Yury Zuenko, Ludmila Chernoivanova, Alex Vdovin, and Elena Ustinova

Pacific Fisheries Research Center (TINRO)
Vladivostok, Russia

Saffron cod fluctuations in the Japan Sea: an evidence of match / mismatch hypothesis

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

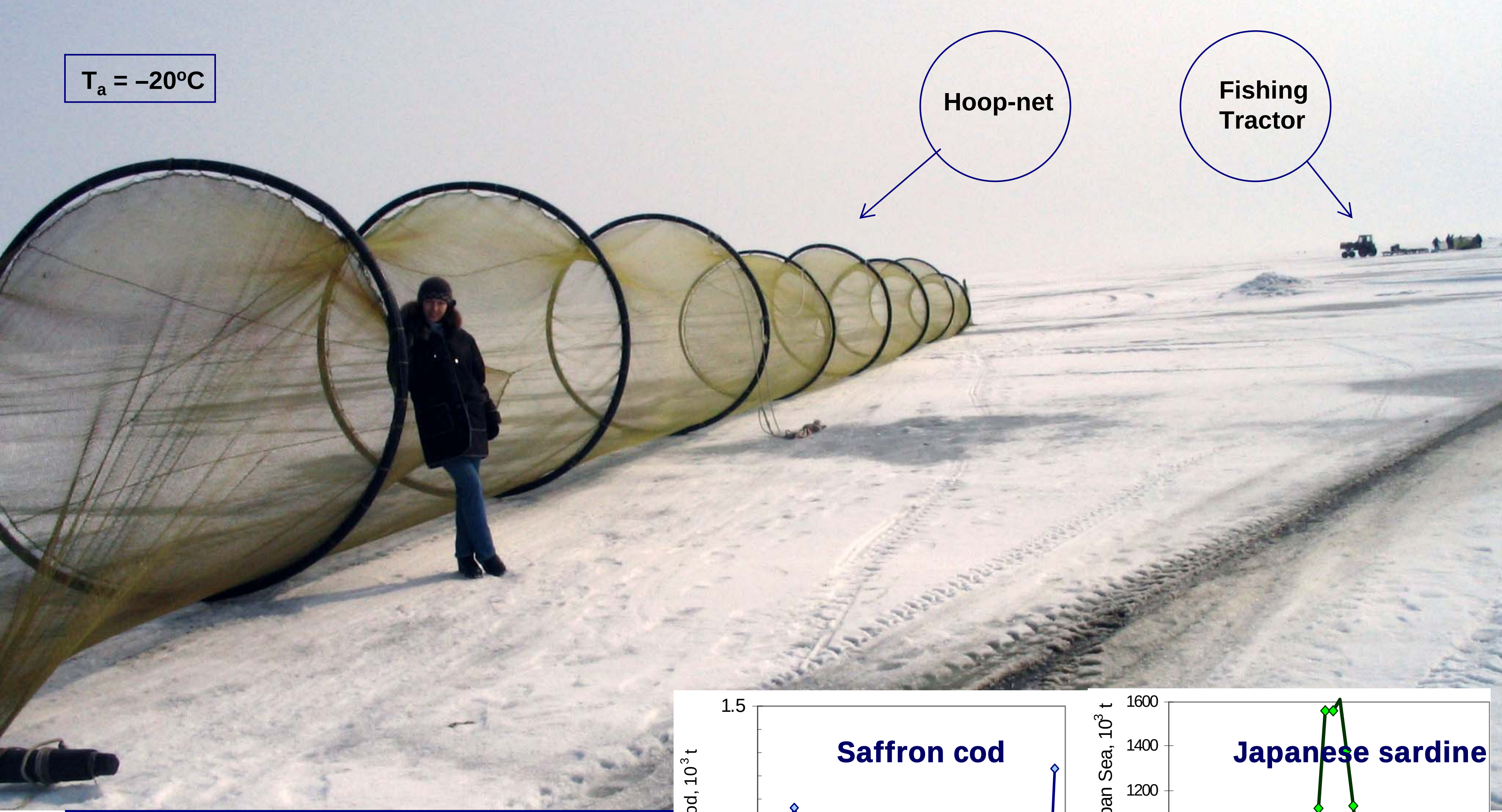
Outline:

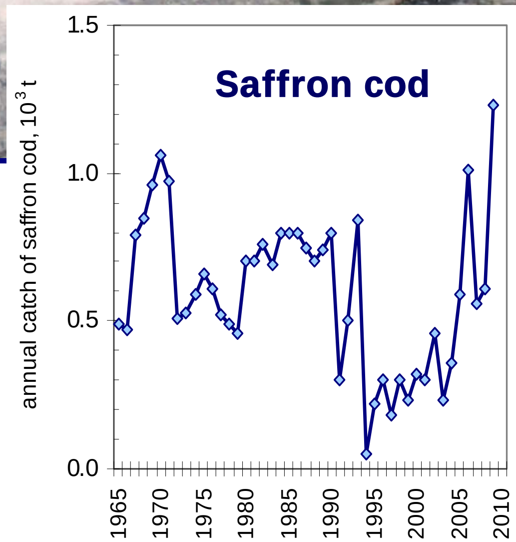
1. **Fluctuation of the saffron cod population in Peter the Great Bay**

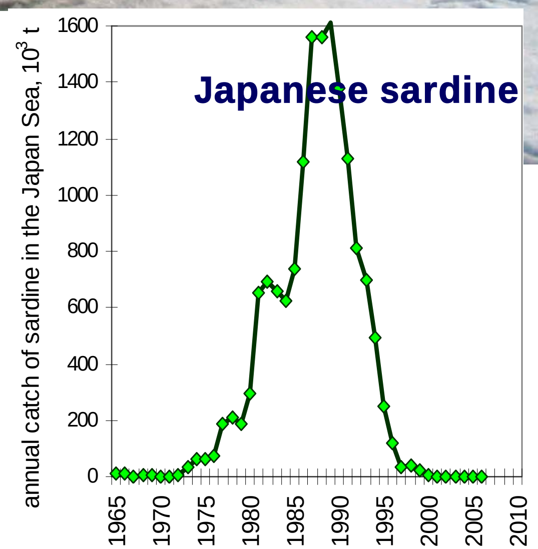
2. Match/mismatch mechanism for saffron cod

