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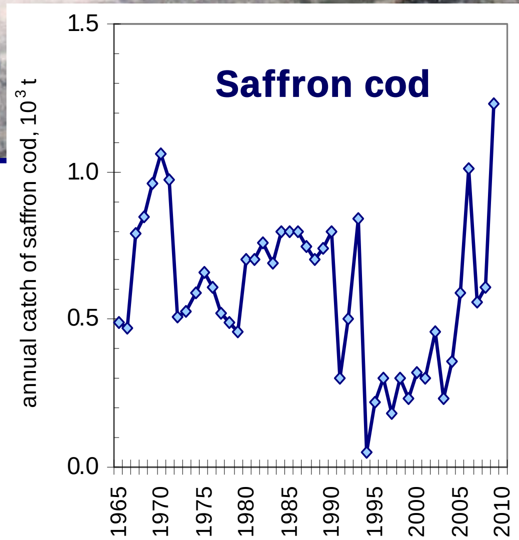
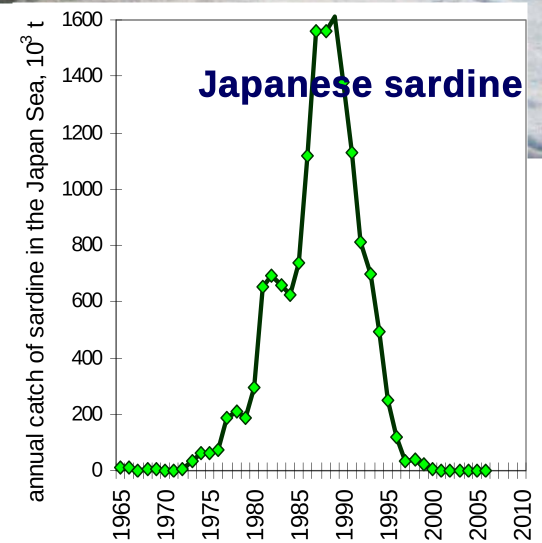
Climate change effect on the saffron cod *Eleginus gracilis* reproduction, stock, and fishery in the Japan Sea

Outline:

1. Fluctuation of the saffron cod population in Peter the Great Bay
2. Match/mismatch mechanism for saffron cod
3. Nature of winter climate change in Peter the Great Bay
4. Schemes of the saffron cod stock formation in 1990s and 2000s





Goals:

- To understand mechanisms of the saffron cod stock and catch fluctuations
- To estimate possible effect of recent climate change on the saffron cod population in Peter the Great Bay

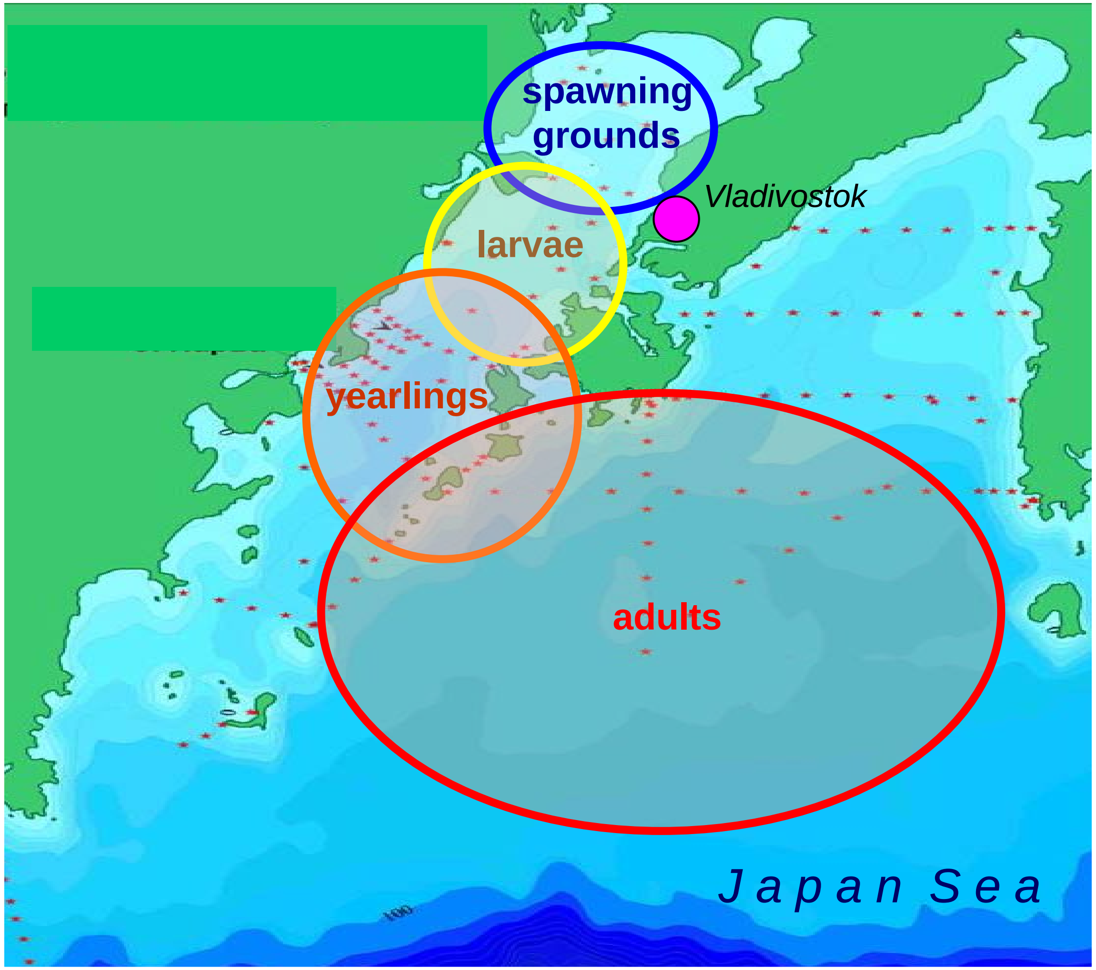
Area of study: **Peter the Great Bay**

The main spawning grounds of saffron cod are located in the shallow Amur Bay where it spawns under the ice in winter.

