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Winter monsoon influence on reproduction of winter-spawning fish (Japanese sardine and Saffron cod) in the Japan / East Sea

Outline:

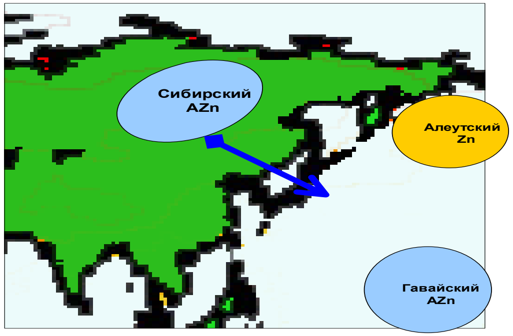
1. Winter monsoon nature, changes, and nature of changes
2. Saffron cod fluctuations in Peter the Great Bay and their reasons
3. Japanese sardine fluctuations in the Japan Sea and their reasons
4. Scheme of climate change influence on winter-spawning fish species

Courtesy of Elena Ustinova

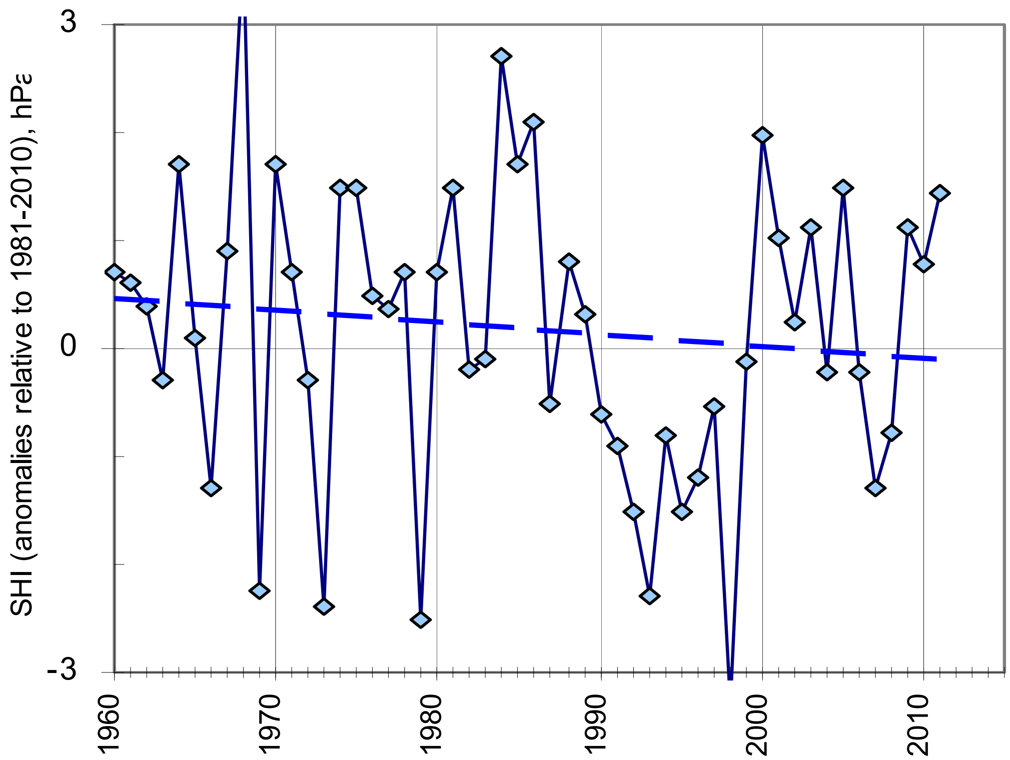
Winter monsoon: trend

Winter monsoon is driven by atmospheric pressure heightening over the continent in winter because of low air temperature. Its activity could be described by the Siberian High Index (SHI) – mean atmospheric pressure over northern Asia.

A significant negative trend of SHI is observed in the last three decades with the inclination –0.02 hPa per year. This tendency corresponds to winter warming on the continent and possibly is caused by enhancing of heat-insulating properties of the atmosphere (“greenhouse effect”).



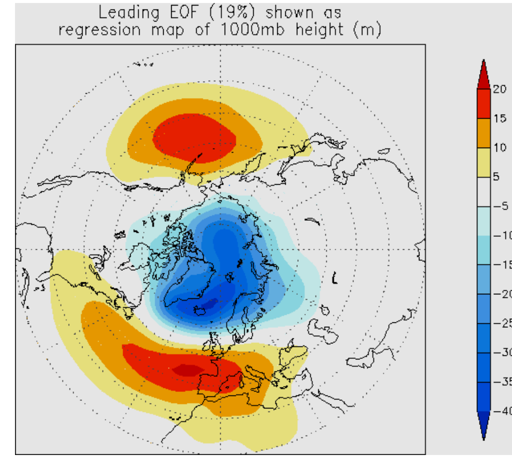
Scheme of winter monsoon



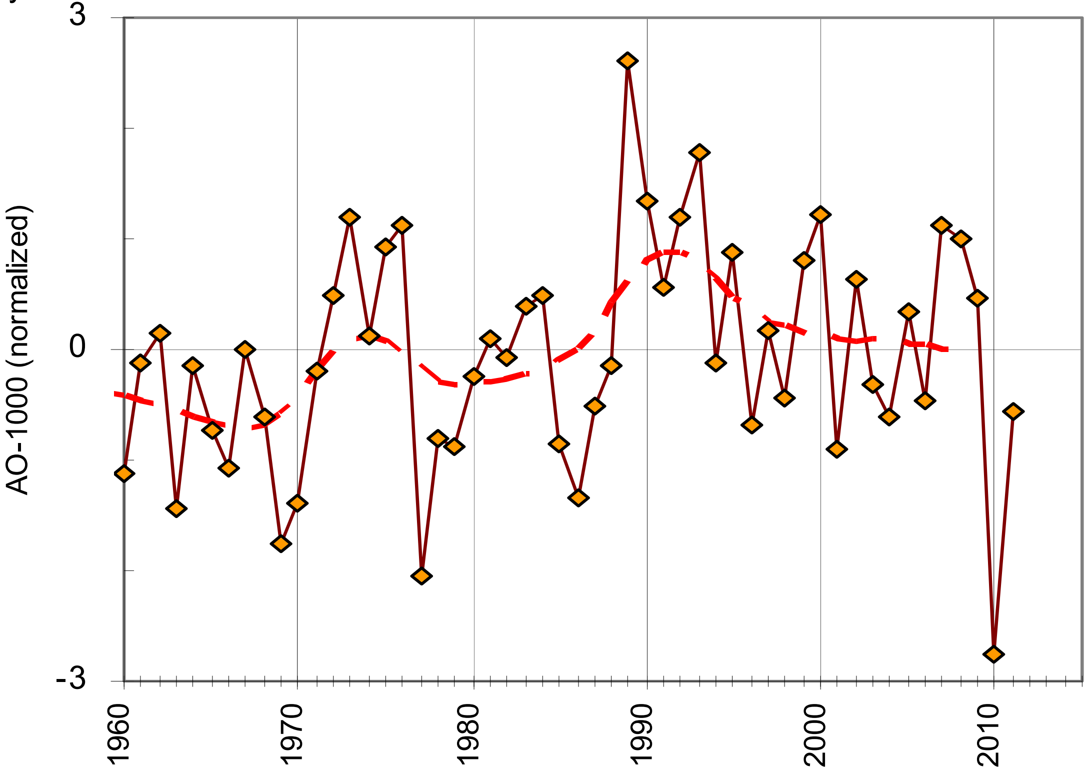
***Siberian High Index** changes. Its lowering means the weakening of winter monsoon that prevents the sea surface cooling in the Japan Sea*

Winter monsoon: decadal oscillation

Decadal oscillation of Siberian High is determined by Arctic Oscillation (AO) (r = –0.42 for the 60-year time series) – the process of periodic redistribution of air masses between polar and moderate latitudes. In positive AO phases (1970s, 1990s), zonal transfers across the continent become stronger that makes winters in Siberia warmer and Siberian High – weaker; and in negative phases (1980s, 2000s) the AO makes Siberian High stronger. The last decade is the phase of negative AO and strong winter monsoon, but in real it was not strong because of the trend to its weakening, except of few years.



AO pattern



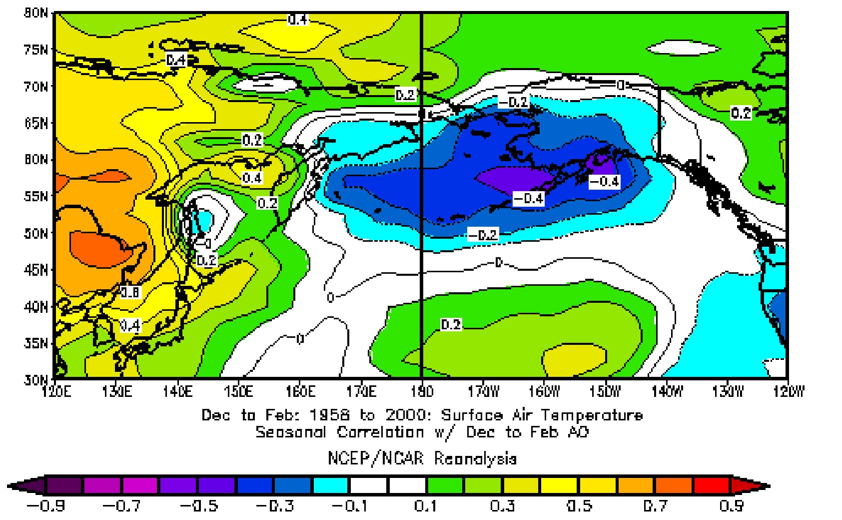
***Arctic Oscillation Index** changes. Its heightening means the strengthening of zonal transfers which make warmer the winters in Siberia (from http://jisao.washington.edu/analyses0302/)*

The sharpest SHI (and AO) change happened in the late 1980s because of coincidence of the trend and decadal oscillation.

Winter monsoon –> SST

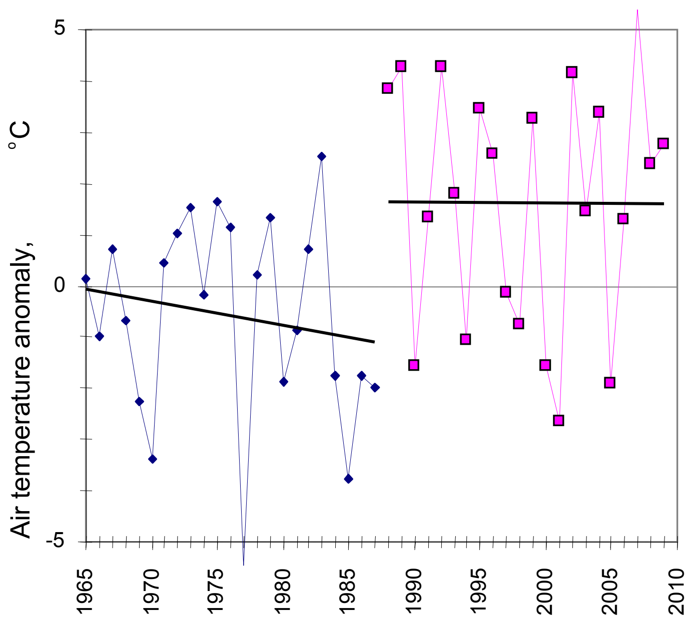
Winter air temperature in the Japan Sea correlates strongly both with winter AO index (r = +0.62 for January) and SHI (r = –0.57 for February). Following to the winter monsoon changes, the air temperature increased abruptly in the late 1980s.