3. Nature of winter climate change in Peter the Great Bay

4. Schemes of the saffron cod stock formation in 1990s and 2000s





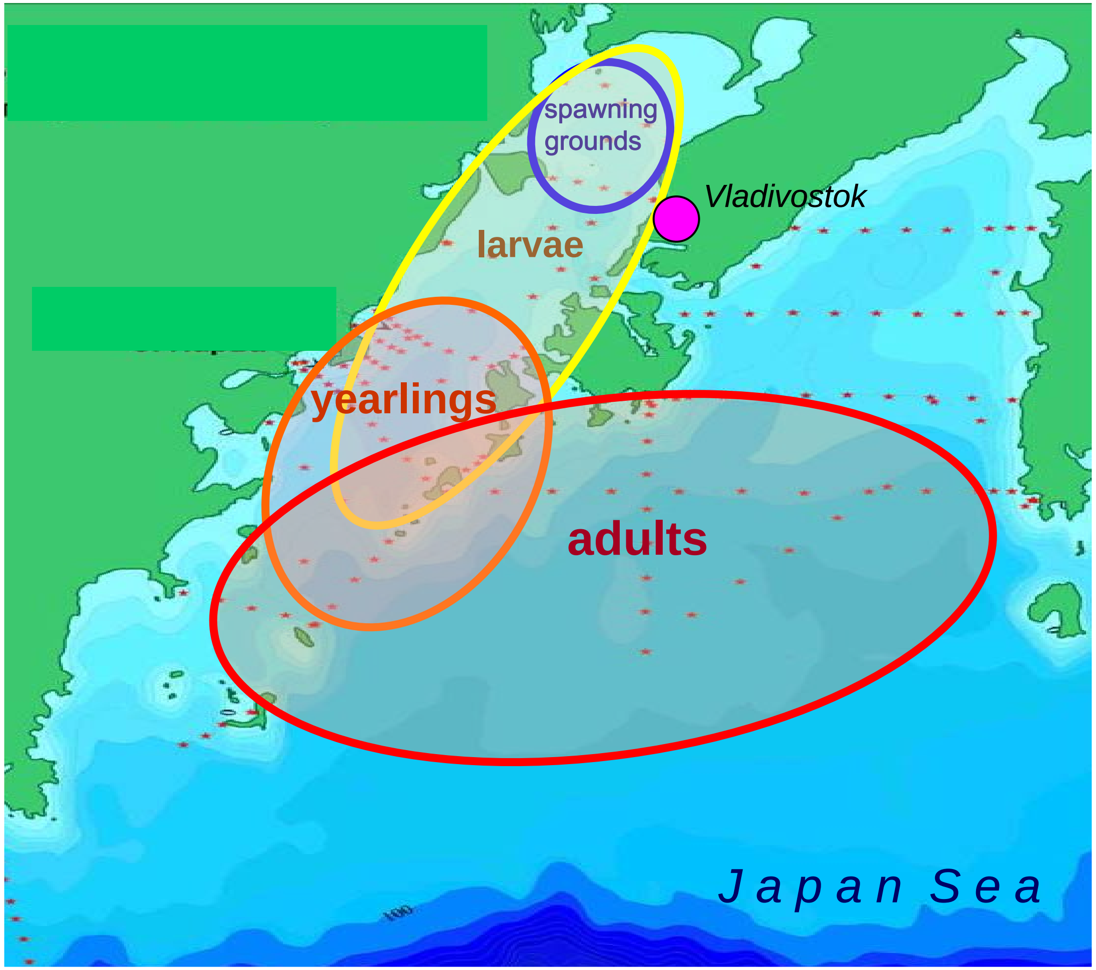


Catch: **collapse in the 1990s**

Saffron cod is one of the main subjects of fishery in Peter the Gray Bay, along with walleye pollock and japanese sardine.

Its annual catch was rather stable until the early 1990s, when its fishery was almost collapsed, at one time with the sardine fishery

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.

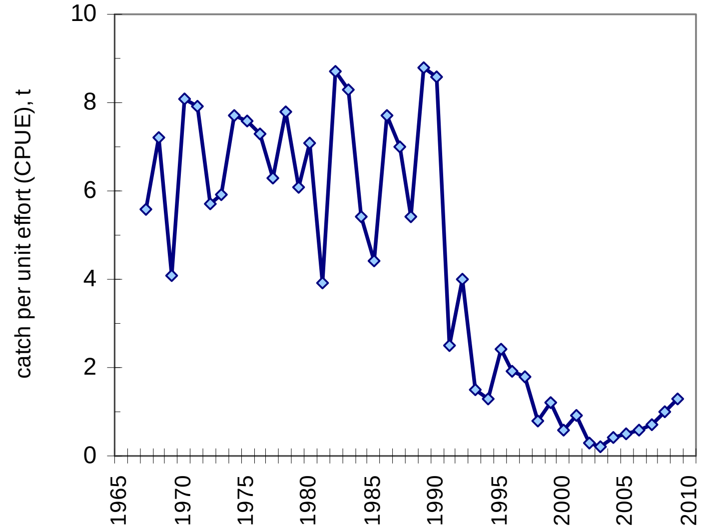
Data sources:

The catch changes were compared with fisheries, biological, and environmental data series

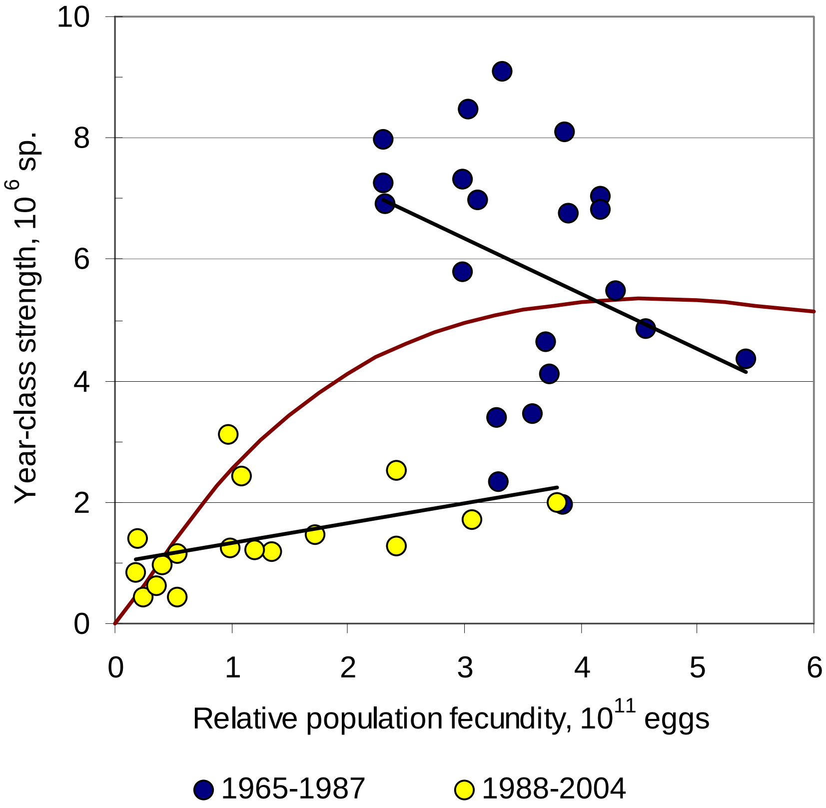
Index	Period	Brief description	Source
Catch of saffron cod	1942-2009	Annual commercial catch in Peter the Great Bay, mainly by hoop nets	Fishery statistics
Catch efforts	1965-2009	Number of hoop nets mounted in Peter the Great Bay	Fishery statistics
Year-class strength for saffron cod	1965-2004	Summary 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 stages percentage in the spawning period (from December to March)	Authors' data
Timing of the peak of saffron cod spawning	1954-2009	Date when the portion of post-spawned females reaches the level 50%	Authors' data
Timing of the spring bloom	1997-2008	Chl *a* concentration at the sea surface from estimated from the 8-days data of SeaWiFS satellite scanner	http://oceancolor.gsfc.nasa.gov/
Sea surface temperature	1981-2002	Daily data for Vladivostok: for January-April averaged to monthly ones (restored to 1954-2006 using significant 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**

The catch decreasing was not inspired by economical reasons (because of political changes) so far as CPUE of the saffron cod fishing decreased even more drastically than the annual catch.