Larvae of saffron cod are distributed mostly in the same area that is high-productive in spring.

Yearlings of saffron cod dwell the sallow areas, as well.

Adults of saffron cod feed on benthos and distribute widely over the bottom of Peter the Great Bay.



Data sources:

Index	Period	Brief description	Source
Catch of saffron cod	1942-2009	Annual commercial catch in Peter the Great Bay, mainly by hoop nets	Fishery statistic
Catch efforts	1965-2009	Number of hoop nets mounted in Peter the Great Bay	Fishery statistic
CPUE for saffron cod	1965-2009	Annual catch per a net (regards mainly to winter), calculated from annual catch and catch effort	Authors' data
Caught number of generations for saffron cod	1965-2004	Summary catch of each generation in the age 1+ and elder normalized for standard catch effort (180 hoop nets)	Authors' data
Maturity of saffron cod	1932-1999	Maturity percentage monitoring in the spawning period (from December to March)	Authors' data
Sea surface temperature	1981-2002	Daily data for Vladivostok: for January-April averaged to monthly ones and restored to 1954-2006 using good correlation with air temperature	Hydrometeorological Agency of Russia
Air temperature	1881-2006	Monthly and daily (since 1965) data for Vladivostok	**http://data.giss.nasa.gov** **http://climexp.knmi.nl/**
Siberian High Index	1900-2006	Mean month atmospheric pressure at the sea surface in 40-65 N 80-120 E averaged for December-February	Panagiotopoluos et al., 2005, with additions
Arctic Oscillation Index	1950-2007	Coefficients of the leading EOF of the atmospheric pressure at the sea level in the zone 20-90 N	http://jisao.washington.edu/analyses0302/

Results: **recruits-spawners dependence**

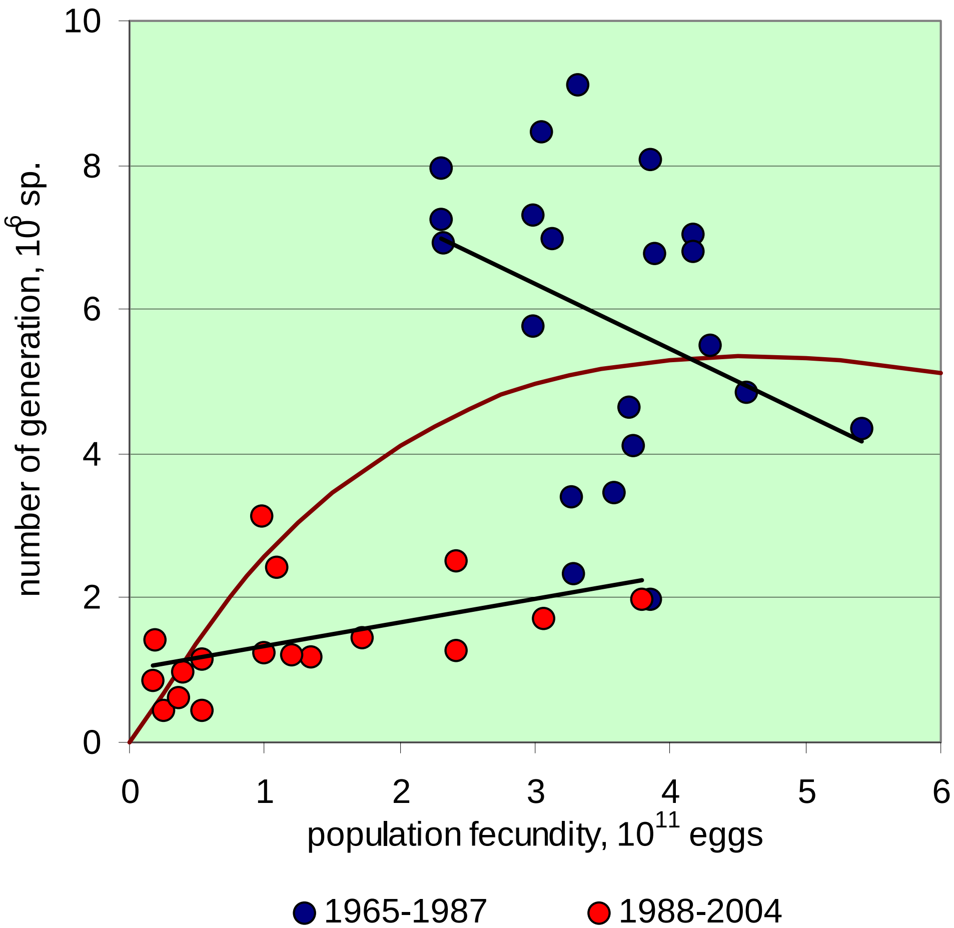
Generally, saffron cod shows positive dependence of generation abundance on the number of spawners recalculated to the population fecundity. The dependence could be approximated by Ricker equation

$$R = aS\,e^{-bS} \quad \text{with } r^2 = 0.43.$$

However, this dependence reflects only the difference between two states of the cod stock:
- the high stock before the late 1980s and
- the low stock after the late 1980s

Within the first period the recruits-spawners dependence was negative, and within the second period it was insignificant.

That means that the recruitment success depends on other factors, as environments.