Winter SST had similar changes as the air temperature.

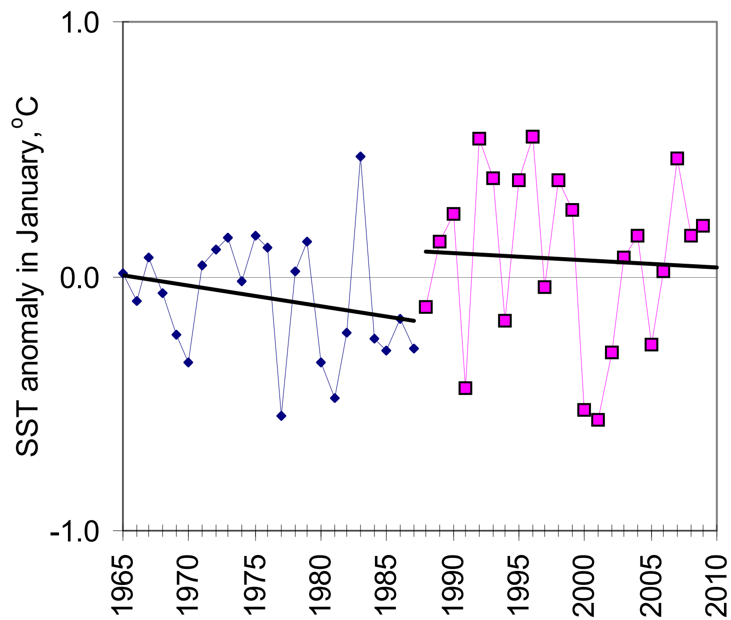


Correlations of air temperature with AO index. (from: Wu, Wang, 2002)

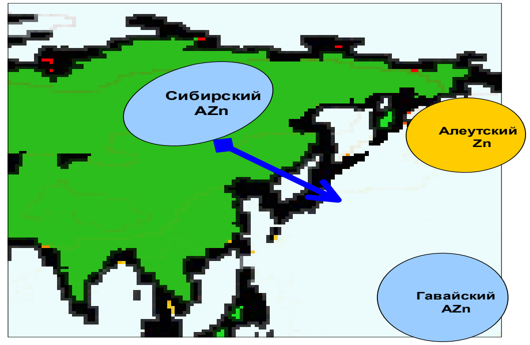
NOAA–CIRES/Climate Diagnostics Cent



Mean month air temperature anomalies in Vladivostok in January



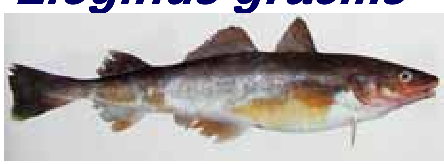
Mean month SST anomalies in Vladivostok in January



How the winter monsoon
(its weakening, decadal oscillations, shift in the late 1980s)
influences on winter-spawning species?

?

Saffron cod
Eleginus gracilis



(spawns at the coast of Primorye, usually with the peak in January)

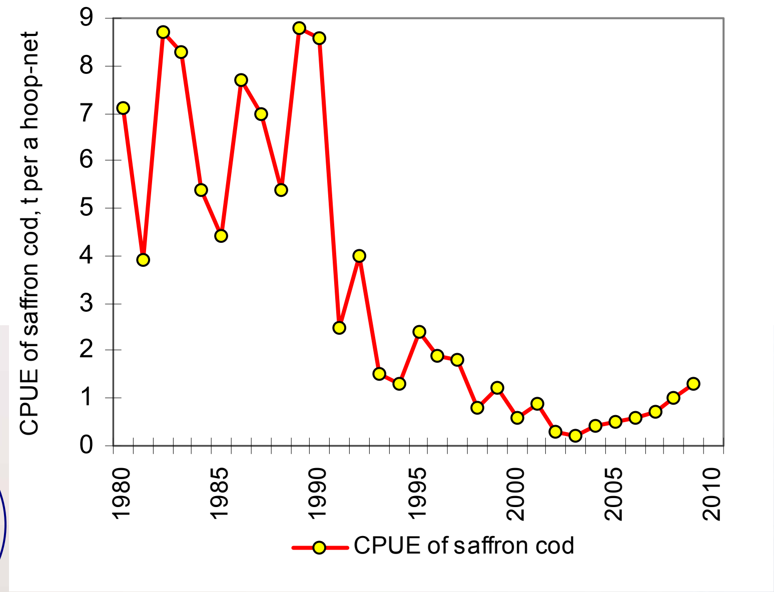
Japanese sardine
Sardinops melanosticta

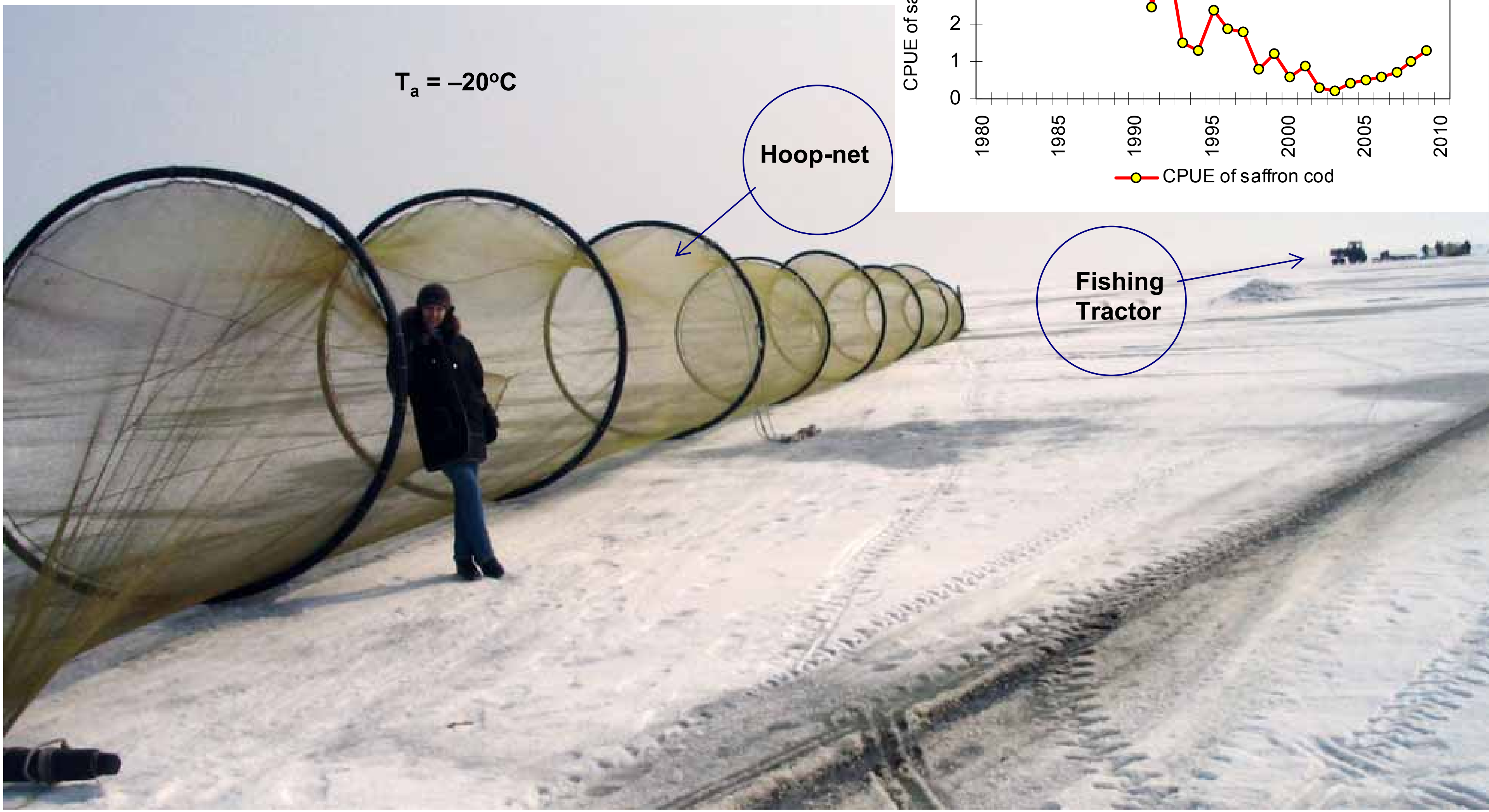
(spawns at the coast of Honshu, with the peak in March-April, sometimes in February or May)

Saffron cod: catches

Saffron cod is caught mostly by hoop-nets in winter, under the sea ice, when it migrates to shallows for spawning. The main fishing grounds of saffron cod are located in Peter the Great Bay near Vladivostok.

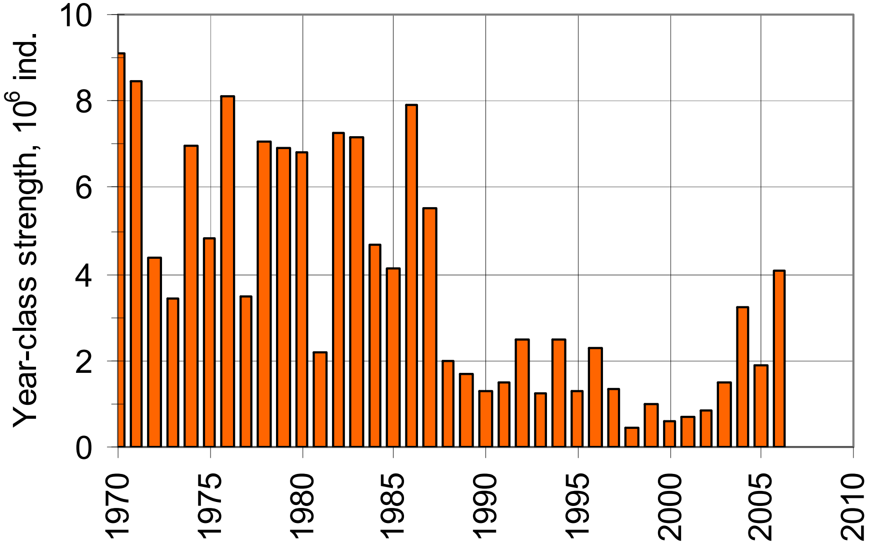
Catches of saffron cod have a decreasing tendency, with abrupt fall in the early 1990s and partial recovery in the 2000s..



