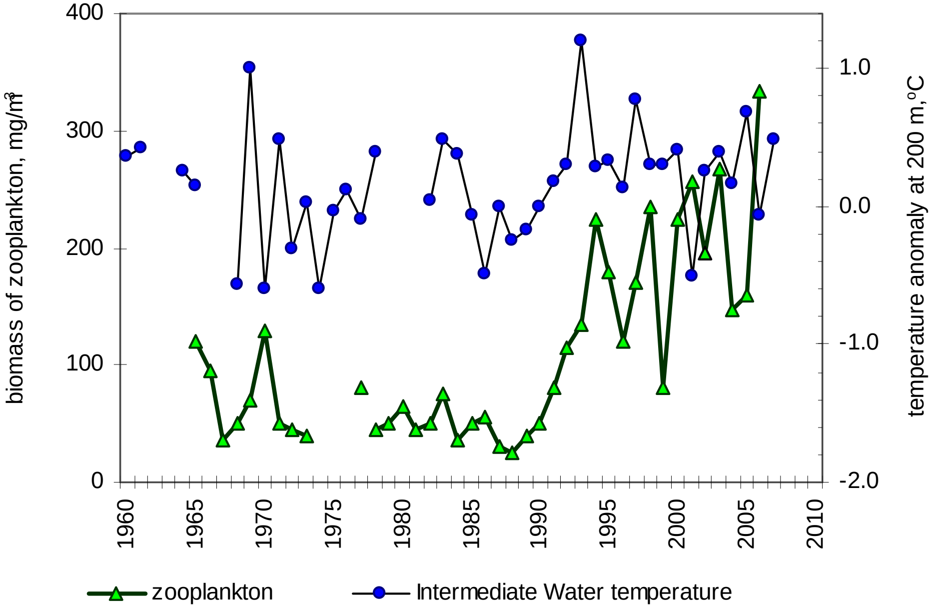
Frequency of summer blooms in Peter the Great Bay (Orlova et al., 2002)

Summer: (blooming is possible in the coastal zone only) – phytoplankton abundance has no climatic trend but has interdecadal fluctuations

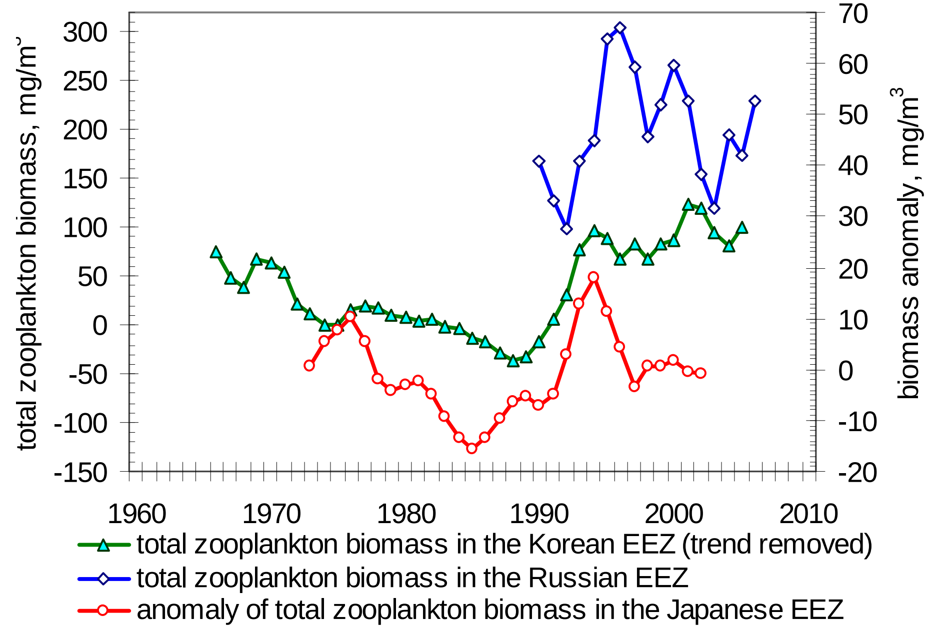
Autumn: terms and intensity of autumn blooming are very stable

Results: **zooplankton abundance - increasing**

Positive trend of the Intermediate Water temperature causes
the tendency for zooplankton abundance increasing since late 1980s



Changes of the Intermediate Water temperature and the mean annual biomass of zooplankton in the southwestern Japan Sea