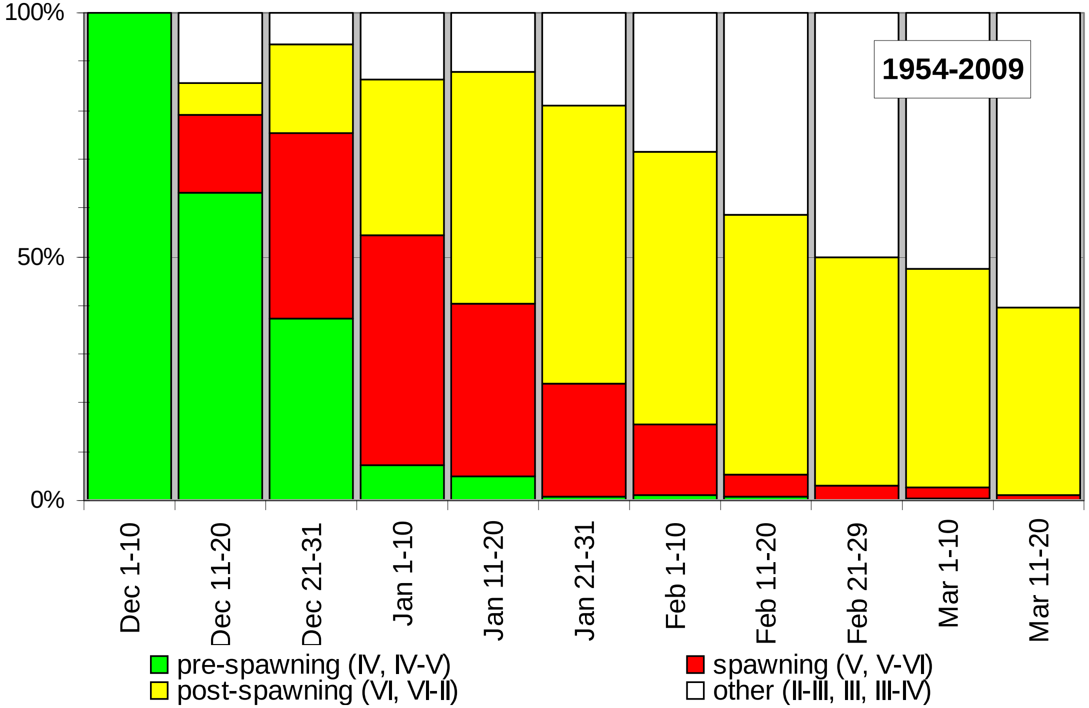


Dependence of the saffron cod generations number on its population fecundity

Results: **dynamics of spawning**

The saffron cod spawns under the sea ice, in December-February.
Its eggs develop at the sea bottom in conditions of temperature below zero.

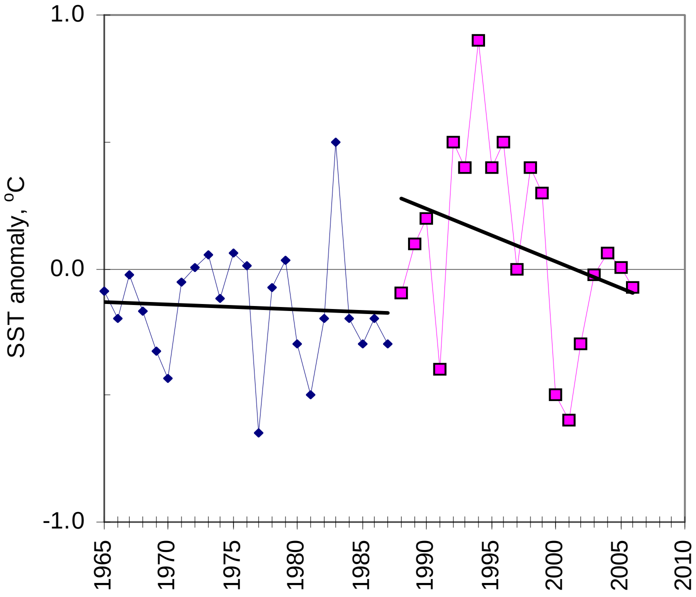
On average, the mass spawning of saffron cod occurs in early January



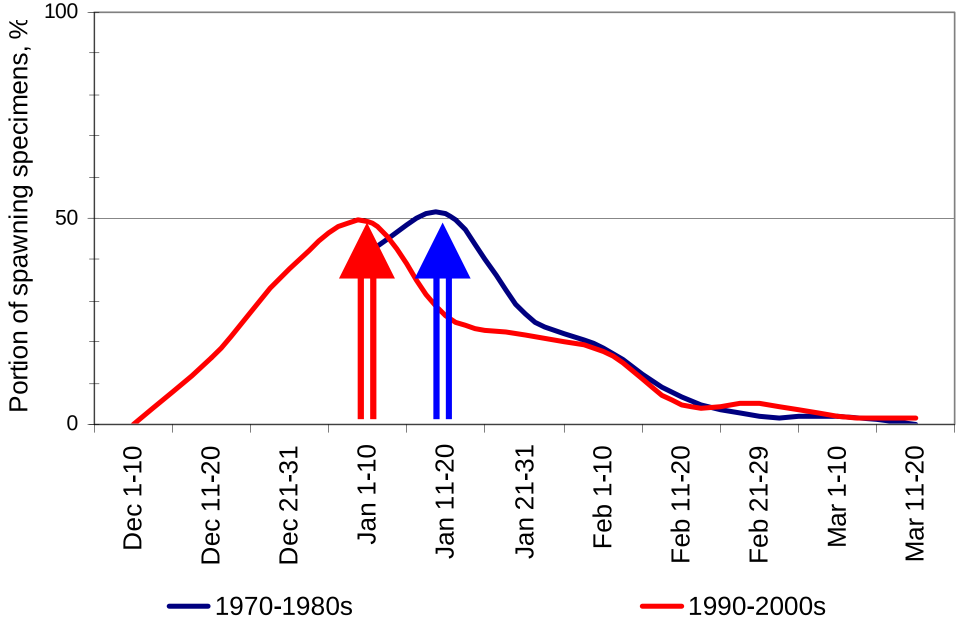
Average dynamics of maturing for saffron cod in Peter the Great Bay