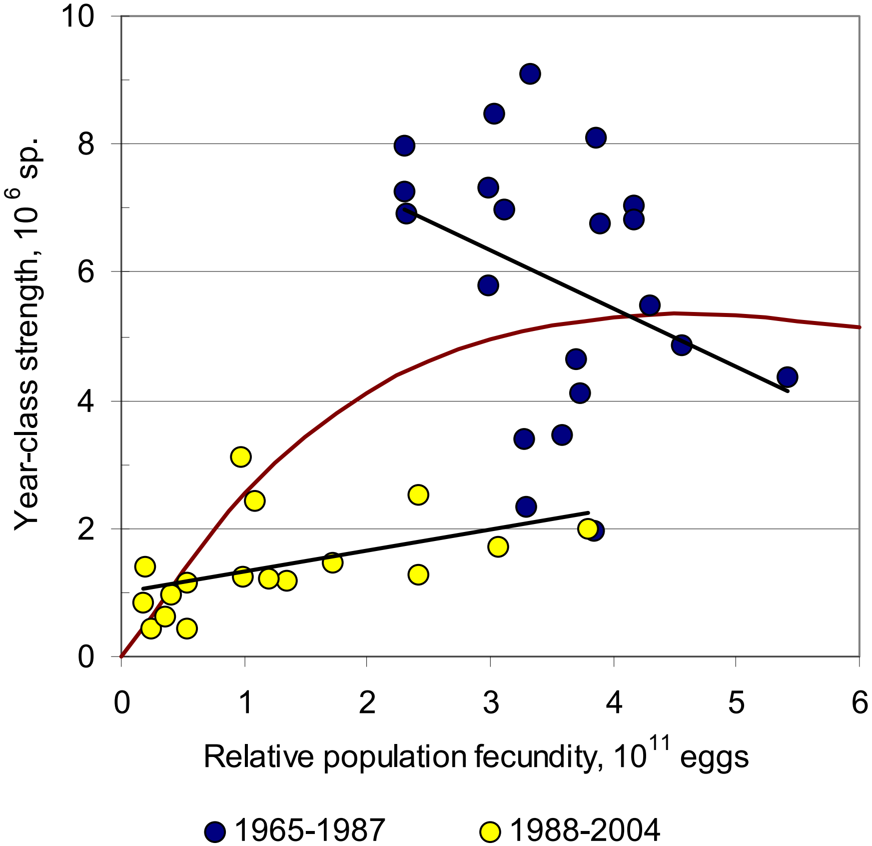


Saffron cod: year-class strength

Year-class strength of saffron cod has similar changes, as the catches, with sharp decreasing between 1987 and 1988 that corresponds exactly to SHI shift.



Year-class strength of saffron cod (summary catch of each generation in the age 1+ and elder normalized per standard fishing effort)



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

The year-class strength of saffron cod does not depend on population fecundity.

That means that the year-class strength is determined by the progeny survival, and this parameter could be used as an indicator of reproduction success.

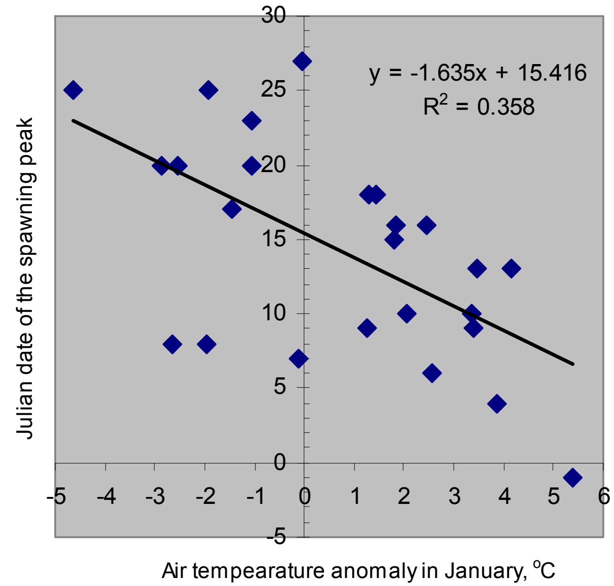
Saffron cod: spawning

Dates of saffron cod spawning change from year to year, so the match-mismatch hypothesis should be checked.

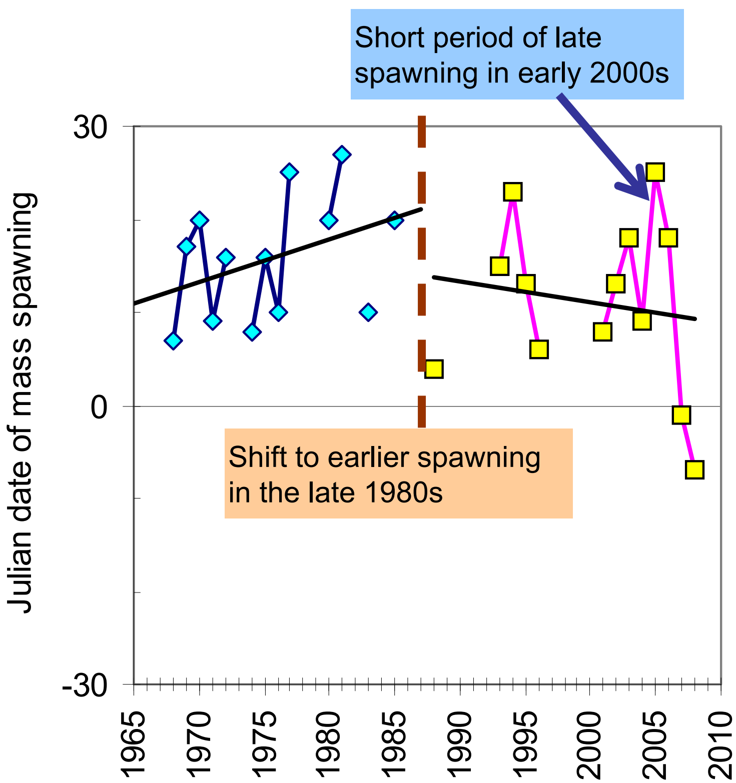
The dates of the spawning peak had a shift in the late 1980s: the mean date of the peak was January 16 in 1970-1985 but January 9 in 1988-2010.

Besides, the dates of the spawning peak have a significant negative correlation with the air temperature in January (r = -0.60)

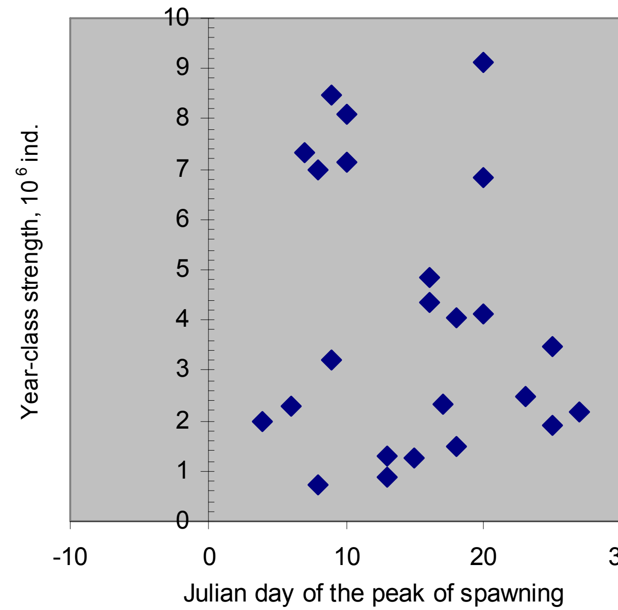
However, the year-class strength doesn't depend directly on the date of spawning



Dependence of the spawning peak date on air temperature in Vladivostok in January of 1965-2008



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



Dependence of the year-class strength on the date of the spawning peak for 1965-2006

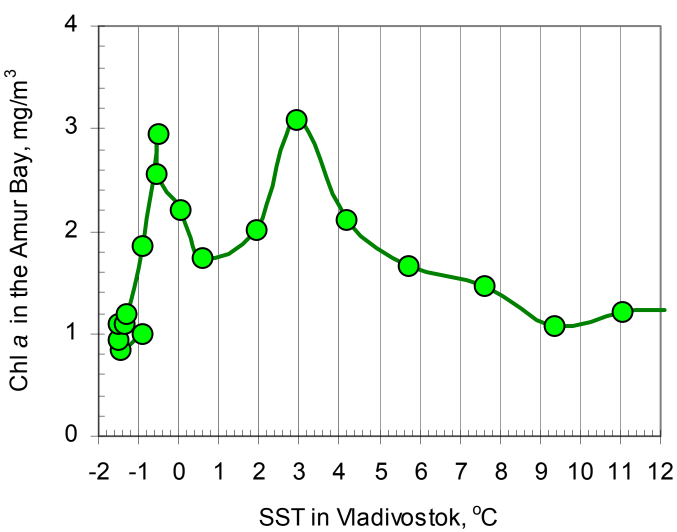
Saffron cod: hatching / blooming

Larvae of saffron cod hatch in spring and consume small-sized zooplankton developed in mass immediately after the spring bloom of phytoplankton.

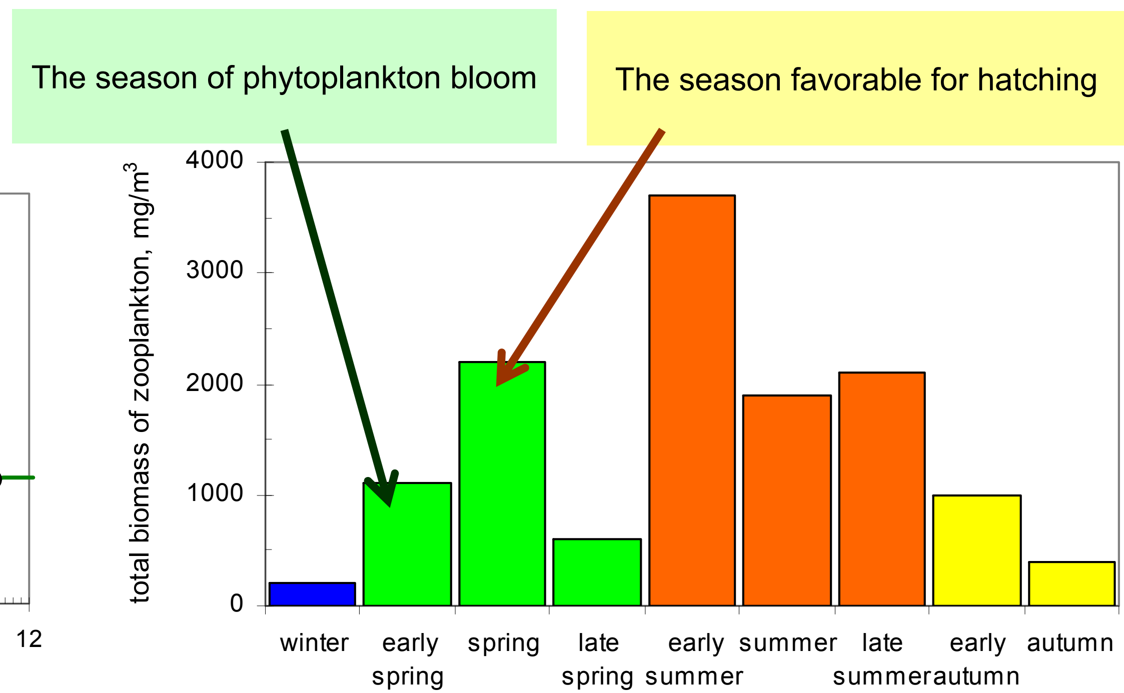
The timing of spring bloom is defined from the observations of satellite color scanners. Following SeaWiFs data, the spring bloom appears in April when SST reaches the value 2-3°C.