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



Dependence of the saffron cod year-class strength on its population fecundity

Saffron cod shows positive dependence of its year-class strength 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.

Outline:

1. Fluctuation of the saffron cod population in Peter the Great Bay

2. **Match/mismatch mechanism for saffron cod**

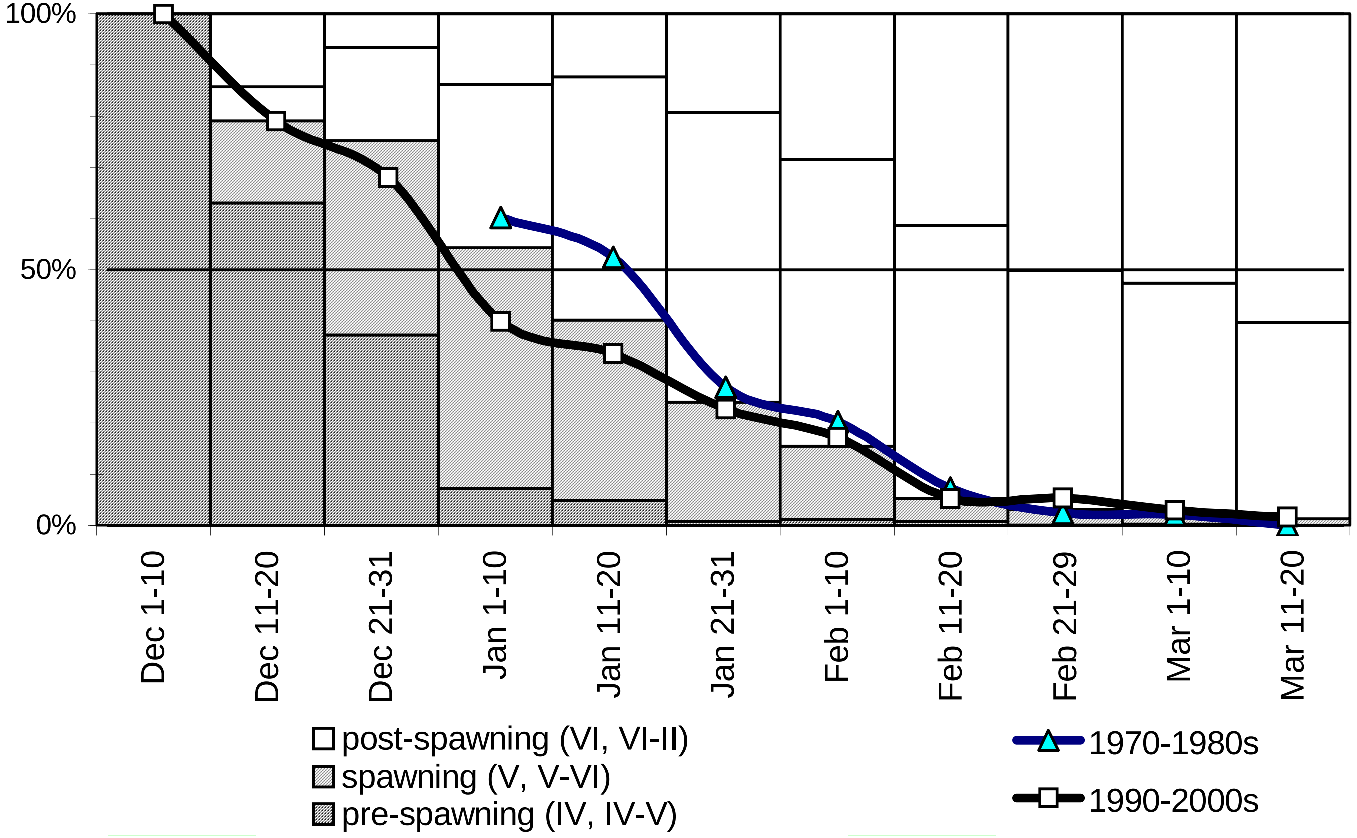
3. Nature of winter climate change in Peter the Great Bay

4. Schemes of the saffron cod stock formation in 1990s and 2000s

Results: **seasonal 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

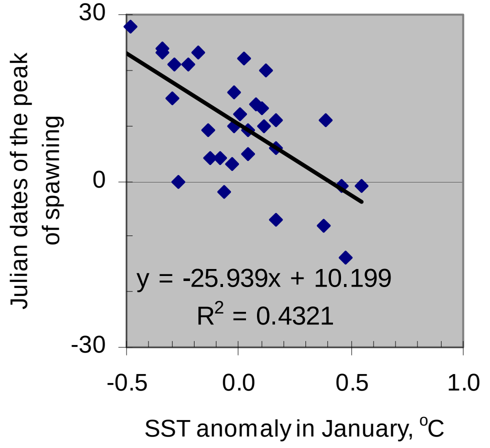


Mean for 1954-2009 dynamics of maturing for the saffron cod in Peter the Great Bay (bars) and dynamics of the portion (%) of pre-spawning and spawning females (stages IV, IV-V, V,V-VI) averaged for the 1970-1980s and 1990-2000s.

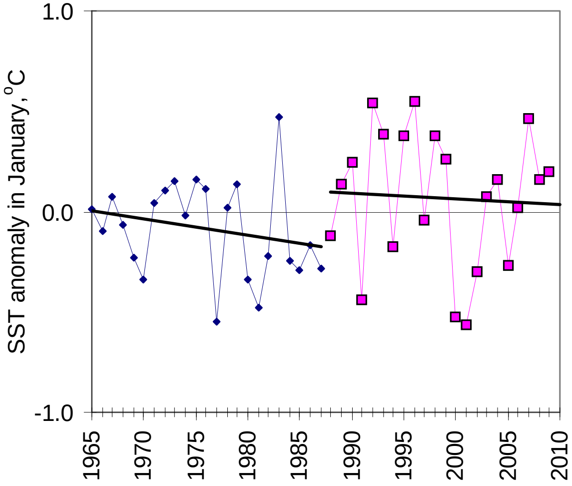
The level 50 % of pres-spawning and spawning females corresponds to the peak of spawning