Results: **dynamics of spawning**

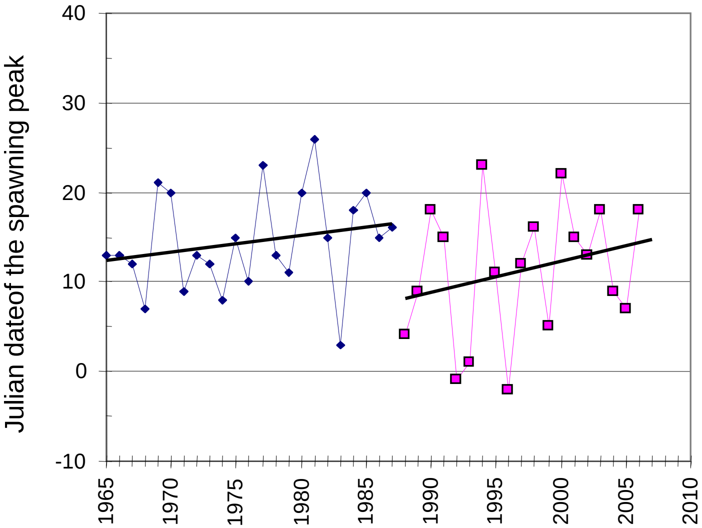
The time of mass spawning differs from year to year. Generally, it became earlier in the last decades. The dates of the spawning peak are opposite to water/air temperature in January (r = 0.66), so the shift to warming in late 1980s caused the shift to earlier spawning.



Mean month SST anomalies in Vladivostok in January



Portion (%) of the saffron cod spawning females (stage V) in 1970-1980s and 1990-2000s

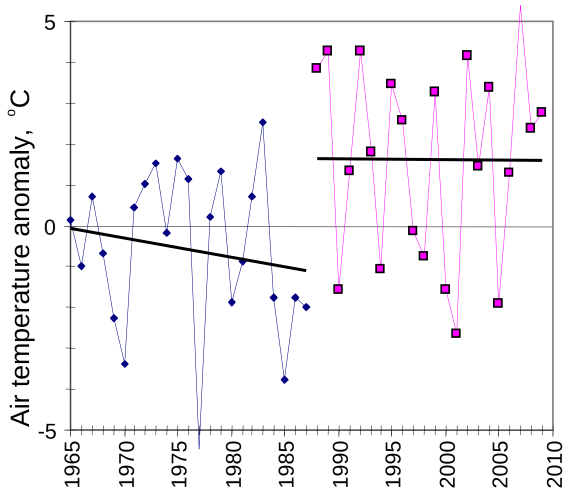


Year-to-year changes of the date of spawning peak. Shift to earlier dates occurred in late 1980s

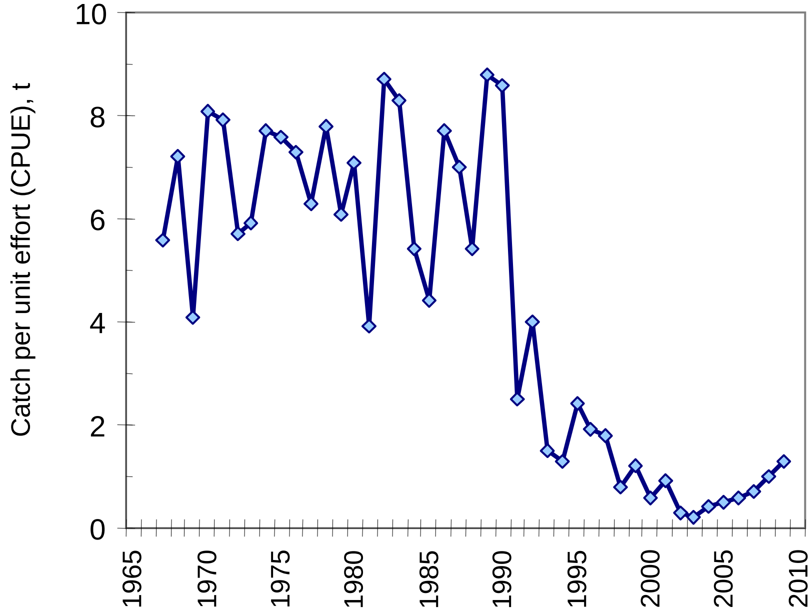
Results: **dynamics of catch and generation number**

The shift to earlier spawning (because of the climate shift to warming) caused a sharp lowering of the saffron cod generations number in the late 1980s, and later, in the early 1990s – a sharp decline of catch.

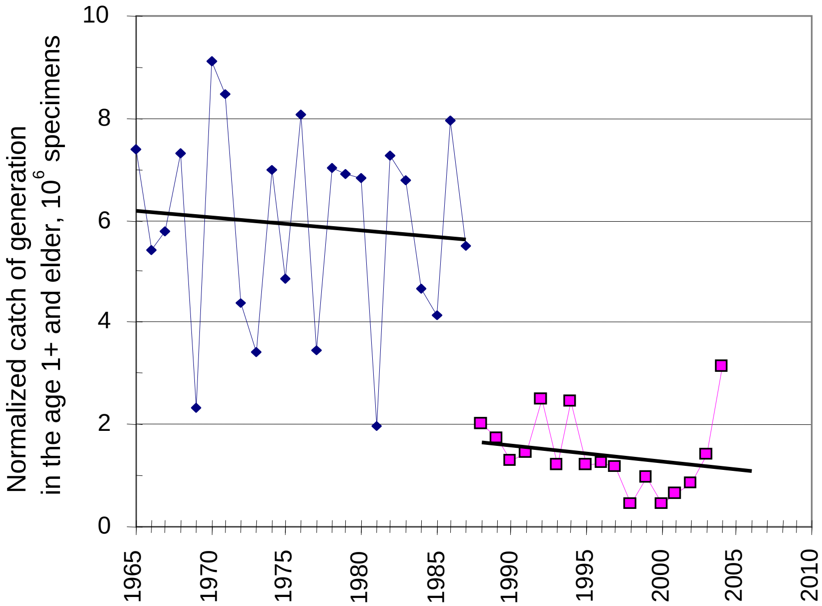
We suppose that early spawning is unfavorable for the saffron cod reproduction because of longer period until spring bloom of the prey for its larvae – small copepods.