Biological seasons in Peter the Great Bay (from: Nadtochy, Zuenko, 2001)

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



Dependence of Chl a concentration in the Amur Bay (by SeaWiFS data) on SST, averaged for 1998-2008

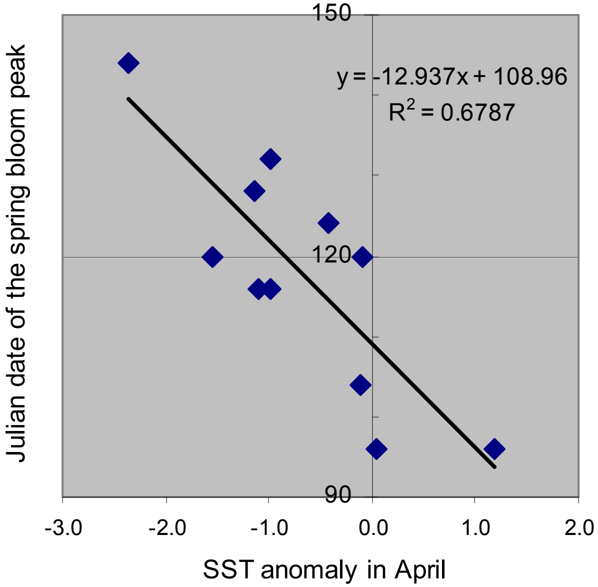


Mean total biomass of zooplankton in different seasons at the main spawning grounds of saffron cod

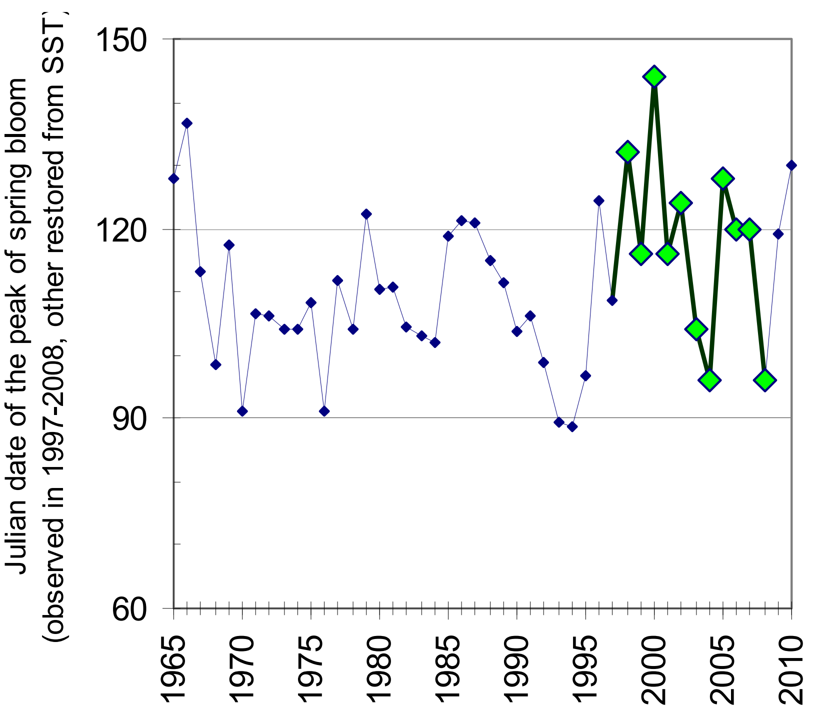
Saffron cod: hatching / blooming

The dependence on SST (negative, r = 0.82) allows to reconstruct the dates of spring bloom for the years before SeaWiFS observations. This dates have a year-to-year variability with the range about 1.5 months determined by SST variations, but have no any significant trend.

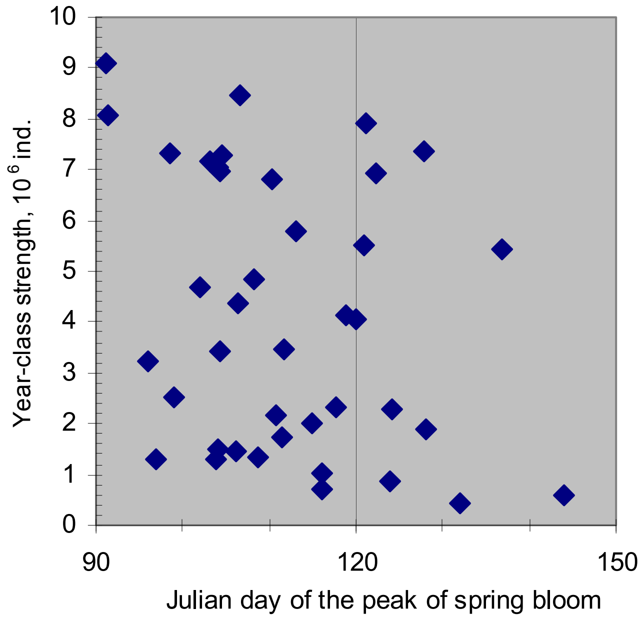
The year-class strength of saffron cod doesn't depend directly on the date of spring bloom, though the strongest classes form mostly in the years with earlier blooming



Dependence of the date of spring bloom peak in the Amur Bay in 1998-2008 on SST anomaly



Year-to-year timing of Chl a concentration in the Amur Bay (by SeaWiFS data and restored from SST)

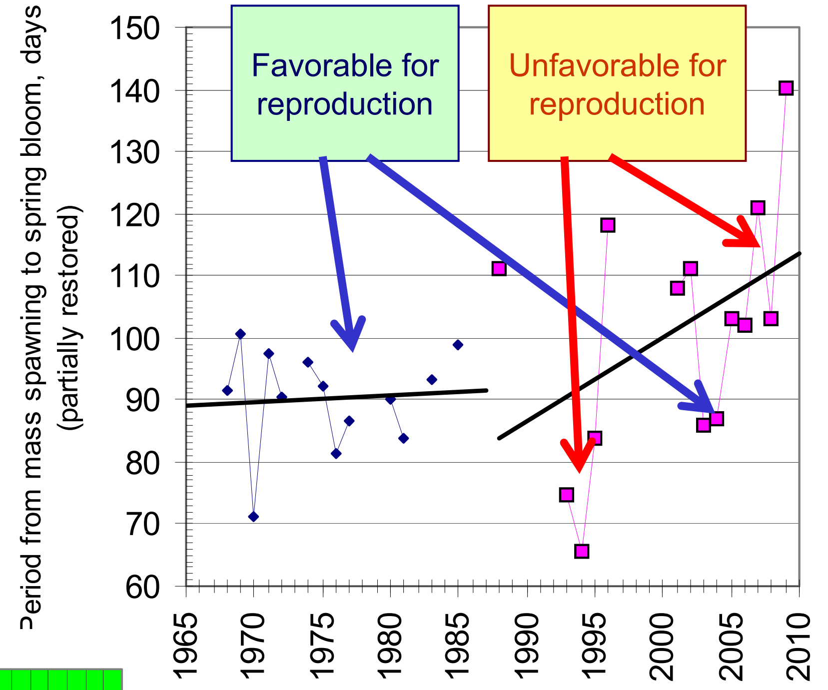


Dependence of the year-class strength on the date of the spring bloom peak (no relationship)

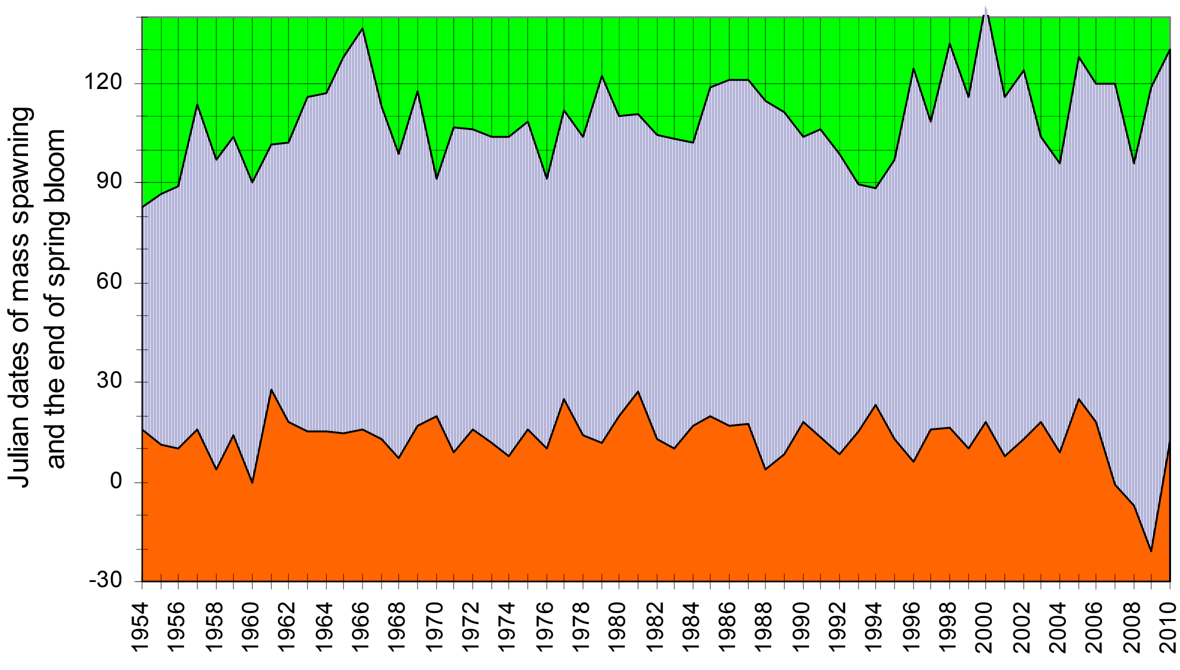
Saffron cod: embryonal development

So, neither the date of spawning nor the date of spring bloom are important for success of reproduction. But following to Cushing's match/mismatch hypothesis the match of larvae hatching with the spring bloom is necessary. For the match, the time interval from spawning to spring bloom should be equal with the time of embryonal development.

In the case of saffron cod, this interval was stably about 90 days in 1970-1980s, when its reproduction was successful, but became longer in 1990s (with exclusion of some years) .



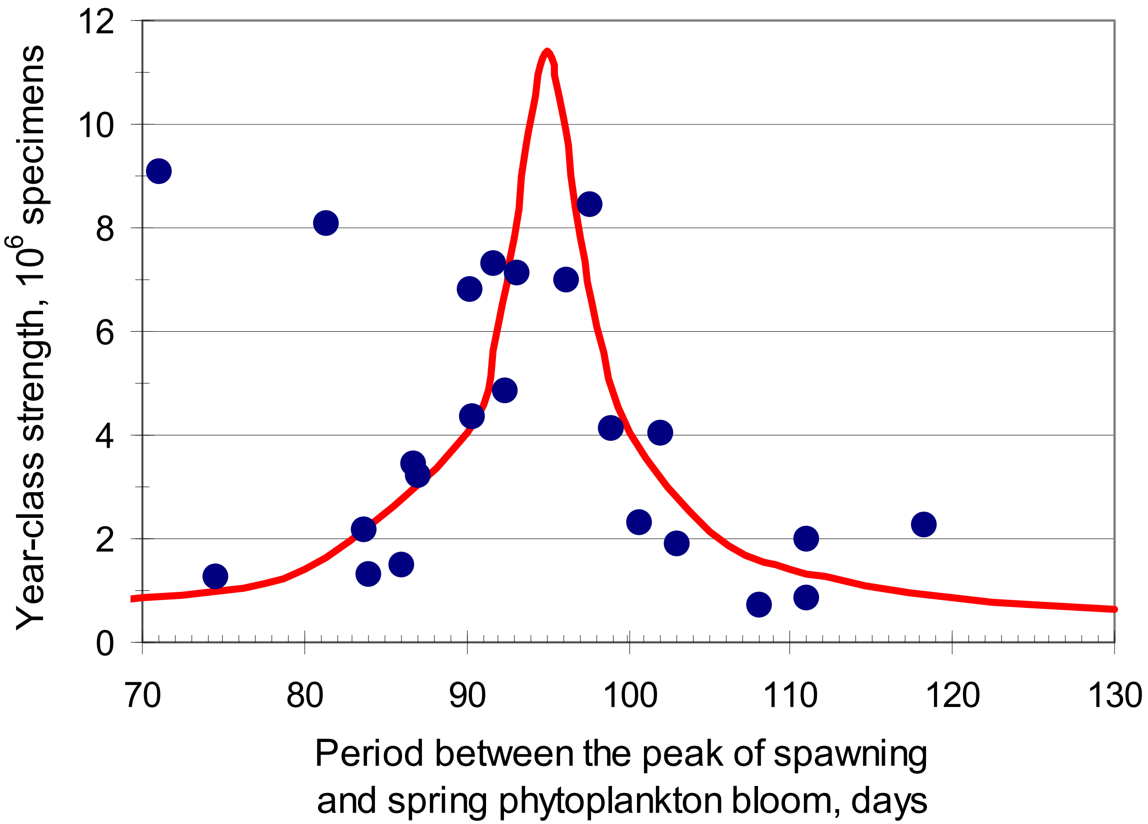
Year-to-year changes of the time interval between the peak of saffron cod spawning (observed data of spawning only) and the peak of spring bloom.
Trends before and after 1988 are shown



Year-to-year timing of the peaks of saffron cod spawning and spring bloom (observed + restored data). Time interval between the peaks is shaded

Saffron cod: reproductive success

The dependence of the year-class strength on the time between spawning and blooming is approximated by a resonance function. After tuning of the function, the optimal interval is determined as 95 days.