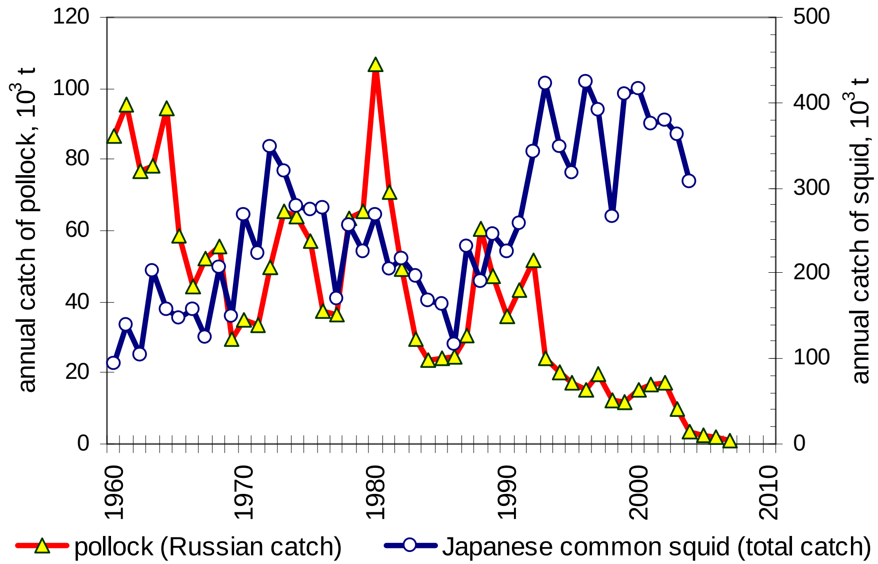


Zooplankton abundance changes in different parts of the Japan Sea

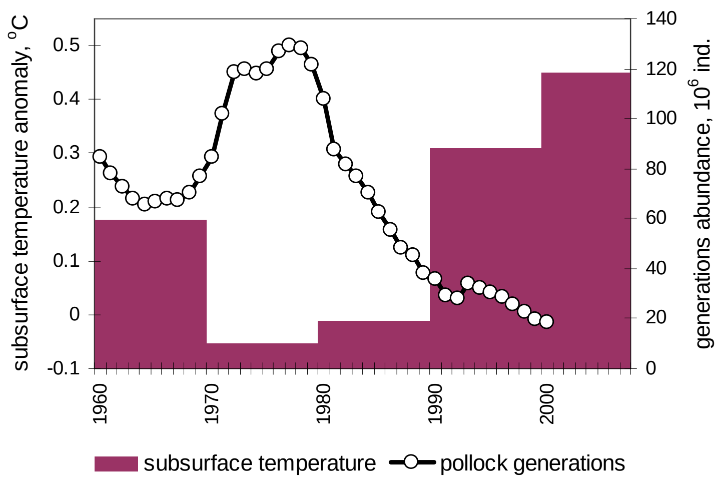
Results: japanese common squid *VS* walleye pollock

Large-scale fluctuations of the pollock population at Primorye are opposite to the large-scale changes of the Intermediate Water temperature that is possibly conditioned by biocenes reconstruction near the biogeographic border between subarctic and subtropic zones. That's why **recent climatic changes are unfavorable for pollock in the Japan Sea**

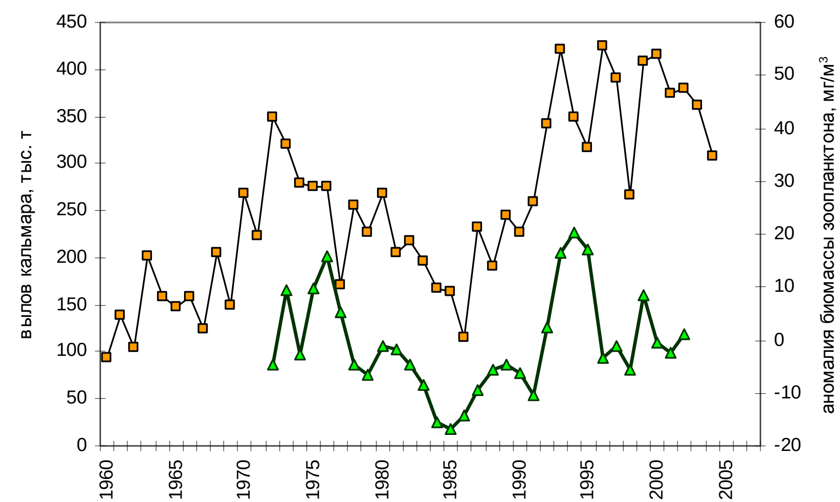
Japanese common squid abundance depends on winter monsoon because of the spawning grounds position change and the change of MLD: **recent winter monsoon weakening is favorable for the squid reproduction**; besides, its abundance depends on zooplankton abundance at the spawning grounds: **recent increasing of zooplankton is favorable for the squid**, as well



Catch of japanese common squid and pollock in the Japan Sea



Interdecadal changes of the number of pollock generations (Primorye population) and the Intermediate Water temperature anomaly