Mean month air temperature anomalies in Vladivostok in January



Annual CPUE for saffron cod in Peter the Great Bay, tons per a hoop net



Number of generations in catch of saffron cod (summary catch of each generation in the age 1+ and elder)

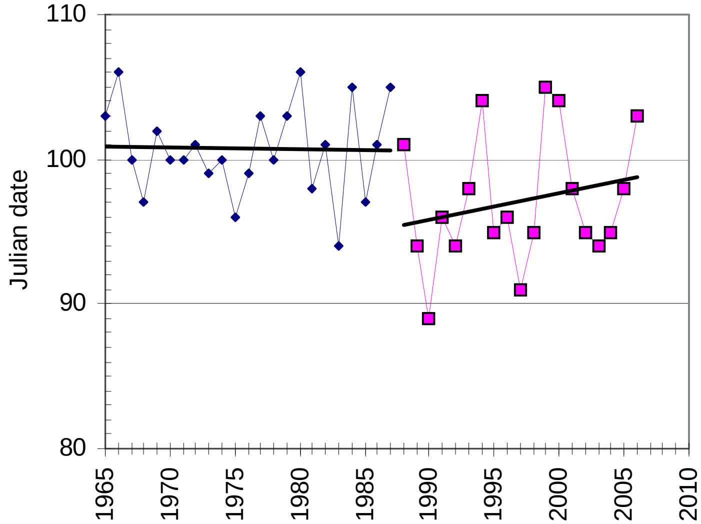
Results: **seasonal succession of plankton**

The larvae of saffron cod feed on small-sized zooplankton, mostly nauplia of Copepoda.

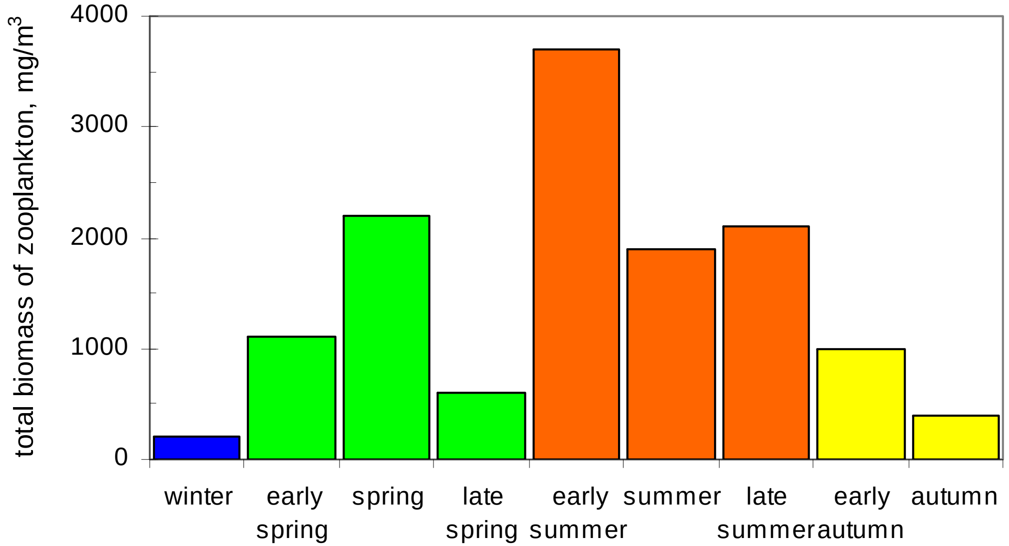
Seasonal development of plankton in the coastal waters of the Japan Sea is a succession of “seasons” with specific features. Zooplankton is the most abundant in the spring (immediately after the spring bloom of phytoplankton) and early summer. The larvae hatched in April, so they prey upon the spring bloom of cold-water copepods.

The spring season of plankton occurs in Peter the Great Bay in conditions of SST between 2.5 and 8°C. The timing of SST 2.5° (start of spring season) is rather stable from year to year, but had a shift to earlier dates in the late 1980s

Season	*Abundant groups of plankton*
Winter	*Low abundance of all groups*
Early spring	Phytoplankton (spring bloom)
Spring	**Phytoplankton, cold-water Copepoda**
Late spring	Phytoplankton, Sagitta, Euphausia
Early summer	Large-sized cold-water Copepoda
Summer	Meroplankton
Late summer	Cladocera, warm-water Copepoda
Early autumn	Phytoplankton, warm-water Copepoda
Autumn	Sagitta, warm-water Copepoda



Time of the spring season beginning (SST = 2.5°) in Vladivostok (by daily data)



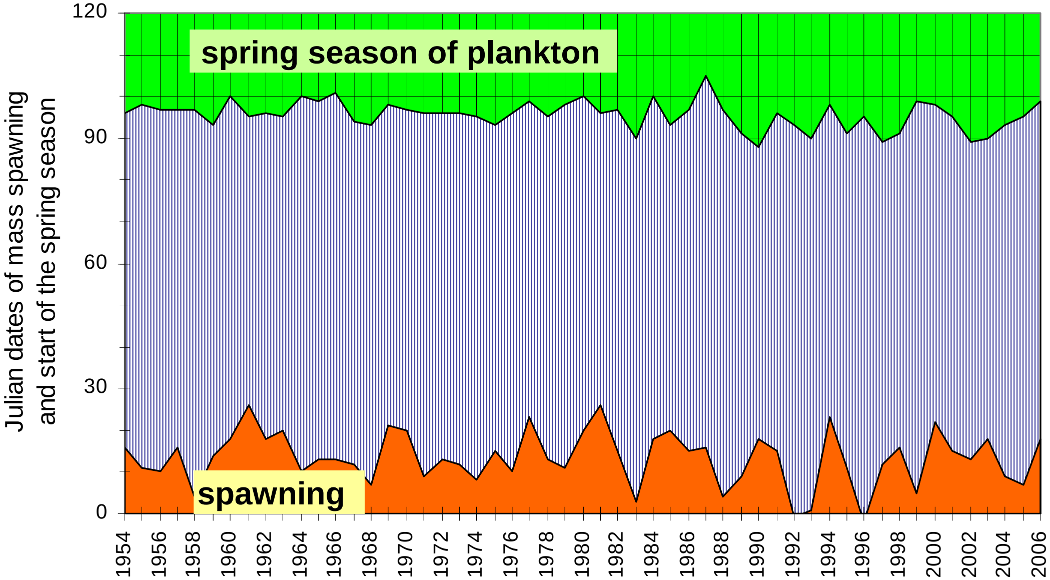
Total biomass of zooplankton in different seasons in the main spawning grounds of saffron cod (northern Amur Bay)