Results: **year-to-year change of mass spawning time**

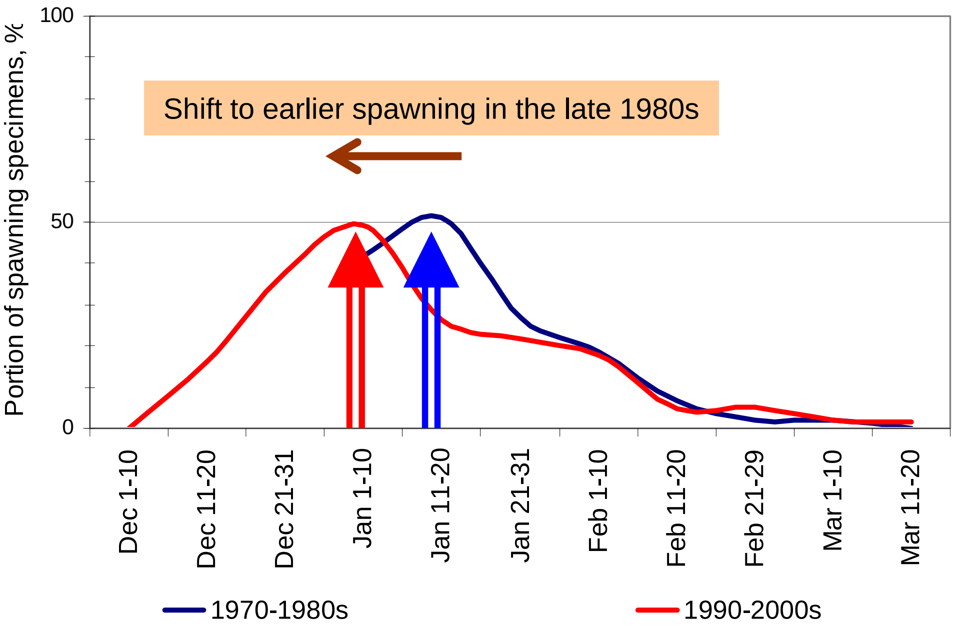
The time of mass spawning differs from year to year. Generally, it became earlier in the last decades. The dates of the spawning peak are opposite to water/air temperature in January ($r = -0.66$; 1°C SST causes the shift 25 days), so the warming in the late 1980s caused the shift to earlier spawning.



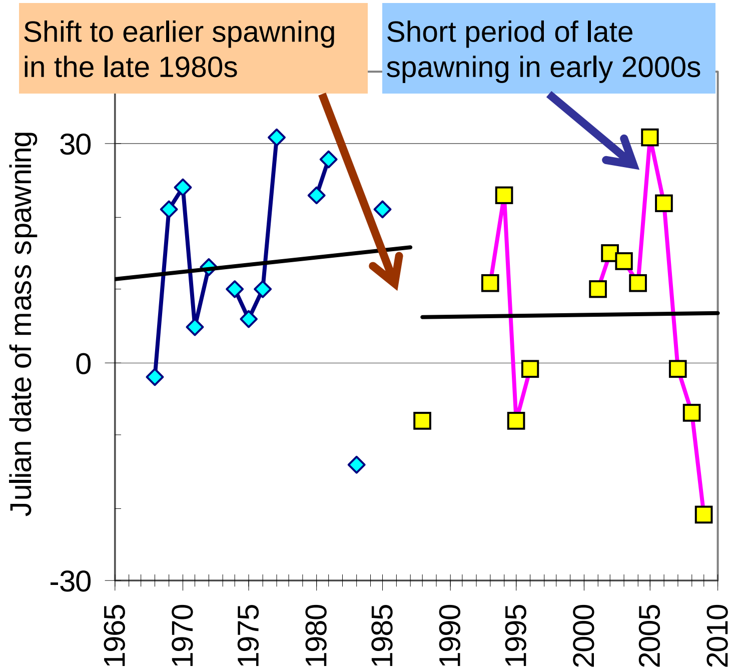
Timing of the spawning peak dependence on SST in Vladivostok in January of 1954-2008 (r = -0.66)



Mean month SST anomalies in Vladivostok in January



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



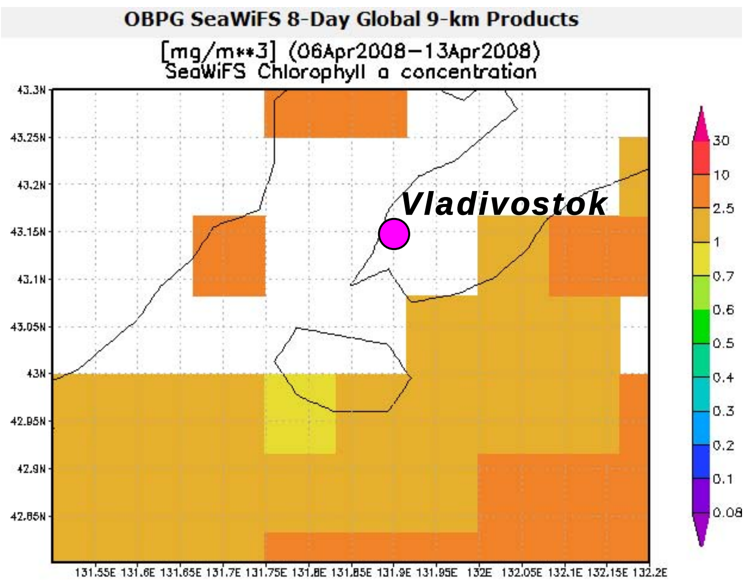
Year-to-year changes of the date of spawning peak.
Shift to earlier dates occurred in late 1980s

Results: **seasonal succession of plankton**

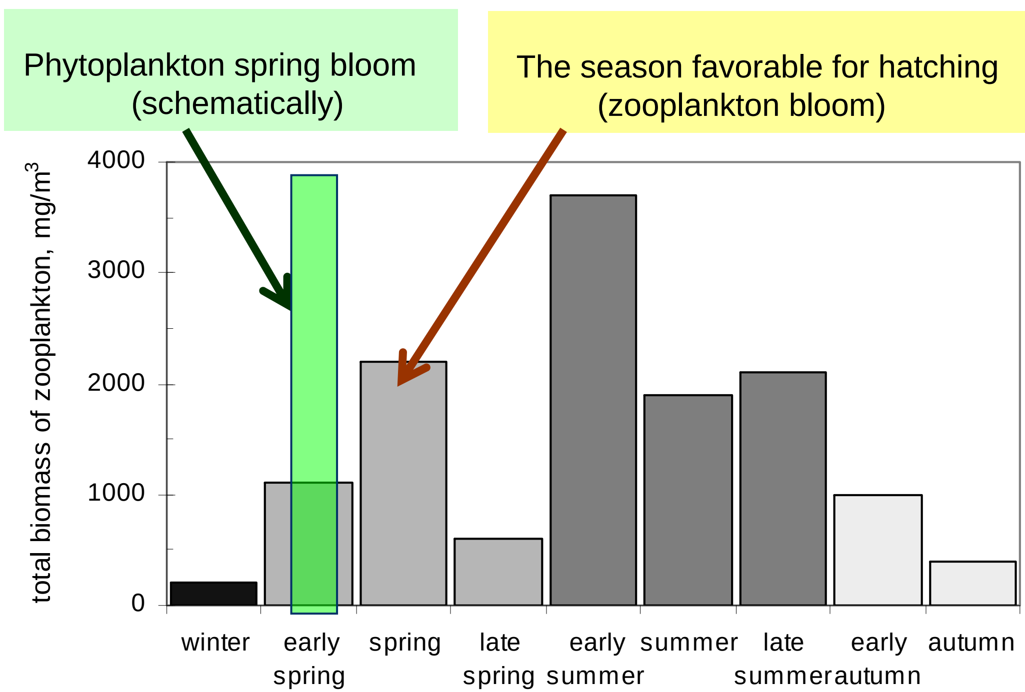
The larvae of saffron cod feed on small-sized zooplankton, mostly nauplia of Copepoda.