Dependence of the saffron cod year-class strength on the interval between its mass spawning and spring bloom

Resonance function:

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

where

N_i – year-class strength for the year i;

T_i – time interval between the peak of spawning and the peak of spring bloom in the year i;

T_R – optimal (resonance) length of the interval;

Q – Q-factor of vibrating system;

a – empiric coefficient.

The saffron cod reproduction is successful and strong year-classes form in the years with T_i close to T_R that provides the best match of the larvae hatching with their prey abundance, but the years with extremely long and extremely short T_i are unfavorable for reproduction.

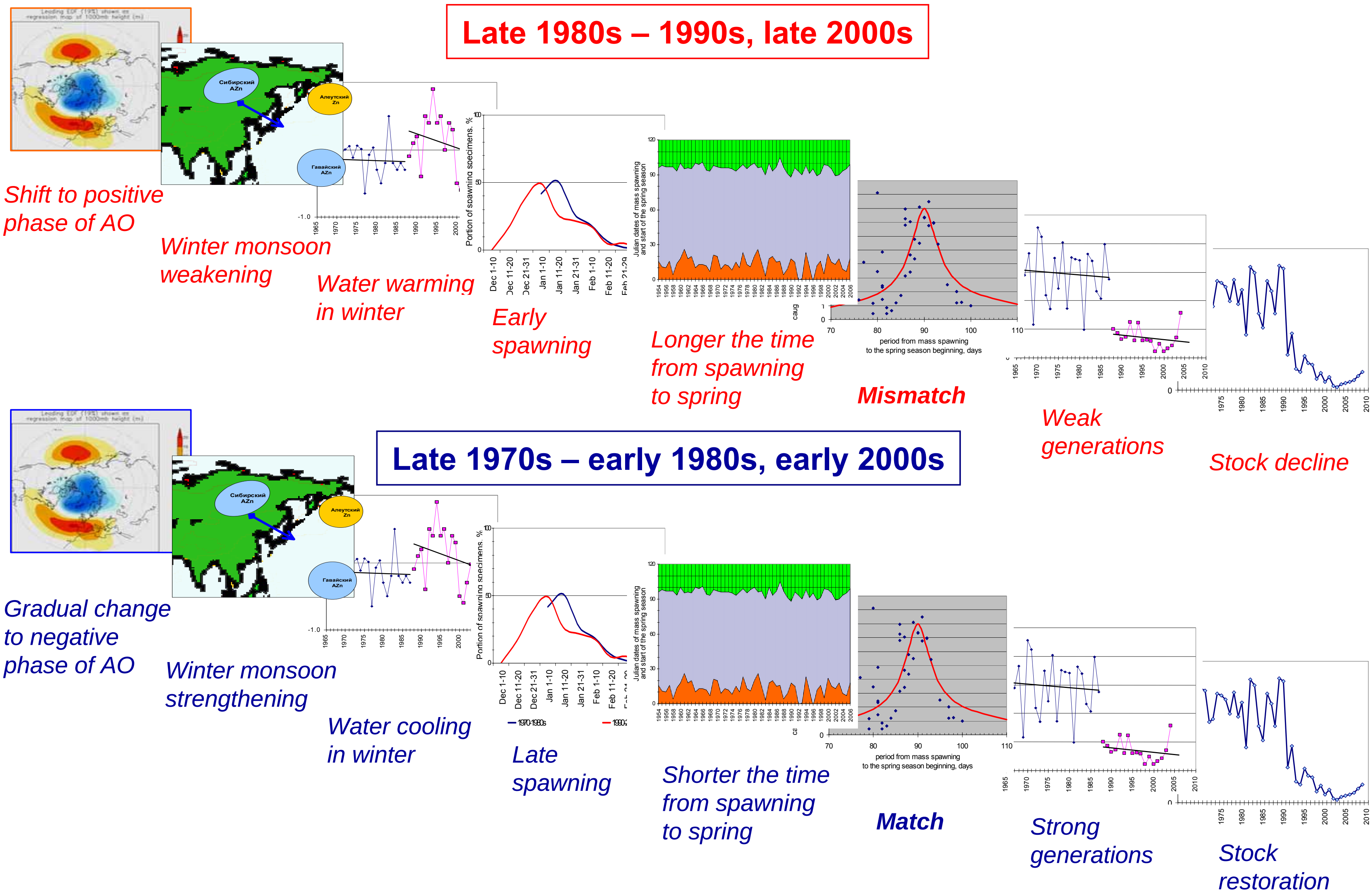
Parameters of this equation determined by its fitting to the data of observations:

T_R = 95 days;

Q = 0.53;

a = 11.4·10⁶ specimens

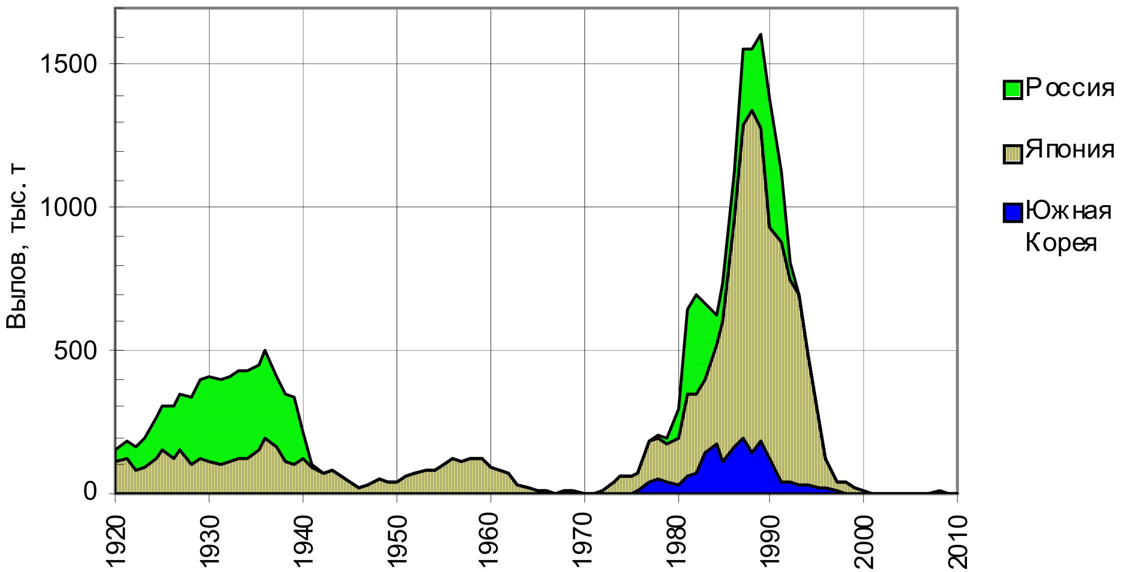
Scheme of climate change influence on the saffron cod population in Peter the Great Bay

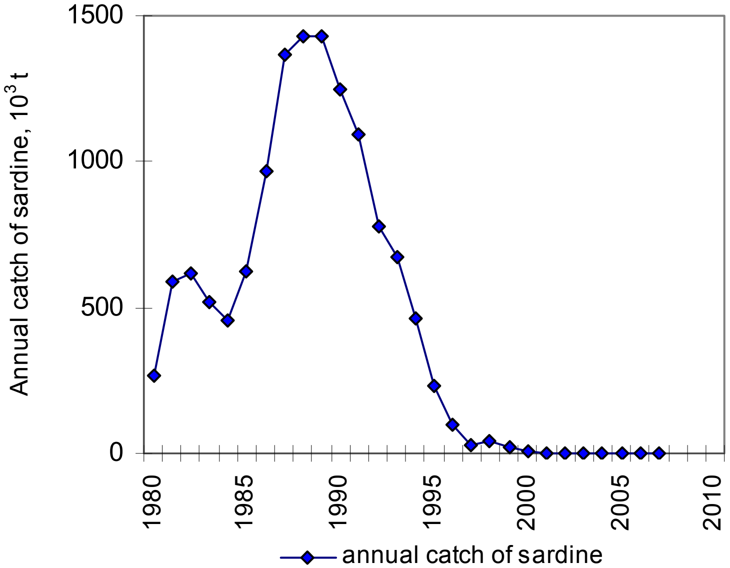


Sardine: catches

In the periods of its high stock, Japanese sardine is the main subject of commercial fishery in the Japan Sea and North-West Pacific. However, its fishery drops to zero in the periods of low stock.

The last period of the sardine abundance was in 1970-1980s when its landing exceeded 5 mln t. Since 2001, sardine is caught as a by-catch only.



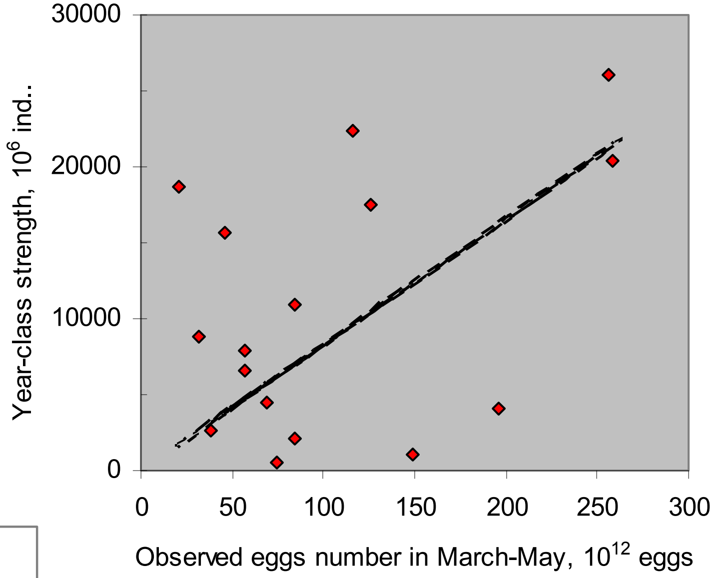


Annual catches of sardine in the Japan and East-China Seas by certain countries (left) and annual total catches of sardine in the Japan Sea by Japan, Russia, and South Korea (right)