Results: **period for embryonic development**

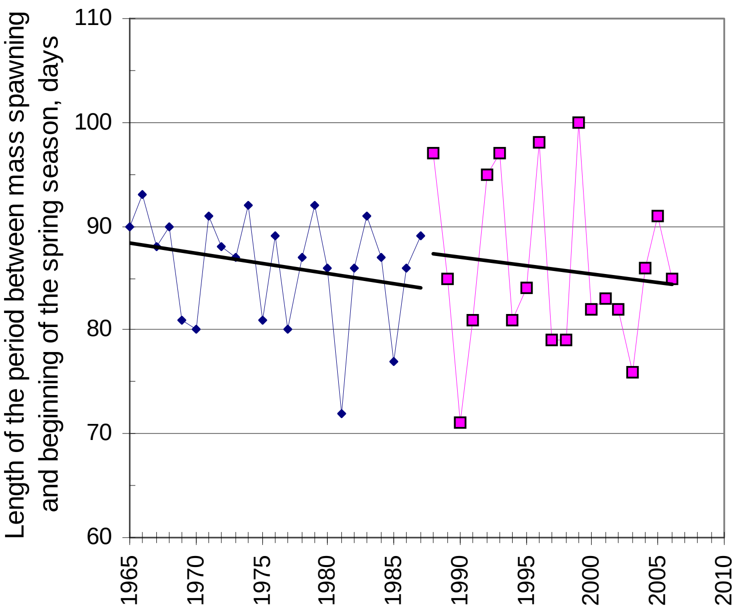
So, for reproductive success, the eggs of saffron cod have to develop in the period from the spawning to the spring season beginning, to be hatched in conditions of their prey abundance.

Length of this period differs from year to year, mainly because of the time of mass spawning changes. It became in several days longer in the late 1980s that obviously was unfavorable for the saffron cod reproduction.

In the years 1988, 1992, 1993, 1996, and 1999 with the period in 10 days longer than normal, the saffron cod reproduction was unsuccessful.



Dates of mass spawning and beginning of spring season. The "striped" period between them is ideal for embryonic development, but sometimes it is too long



Length of the period between mass spawning and beginning of the spring season

Results: **match / mismatch**

In fact, either extremely long and extremely short period between the mass spawning and the spring season beginning are unfavorable for the saffron cod reproduction. In opposite, an optimal length of this period provides the best match of the larvae hatching with prey abundance.

To determine the optimal length, the dependence of generation number (***N***) on the length of period from mass spawning to the spring beginning (***T***) is approximated by resonance function:

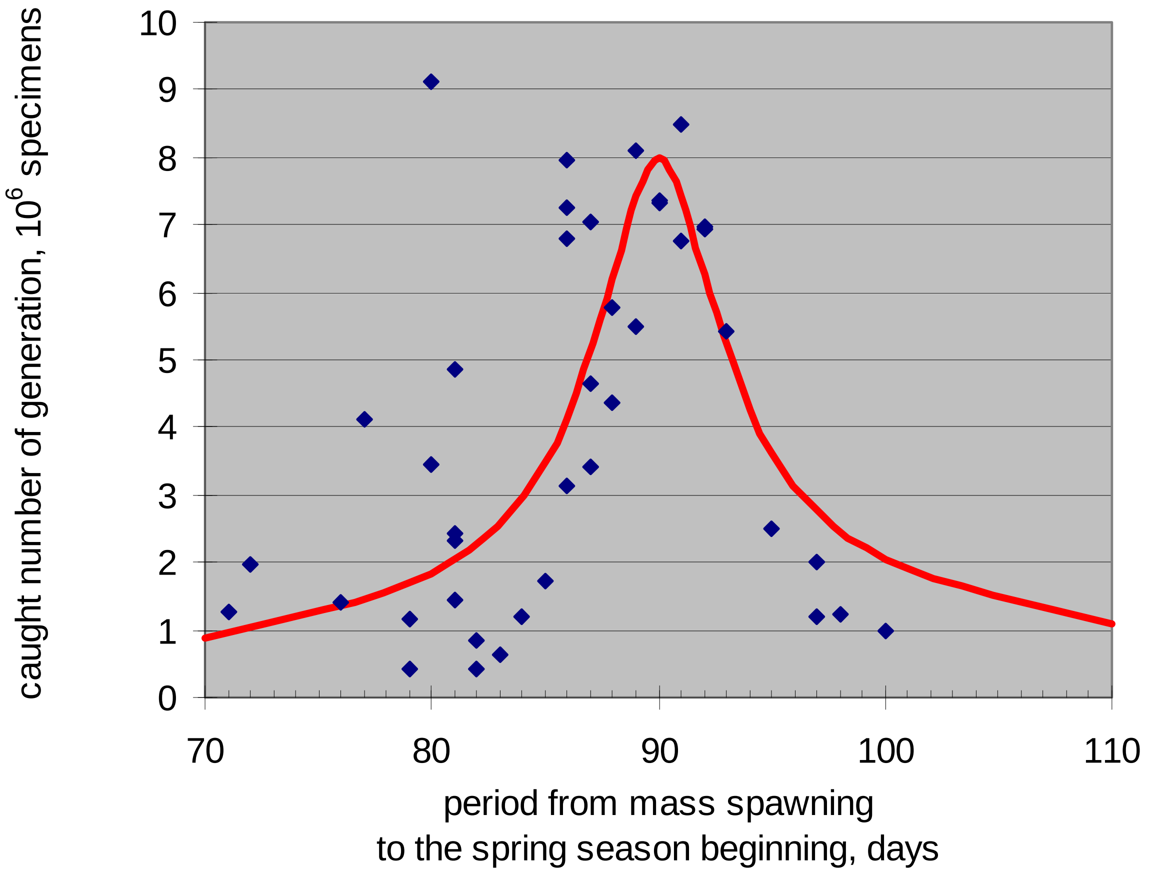
$$N = \frac{a}{\sqrt{1 + \left[Q \cdot \left(\frac{T}{T_R} - \frac{T_R}{T} \right) \right]^2}}$$

where T_R = 90 days – resonance length;
Q = 18.1 – Q-factor of vibrating system;
a = 8.0 – empiric coefficient

If the period $\boldsymbol{T}$ is equal to $\boldsymbol{T_R}$ = 90 days, the saffron cod larvae is hatched in conditions of high abundance of their prey – small copepods.