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 season (immediately after the spring bloom of phytoplankton) and in the early summer. The larvae hatched in April, so they prey upon the spring bloom of cold-water copepods juveniles.

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



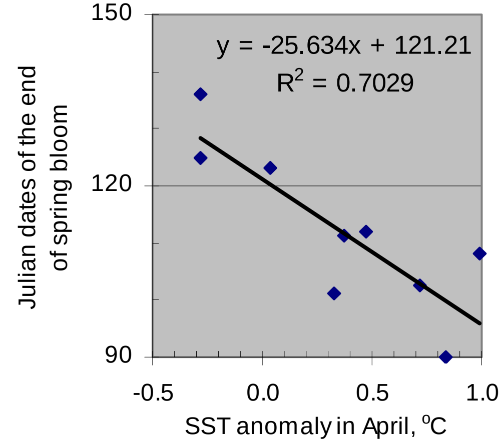
SeaWiFS data on Chl a concentration (mg/m³)
in the Amur Bay on April 6-13, 2008 (spring bloom)



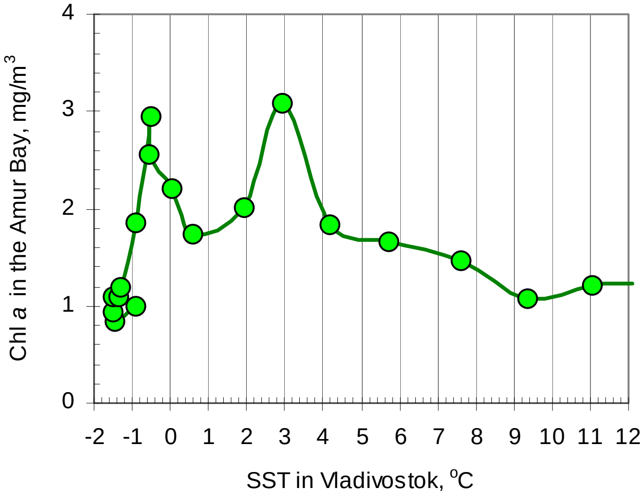
Total biomass of zooplankton in different seasons in the main spawning grounds of saffron cod

Results: **phytoplankton blooms**

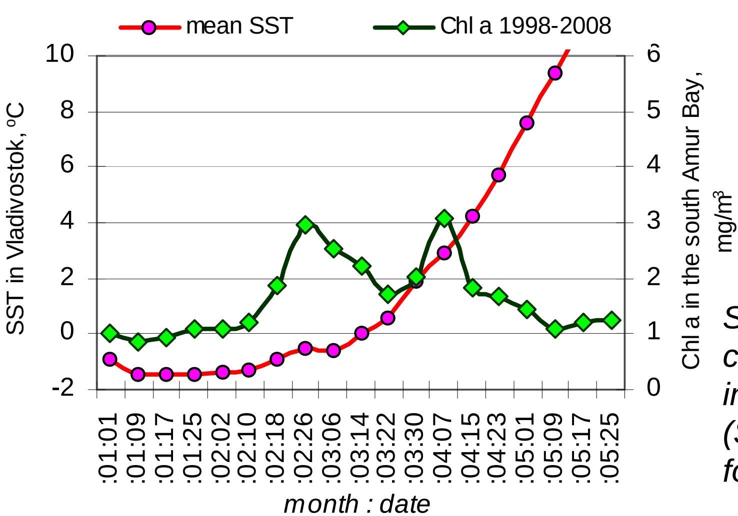
There are 2 phytoplankton blooms in the Amur Bay in winter-spring. The latter develops under SST about 3°C, and therefore its timing depends on SST anomaly: the higher SST, the earlier the spring bloom (r = -0.84; 1°C causes the shift 25 days). Thus, the next season beginning (with small-sized zooplankton abundance) depends on SST, too.



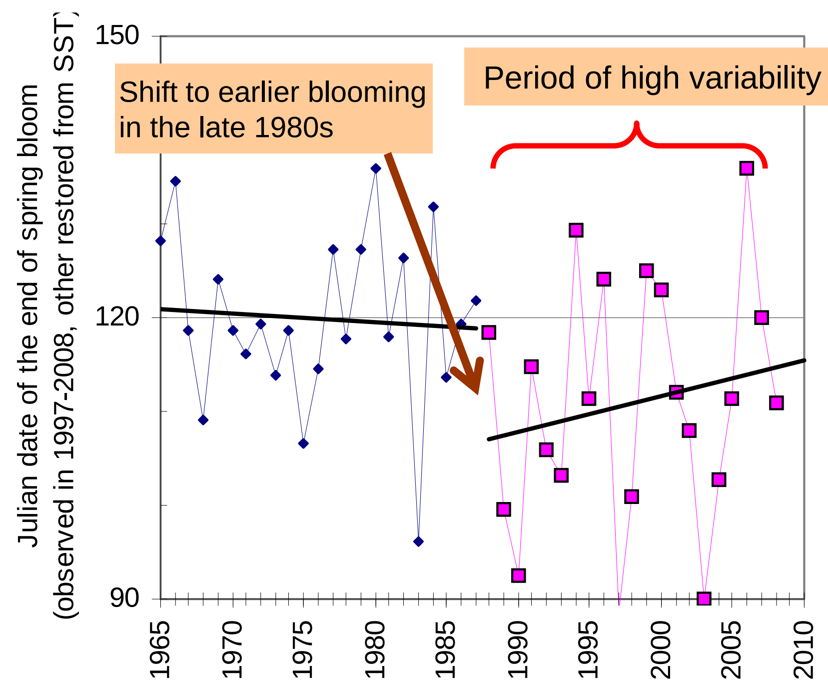
Dependence of the timing of the end of spring phytoplankton bloom in the Amur Bay (SeaWiFS) on SST anomaly in Vladivostok in April



Dependence of Chl a concentration on SST in the Amur Bay (SeaWiFS data)



SST and Chl a concentration in the Amur Bay (SeaWiFS data for 1998-2008)