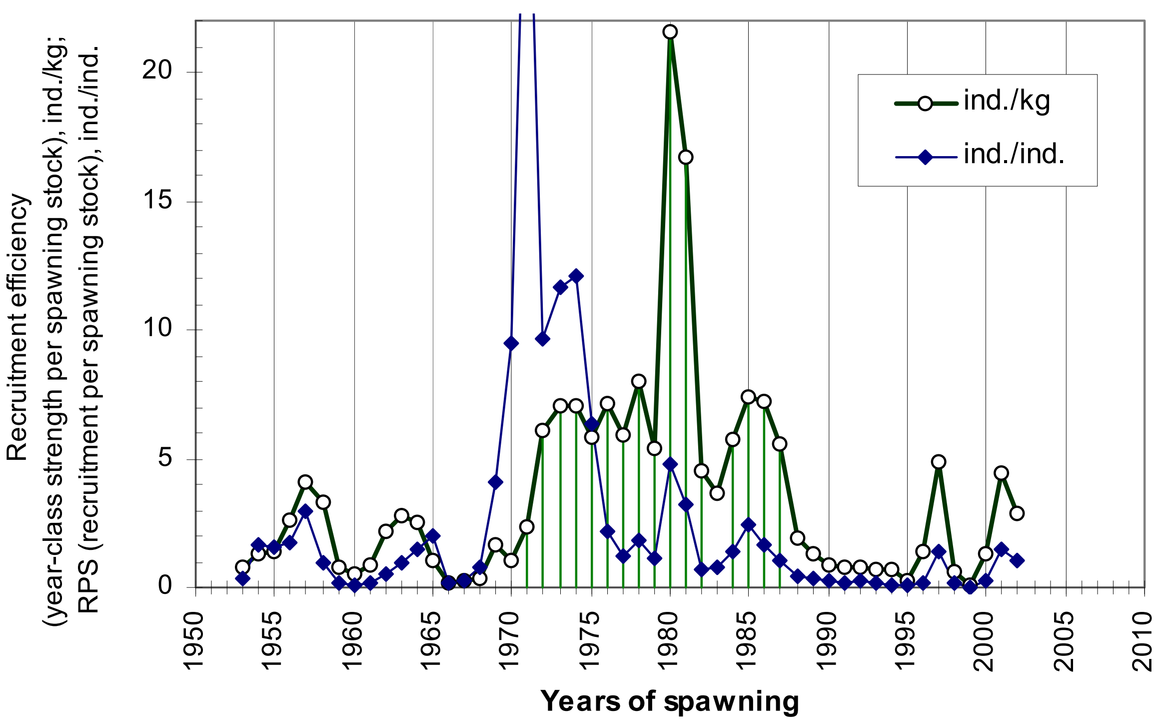
Sardine: year-class strength

In opposite to saffron cod, the year-class strength of sardine depends significantly on population fecundity, so this parameter cannot be a measure of spawning success. That's why the ratio of year-class strength to spawning stock is used as an index of reproduction efficiency for sardine. This index was high (>5 that means successful reproduction) in 1971-1982 and 1984-1987.

Note, that this parameter could be distorted by high catch of juveniles.



Dependence of the year-class strength of sardine (in the Japan and East-China Seas) on the number of sardine eggs counted in the Japan Sea in March-May of the years of reproduction

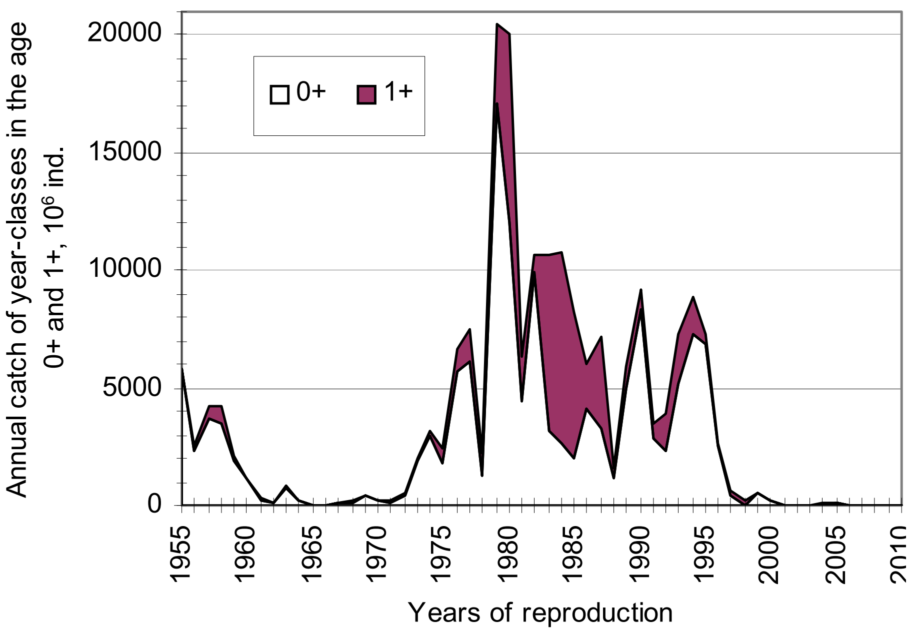


Parameters of the efficiency of sardine reproduction in the Japan Sea.
The ratio ***year-class strength / spawning stock*** [ind./kg] *is the best index*

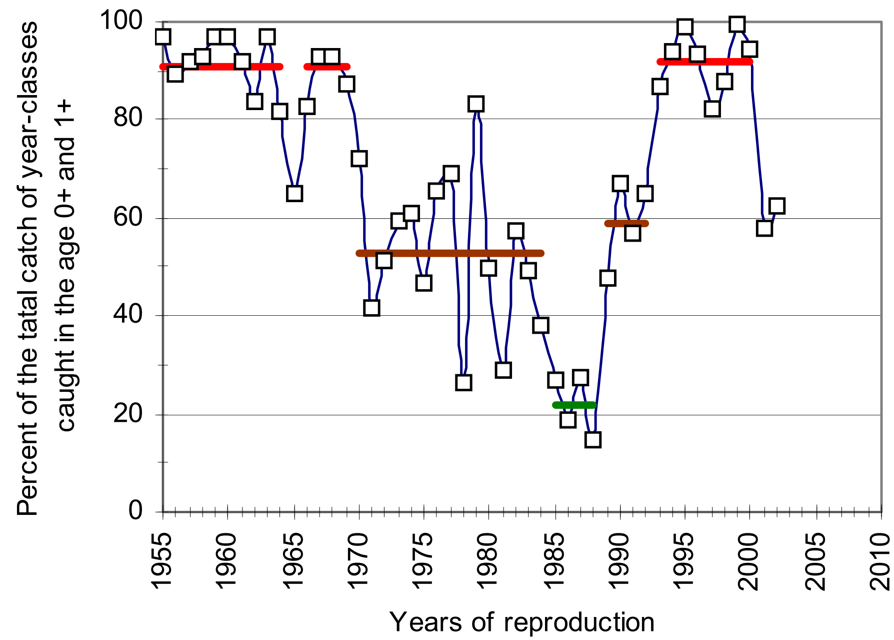
Sardine: catch of year-classes

To remove the influence of juveniles landings, the sardine reproduction was considered separately for the periods with different fishery press onto its early stages.

Japanese landings of the sardine larvae, YOY, and yearlings (ages 0+ and 1+) were relatively high (80-99 % of total catches of the year-classes) for the year-classes born before 1970 and in 1990s; their level was mostly medium (40-80 %) in 1970-1980s; and their level was relatively low (<25%) in few years only (1985-1988).



Japanese catches of larvae, YOY, and yearlings of sardine within the Japan and East-China Seas, by year-classes (from: Ohsimo et al., 2009)



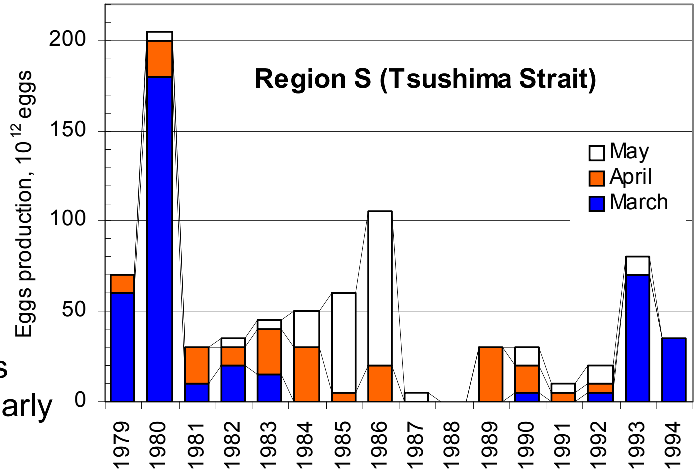
Portion (%) of young (0+ and 1+) sardine catches by Japanese fishermen in the Japan and East-China Seas, by year-classes

Sardine: spawning

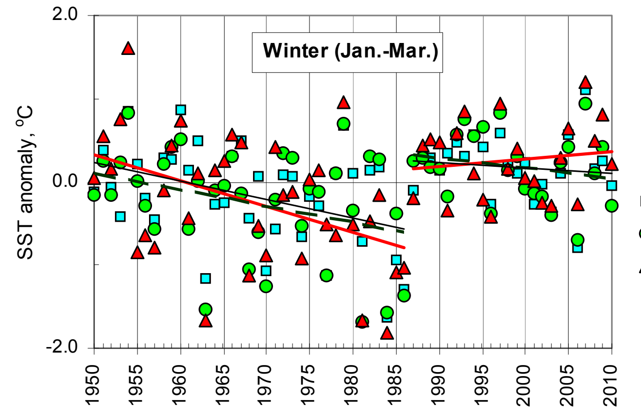
Sardine eggs production has a prominent year-to-year variation but no any significant trend after 1980. It was still very high even after the late 1980s (when the sardine stock decreased quickly).

But timing of the peak of spawning has visible trends: it shifted to May in the early 1980s and became earlier (shifted to March) in the late 1980s

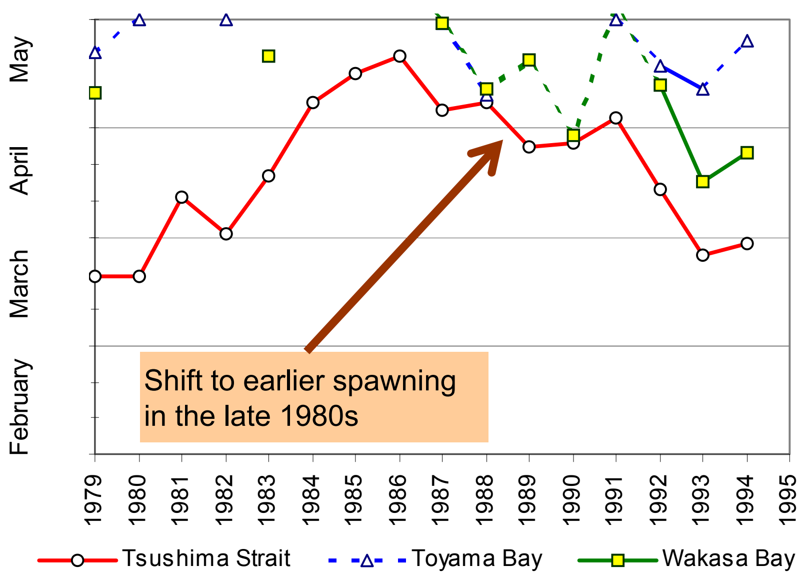
The dates of the spawning peak have negative dependence on SST in the area of spawning (r > 0.7)