If this period is shorter or longer than $\boldsymbol{T_R}$, the prey abundance is lower, so weak generations of saffron cod are formed.

In 1990s, this period was mainly longer than $\boldsymbol{T_R}$, that caused the population collapse.

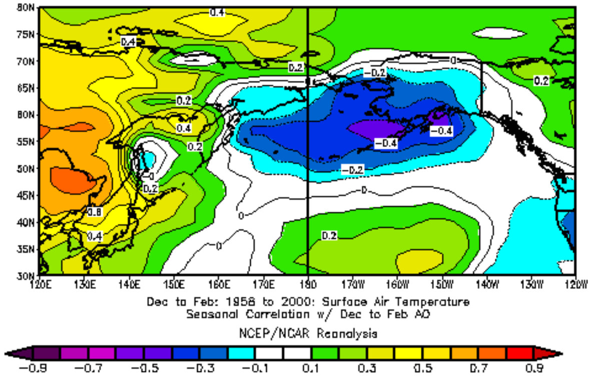


Dependence of the saffron cod generation number on the length of period between mass spawning and spring season beginning

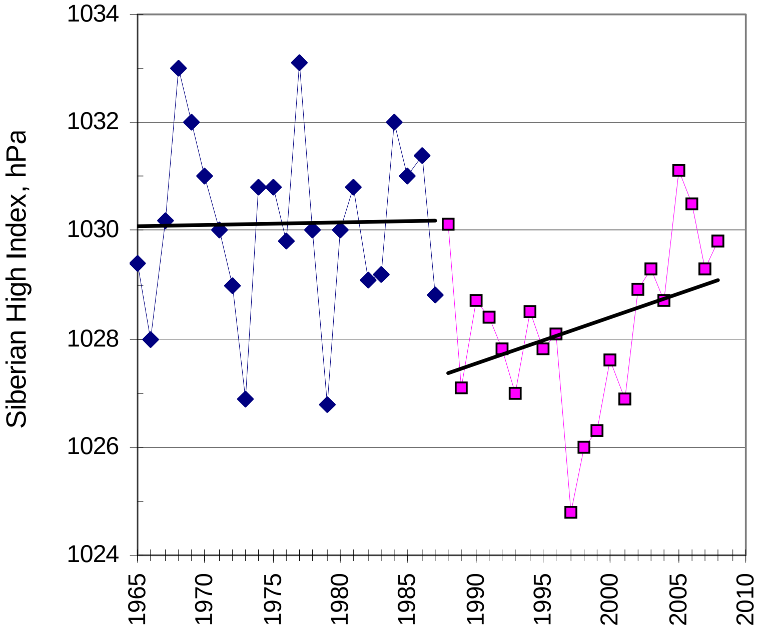
Results: **winter warming in the Japan Sea**

Winter warming was observed in the late 1980s both in the spawning area of saffron cod and in the whole Japan Sea. Obviously, it was driven by a large-scale mechanism.

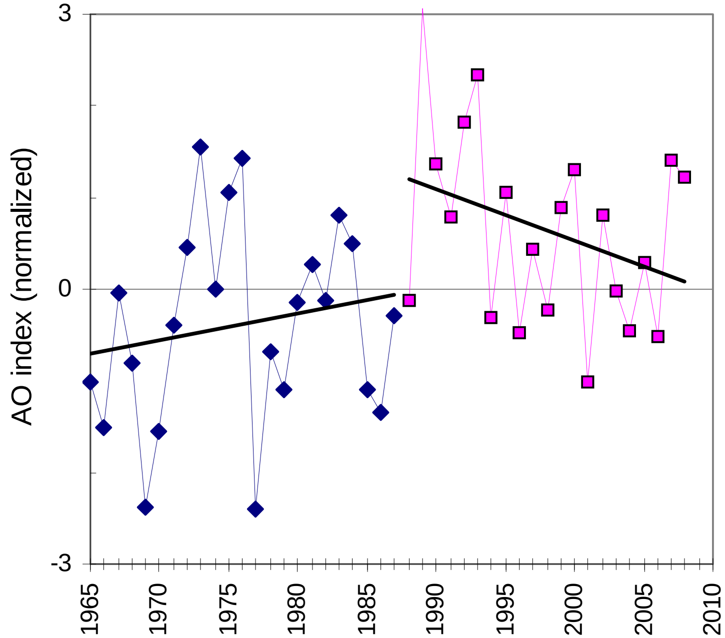
Air temperature in January correlates strongly (r = +0.62) with winter Arctic Oscillation Index, and the temperature in February – with the Siberian High Index (r = –0.57). The indices are interdependent. They both have a prominent shift in the late 1980s.