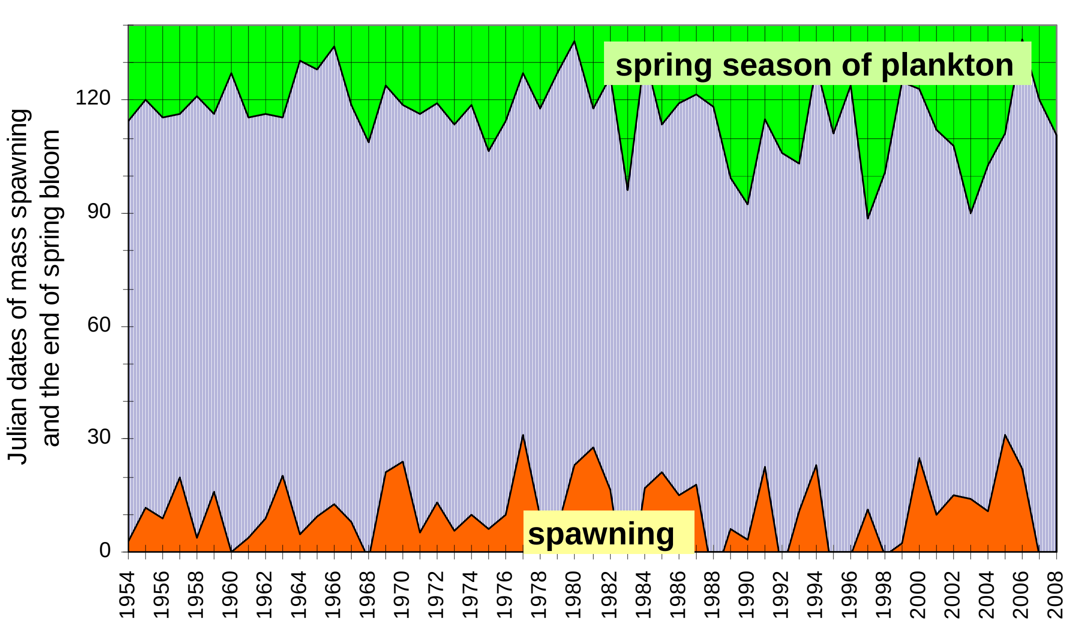


Time of the end of spring bloom of phytoplankton (spring season beginning) in the Amur Bay (restored from SST). High variability occurred in 1990-2000s

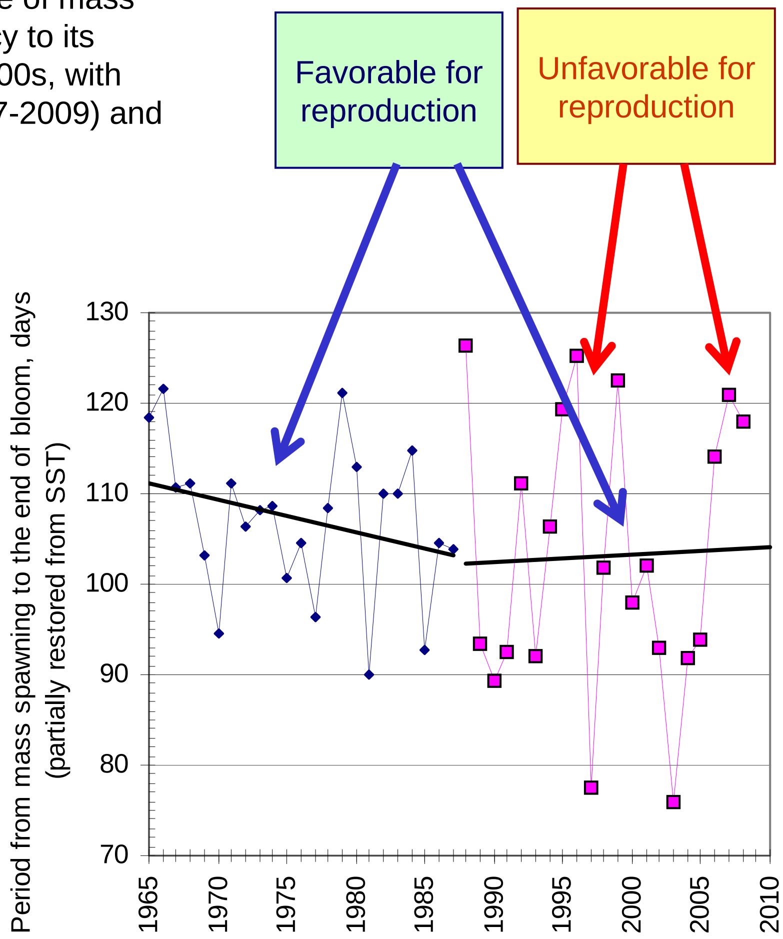
Results: **period for embryonic development**

For reproductive success, the eggs of saffron cod have to develop in the period from the spawning to the end of spring bloom, to be hatched in conditions of their prey (zooplankton) abundance.

Length of this period differs from year to year, because both of the time of mass spawning and the time of spring bloom changes. There was a tendency to its shortening before the late 1980s; it became highly variable in 1990-2000s, with extremely long periods in several years (1988, 1995, 1996, 1999, 2007-2009) and mainly short periods in the early 2000s.



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 the spring season (after spring bloom)

Results: **match / mismatch**

In fact, both extremely long and extremely short periods between the spawning and zooplankton bloom 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, dependence of the year-class strength (***N***) on the length of period from mass spawning to zooplankton bloom (***T***) is approximated by resonance function:

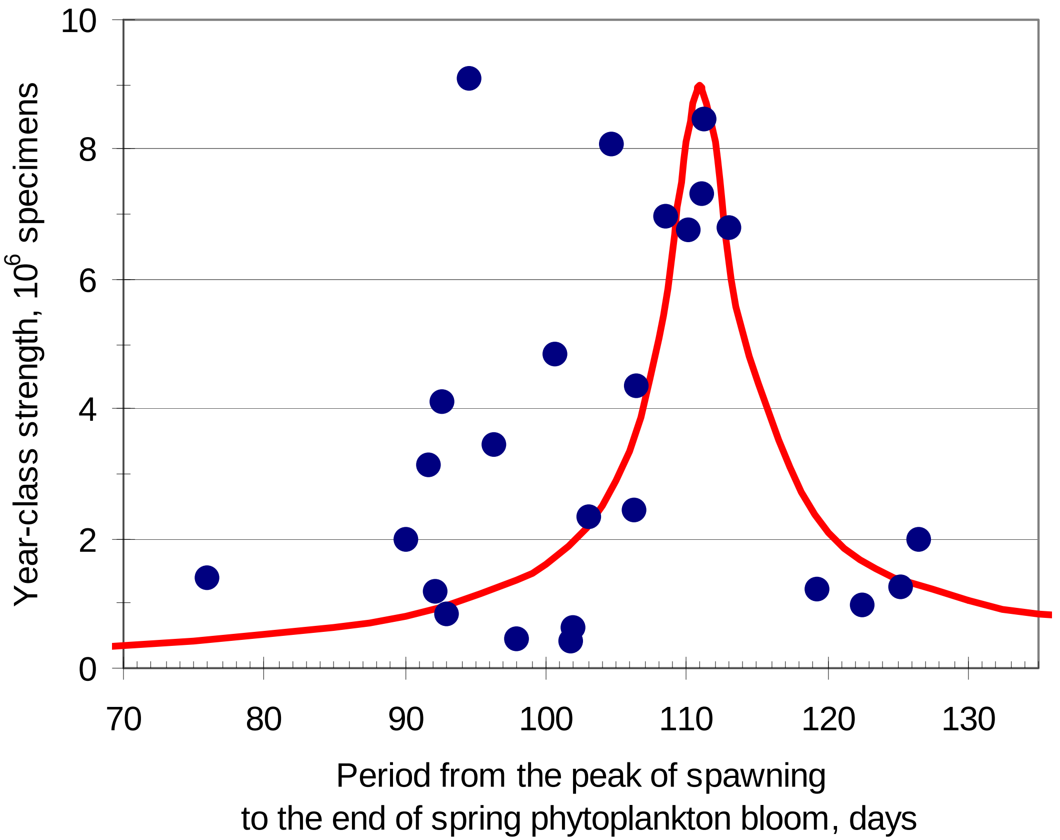
$$N = \frac{a}{\sqrt{1 + \left[Q \cdot \left(\frac{T}{T_R} - \frac{T_R}{T} \right) \right]^2}}$$

where T_R = 111 days – resonance length;
Q = *26*.6 – Q-factor of vibrating system;
a = 9.0 – empiric coefficient   (r^2 = 0.43)

If the period ***T*** is close to $\boldsymbol{T_R}$ = 111 days, the saffron cod larvae is hatched in conditions of high abundance of their prey.

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

In 1990s, this period was usually longer than $\boldsymbol{T_R}$ (or too short sometimes) that caused the population collapse. It became optimal again in early 2000s, and several strong generations had formed, but was too long again in 2007-2009.



Dependence of the saffron cod year-class strength on the length of period between mass spawning and zooplankton bloom

Outline:

1. Fluctuation of the saffron cod population in Peter the Great Bay

2. Match/mismatch mechanism for saffron cod

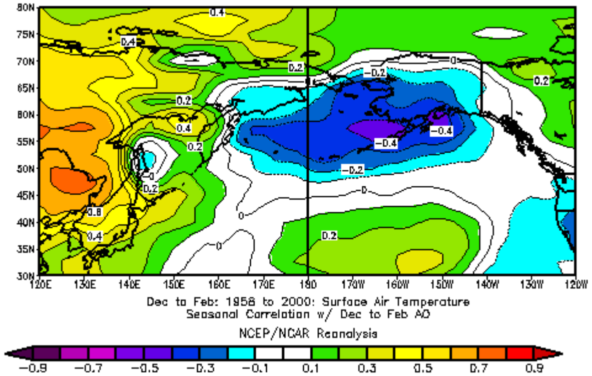
3. **Nature of winter climate change in Peter the Great Bay**

4. Schemes of the saffron cod stock formation in 1990s and 2000s

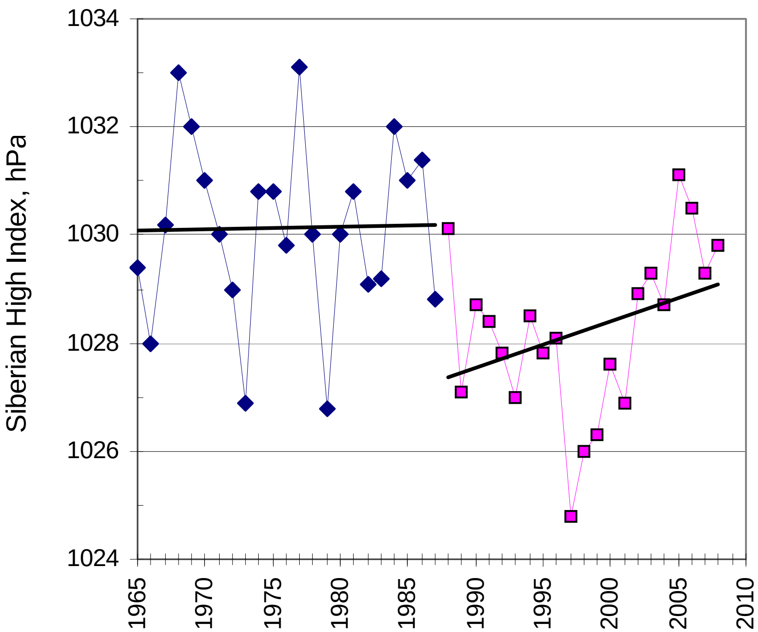
Results: **winter warming in the Japan Sea**

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.

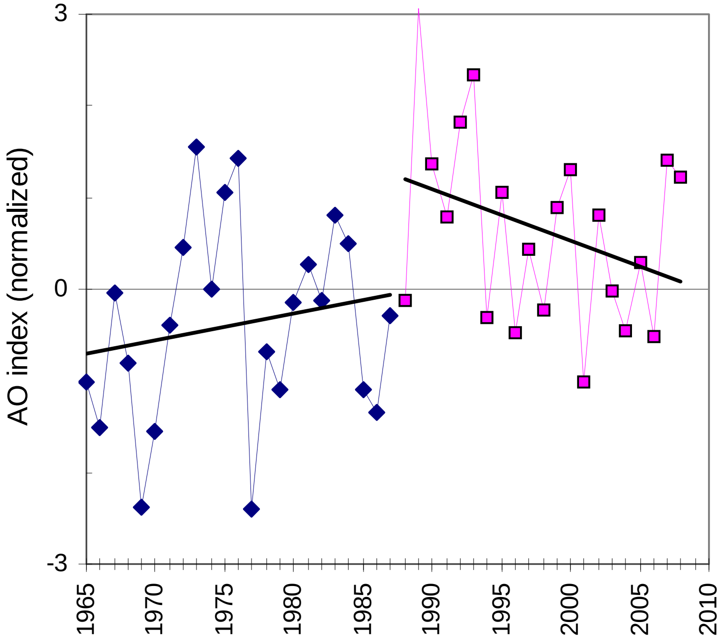
Air temperature in January correlates strongly (r = +0.62) with winter Arctic Oscillation Index, and the temperature in February – with the Siberian High Index (r = –0.57). The indices are interdependent. They both have a prominent shift in the late 1980s.