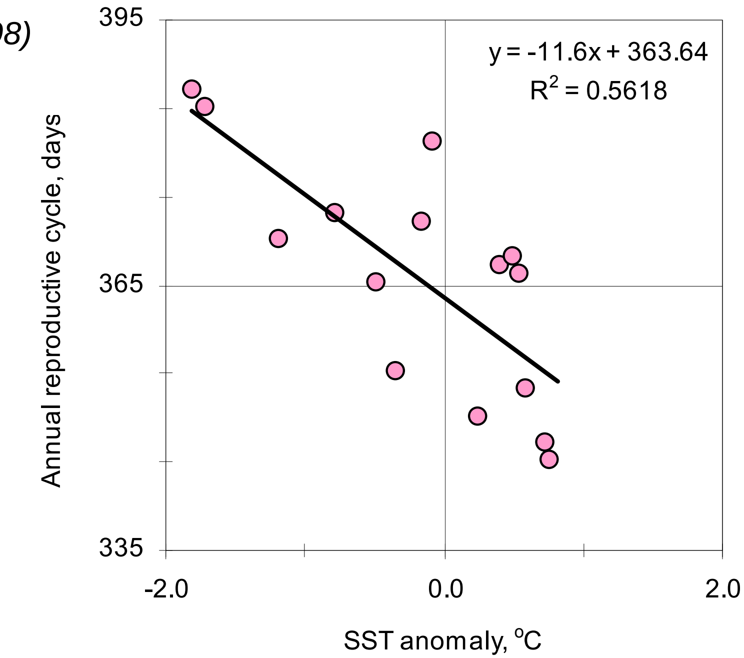
Annual estimations of the sardine eggs production in the main spawning grounds in the Japan Sea at the Tsushima Strait (from: Goto, 1998)



Year-to-year changes of SST in certain parts of the sardine spawning grounds in the Japan Sea.
Regime shift occurred in the late 1980s



Year-to-year changes of the date of the sardine spawning peak in different parts of its spawning grounds in the Japan Sea (calculated from the data published by Goto, 1998)

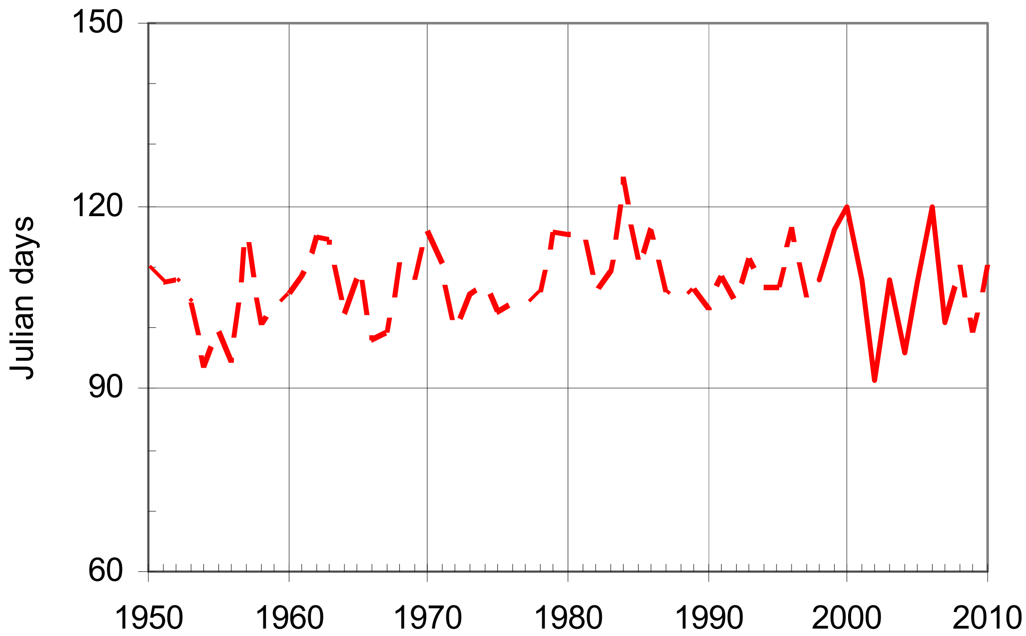


Dependence of the annual reproductive cycle length (from spawning to spawning) on winter SST for the main spawning ground of sardine in the Japan Sea

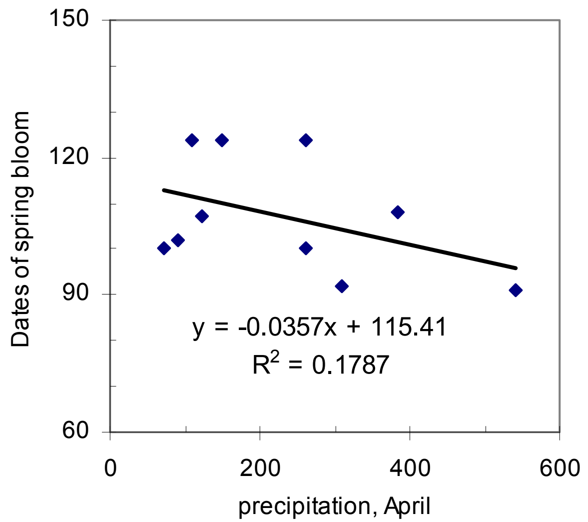
Sardine: hatching / blooming

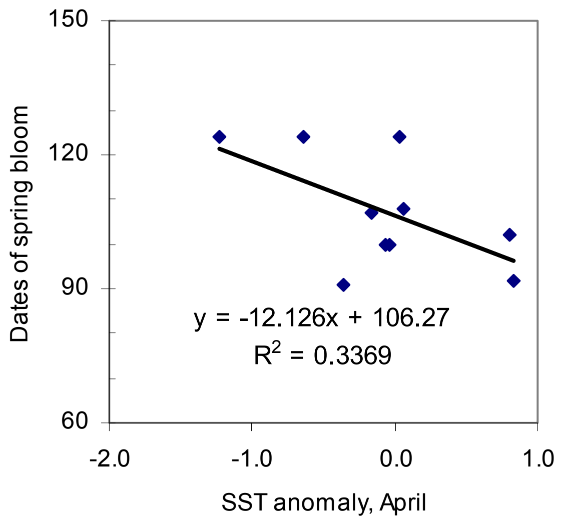
Sardine larvae hatch in spring, during spring bloom of plankton and prey mainly on early stages of copepods (sardine adults can consume phytoplankton). Dates of spring bloom in the sardine spawning grounds have a year-to-year variability with the range about 1.5 months. Their variability for the times before SeaWiFS observations are reconstructed, as well.

The tendency to earlier blooming began after the 1980s but it was not strong. Generally, the date of the peak of blooming in the main spawning grounds of sardine is rather stable and fluctuates within April.



Year-to-year changes of the date of spring bloom peak in the main area of sardine spawning grounds (by SeaWiFS data and restored)



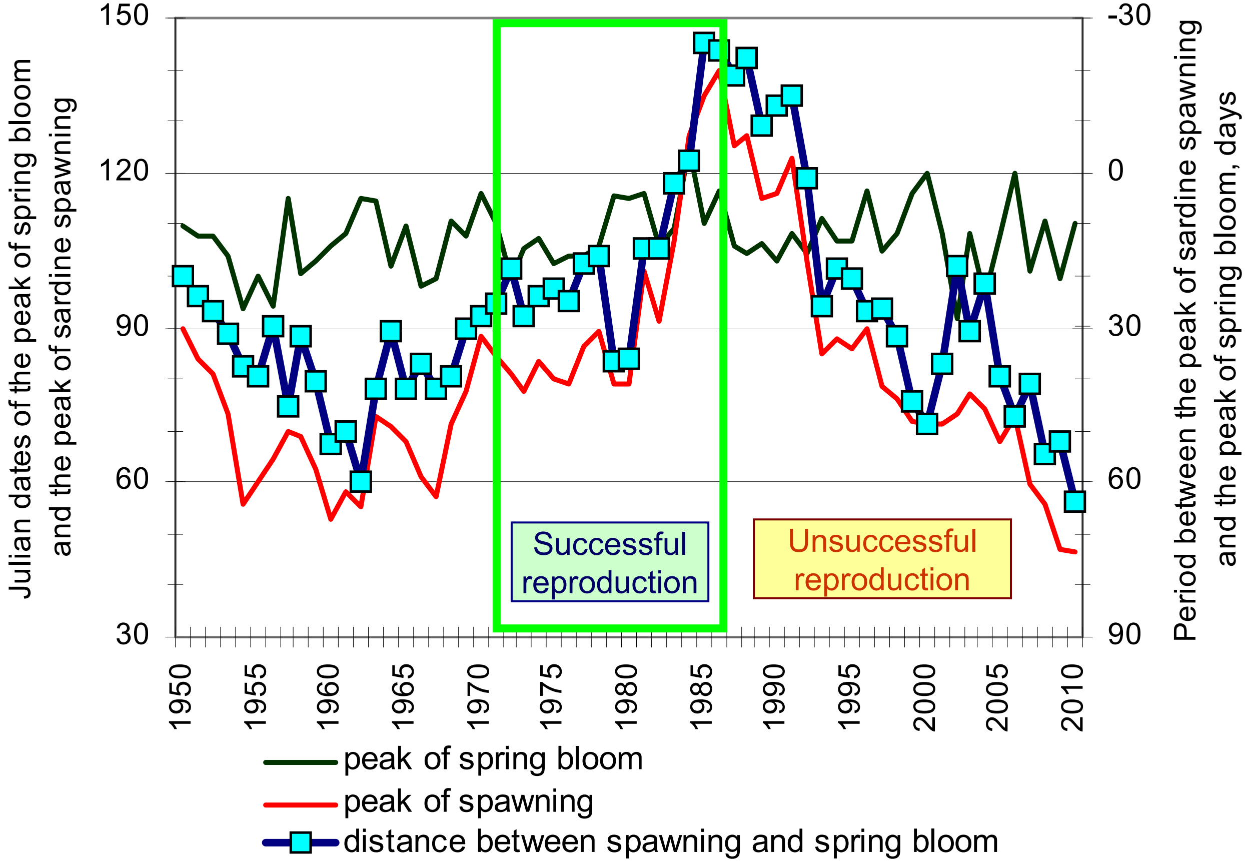


Dependence of the date of spring bloom peak on the main spawning grounds of sardine on SST and precipitation

Sardine: embryonal development

Following to match/mismatch hypothesis, for success of reproduction, the time interval between the spawning and spring bloom should be equal with the time of embryonal development. However, the changes of this time have no visible relation with success of the sardine reproduction because of strong “noise” from fishery on juveniles.

That means that the years with low and high landings of young sardine should be considered separately