Correlations AO index vs air temperature



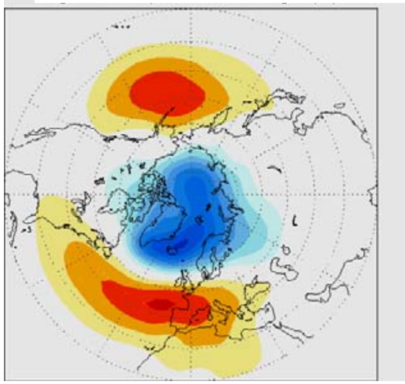
Siberian High Index *changes.*
Its lowering means weakening of winter monsoon that prevents the sea surface cooling in the Japan Sea

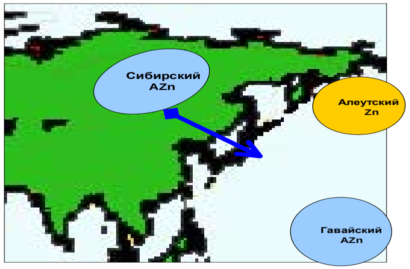


Arctic Oscillation Index *changes.*

Its heightening means strengthening of zonal transfers which make warmer the winters in the Far East of Russia
(from http://jisao.washington.edu/analyses0302/)

AO pattern

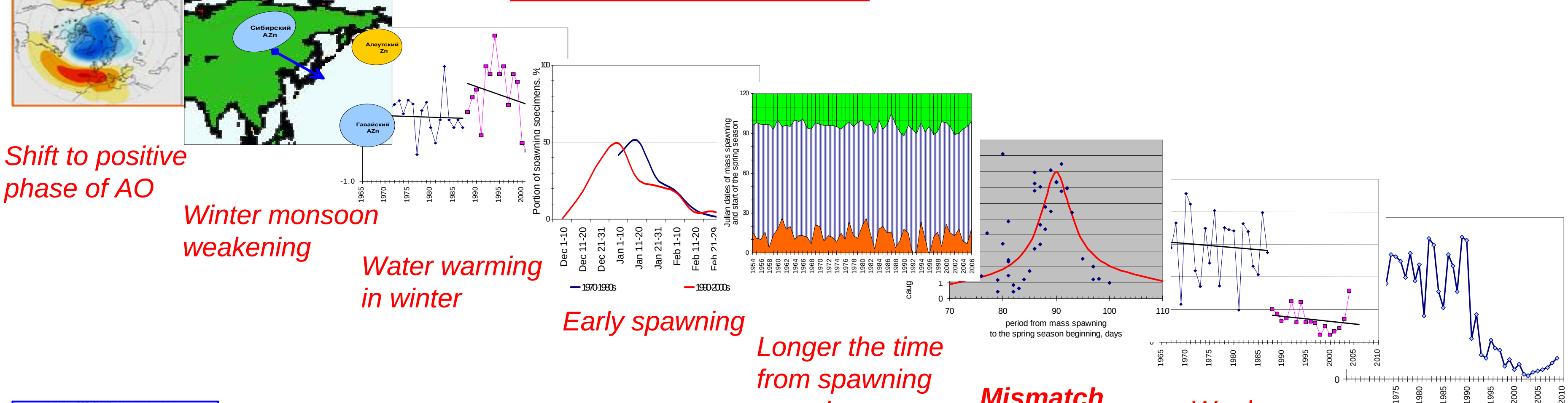




Scheme of winter monsoon

Discussion: **scheme of global climate influence on the saffron cod population in Peter the Great Bay**

Late 1980s – 1990s



Shift to positive phase of AO

Winter monsoon weakening

Water warming in winter

Early spawning

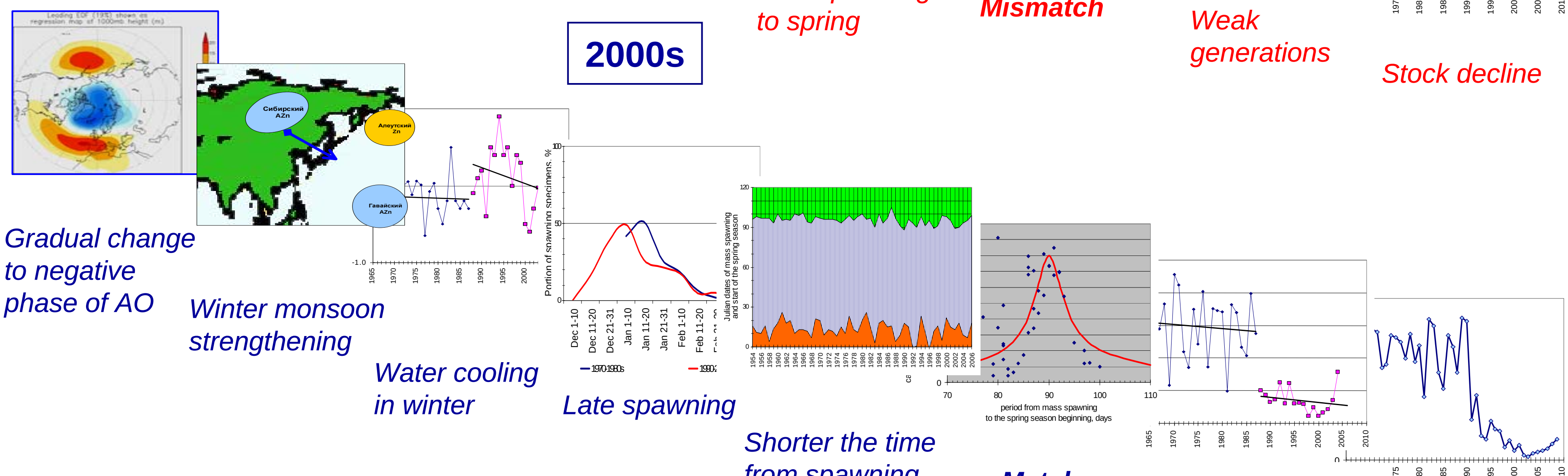
Longer the time from spawning to spring

Mismatch

Weak generations

Stock decline

2000s



Gradual change to negative phase of AO

Winter monsoon strengthening

Water cooling in winter

Late spawning

Shorter the time from spawning to spring

Match

Strong generations

Stock restoration

"Every thing is vibration, everything is resonance…"

Conclusions:

1. AO (+), SHI weakening -> warming (1990s)
   AO (-), SHI strengthening -> cooling (2000s)
   with general tendency to warming

2. The warmer -> the earlier the time of the saffron cod mass spawning
   -> the earlier the time of spring bloom
   -> the longer the period between the mass spawning and bloom of the prey for larvae
   with general tendency to widening of the period

3. Strong generations of saffron cod form only in the case of optimal period between the spawning and blooming (about 90 days). Recent times are favorable for this population.
   However, the tendency to climate warming is not favorable for the saffron cod in the Japan Sea.