Correlations AO index vs air temperature



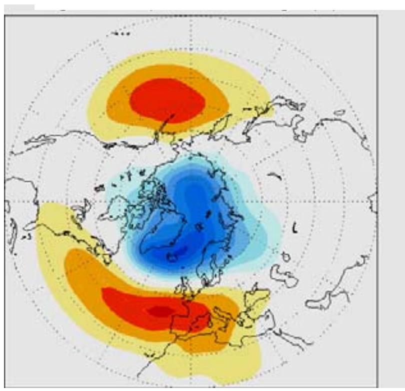
***Siberian High Index** changes.*
Its lowering means weakening of winter monsoon that prevents the sea surface cooling in the Japan Sea

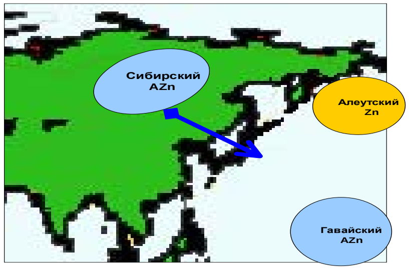


***Arctic Oscillation Index** changes.*

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

Outline:

1. Fluctuation of the saffron cod population in Peter the Great Bay

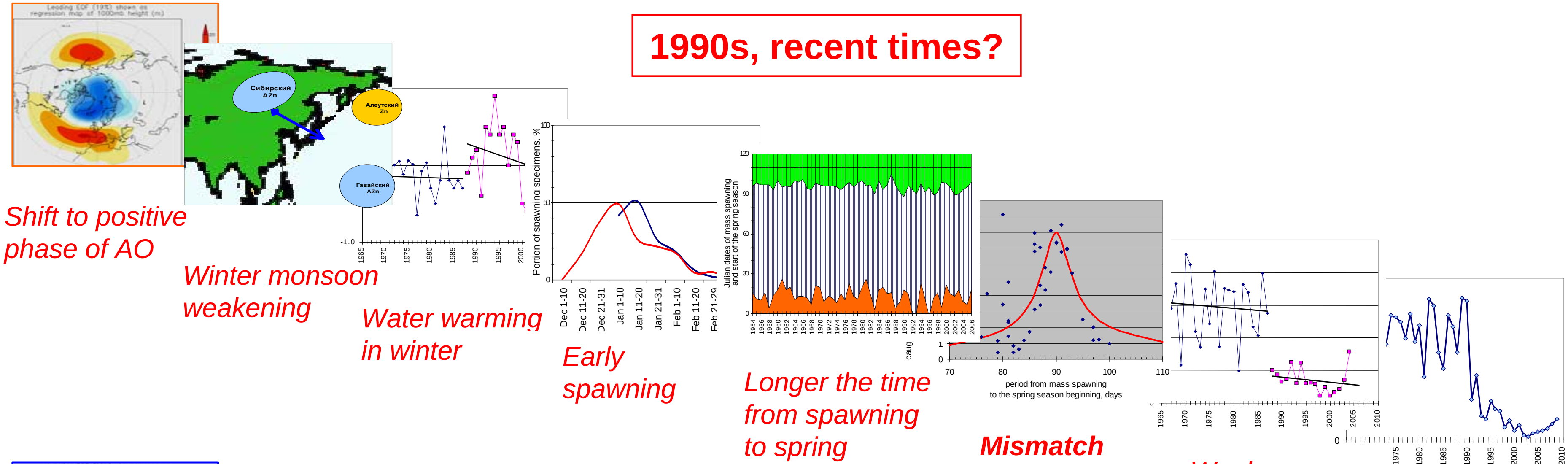
2. Match/mismatch mechanism for saffron cod

3. Nature of winter climate change in Peter the Great Bay

4. **Schemes of the saffron cod stock formation in 1990s and 2000s**

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

1990s, recent times?



Shift to positive phase of AO

Winter monsoon weakening

Water warming in winter

Early spawning

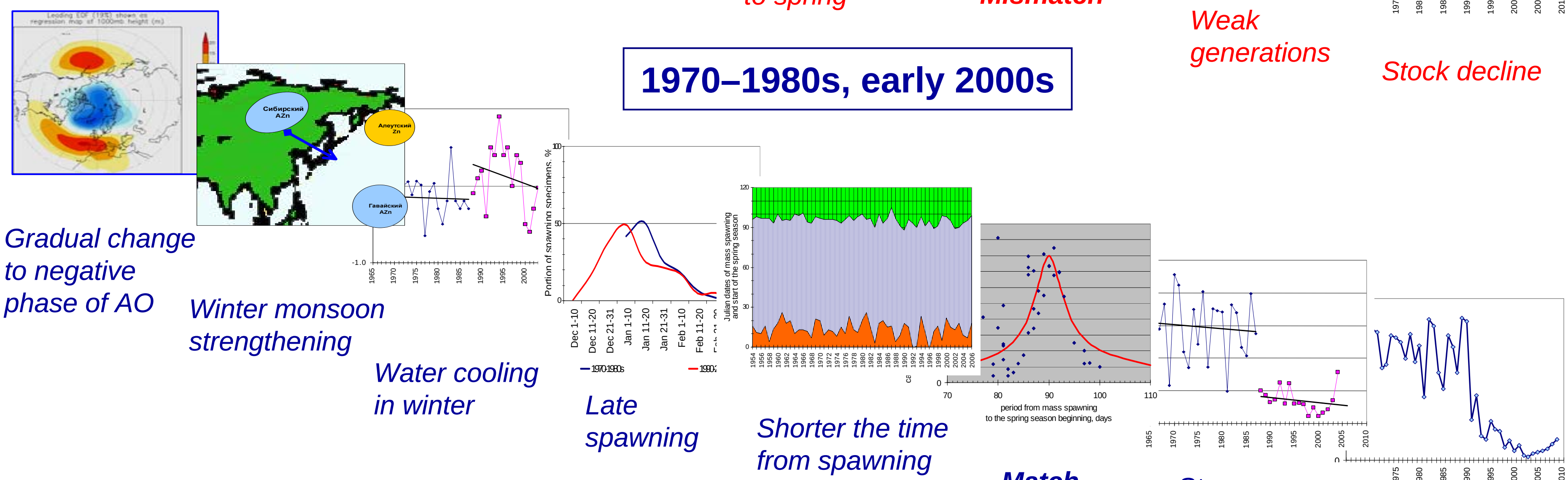
Longer the time from spawning to spring

Mismatch

Weak generations

Stock decline

1970–1980s, early 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. Strong generations of saffron cod in Peter the Great Bay form in the case of optimal period between the spawning and zooplankton bloom (about 111 days)

2. Generally, cold winters and moderate springs are favorable for this saffron cod population; its mass spawning shifts to later dates in conditions of low water temperature, so the period between spawning and zooplankton bloom is optimal for the eggs development (**match**). On the contrary, warm winters and moderate springs are unfavorable for its reproduction because of too long this period, as well as moderate winters and warm springs because of too short this period (**mismatch,** the latter is less dangerous)

3. Decadal changes of winter environments at Primorye coast of the Japan Sea are driven by Arctic Oscillation: its shift to positive phase in the late 1980s caused the winter monsoon weakening and warming. Subsequently, the saffron cod reproduction was successful before the climate shift in 1988/89 and mostly unsuccessful in the last decades