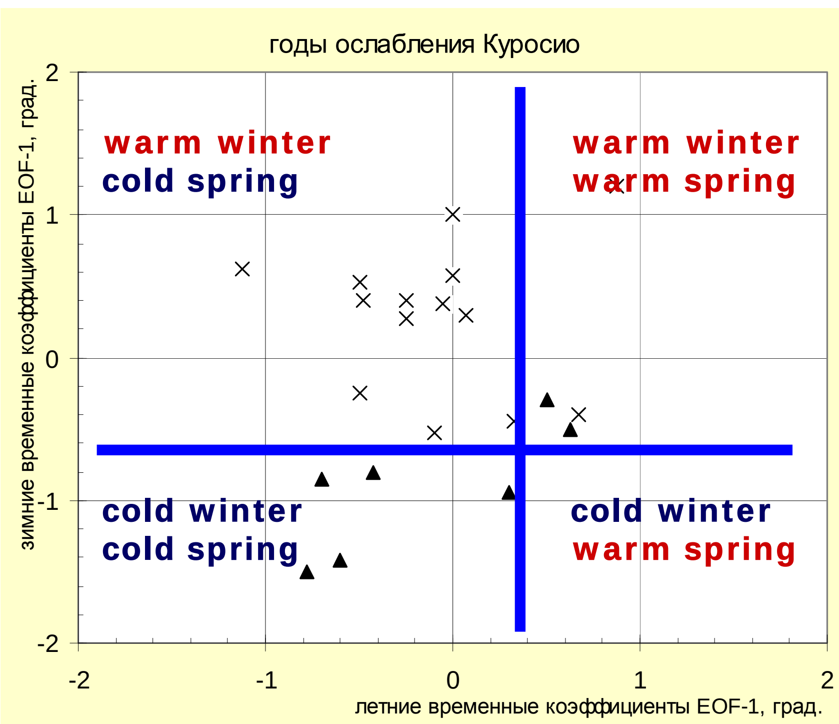
Annual catch of japanese common squid in the Japan Sea (red) and zooplankton abundance in the southeastern part of the Sea (green)

Results:

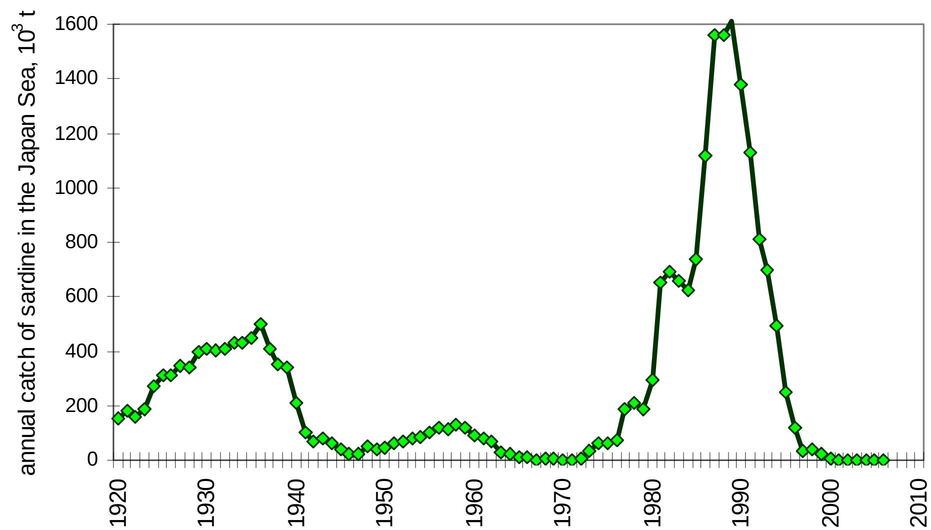
japanese sardine fluctuations don't relate to environmental changes of climatic scale

Previously were found (presented in Yokohama, 2006) that high-abundant generations of sardine are formed in the years with match of SST anomalies at spawning grounds in winter and spring (Cushing criterion). The last bloom of sardine in 1970-1980s was provided by constantly negative SST anomalies, but previous bloom in 1920-1930s – by constantly positive SST anomalies. Therefore, the sardine abundance fluctuations are not connected with long-term trends of water temperature.

New bloom is supposedly possible in conditions of simultaneous rise of winter and spring SST



Sardine spawn success in dependence on winter-spring SST at spawning grounds. Triangles – successful spawning, crosses – unsuccessful spawning



Total catch of sardine in the Japan/East Sea by all countries

Conclusion:

1. Some prominent long-term tendencies in oceanographic processes are revealed for the Japan Sea in the last 3 decades: **warming, oxygen depletion in the deep and bottom layers, convection weakening**. Other oceanographic processes do not have significant tendencies in climatic scale.

2. The main reason of the long-term changes is the **winter monsoon weakening**.

3. Convection weakening provides nutrients storage in the deep and bottom layers and prevents the nutrient upward flux to euphotic layer of the Sea. That means **water productivity lowering**.

4. However, **significant long-term tendencies are not revealed for phytoplankton abundance.**

5. **Warming promotes zooplankton abundance heightening.**

6. The **warming is favorable for the main warm-water species**, as japanese common squid, but unfavorable for cold-water species, as walleye pollock.

7. In general, the changes of the Japan Sea ecosystem could be interpreted as “tropicalization”: the **ecosystem is reorganized from the high-productive, low-efficient state typical for subarctic seas to the low-productive, high-efficient state typical for subtropical seas**. These reconstructions are predominantly positive for regional fishery.