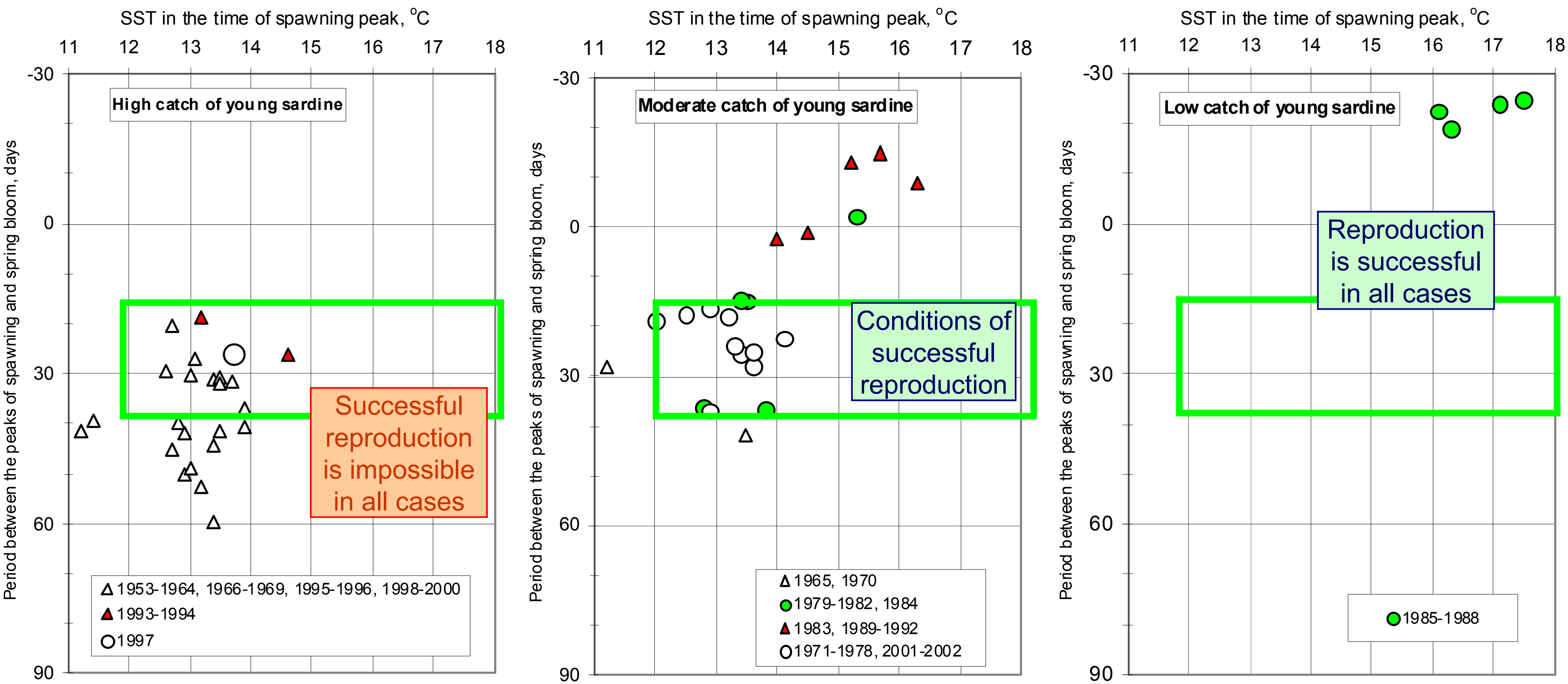
Year-to-year changes of the interval between the peaks of sardine spawning and spring bloom (thick blue line). The dates of the peaks are also shown

Sardine: reproductive success

The relationship of reproduction success on the time between spawning and blooming is very different in dependence on the level of commercial landings of young sardine:

All years with high catch of juveniles were unsuccessful for the sardine reproduction.
All years with low catch of juveniles were successful for the sardine reproduction.

If the catch of juveniles was moderate, the reproduction was successful if the time interval between the peaks of spawning and spring bloom was 15-36 days and SST in the period of mass spawning was > 12 C.



Dependence of the sardine reproduction success on the interval from mass spawning to spring bloom for the years with different degree of its juveniles landings (by Japanese fisheries statistics).
Circles – successful reproduction; triangles – unsuccessful reproduction

Scheme of climate influence on the sardine population in the Japan Sea

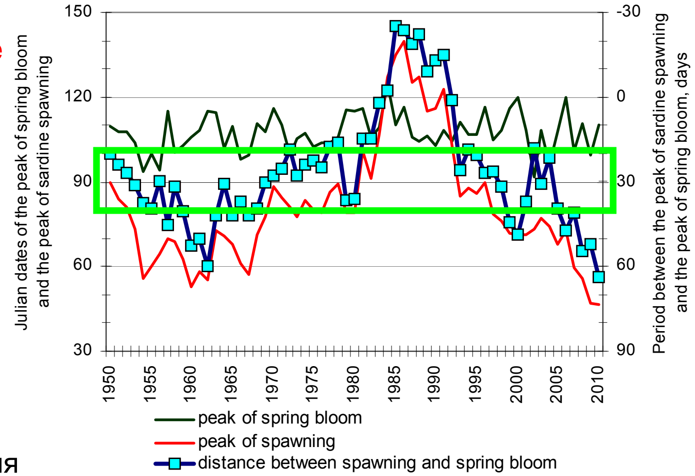
Late 1950s-1960s – **strong monsoon** – improving of environments for reproduction: the dates of spawning changed from too early to optimal in the end of this period, but landings of juveniles were very high –> ***low stock***

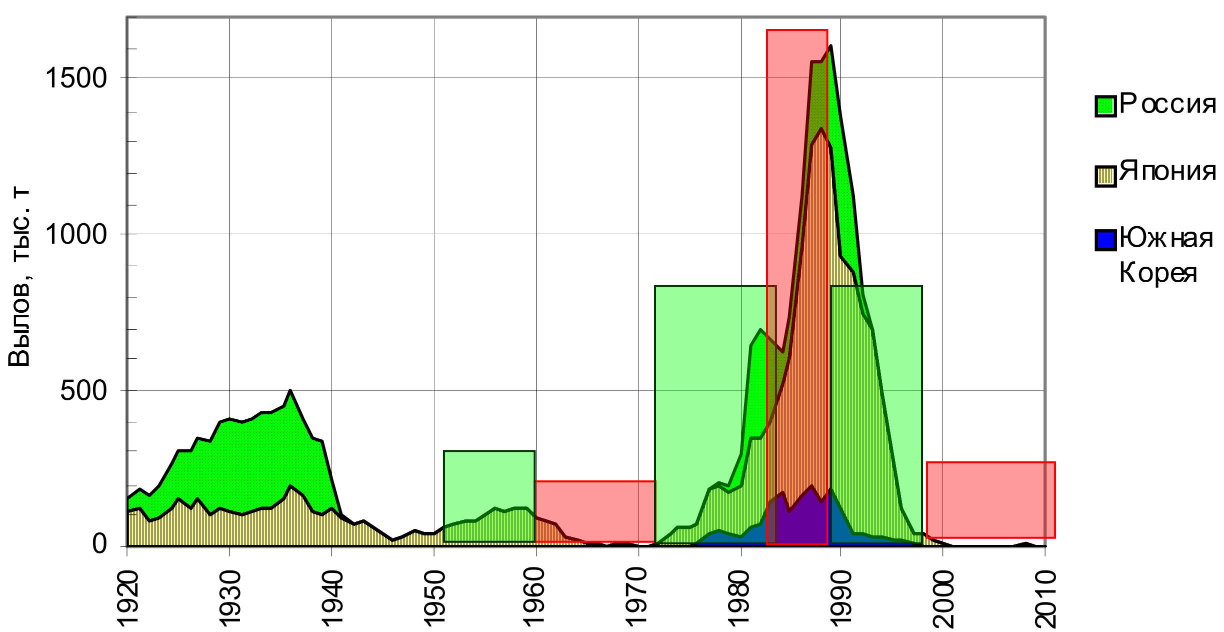
1971-1982 – **weak monsoon** – favorable environments for reproduction because of stably optimal dates of spawning, moderate landings of young fish –> ***quick increasing of the stock***

1983-1988 – **strong monsoon** – worsening environments for reproduction because of too late spawning, but very low landings of young fish -> ***high stock***

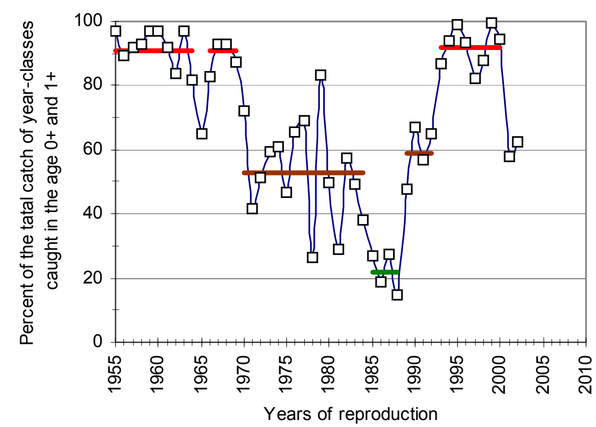
1989-1998 – **weak monsoon** – improving environments for reproduction but extremely high landings of juveniles –> ***decreasing of the stock***

After 1999 (except 2000-2002) – **moderate monsoon** – worsening environments for reproduction because of too early spawning, moderate landings of juveniles



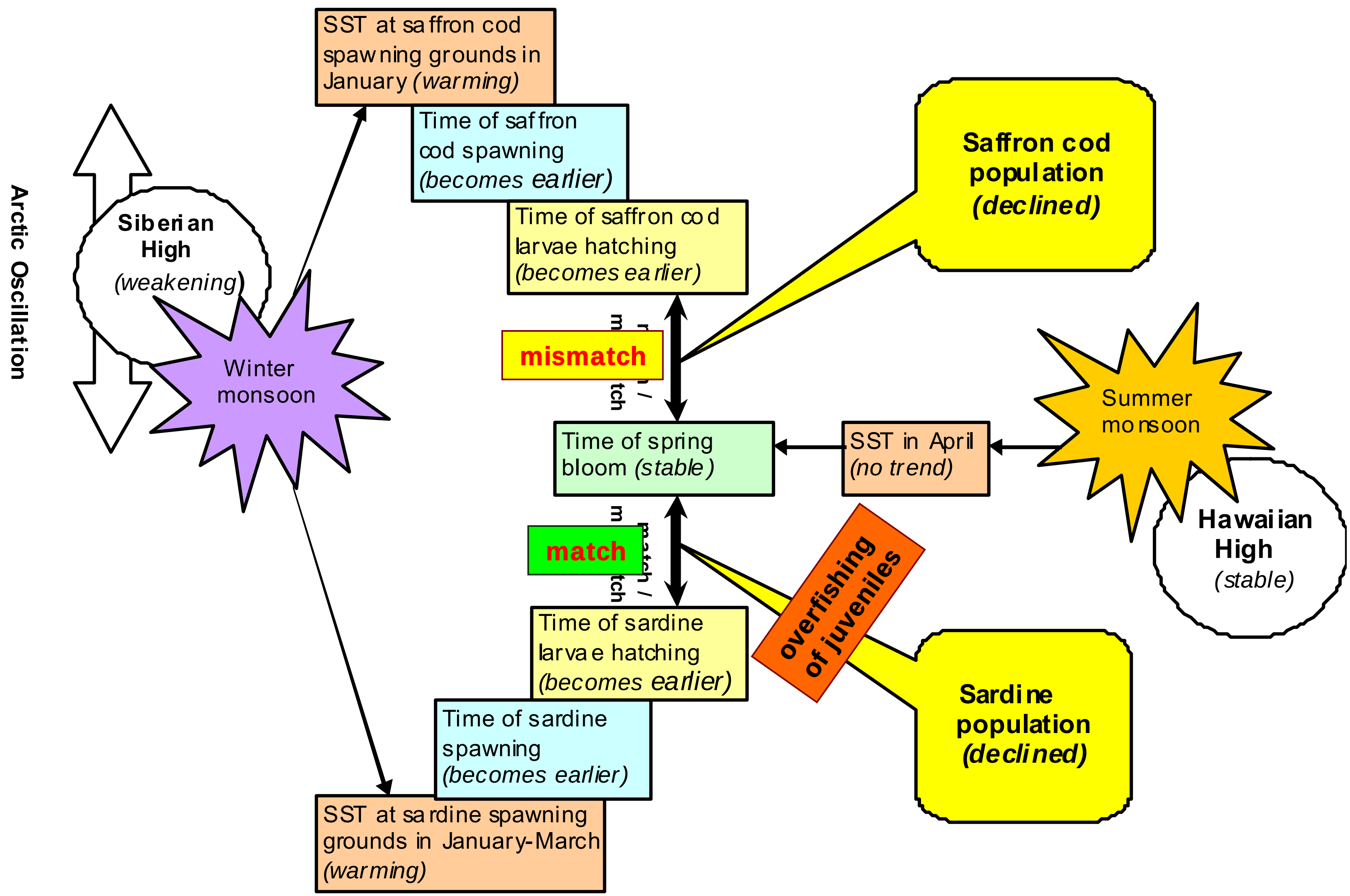


Annual catches of sardine in the Japan and East-China Seas

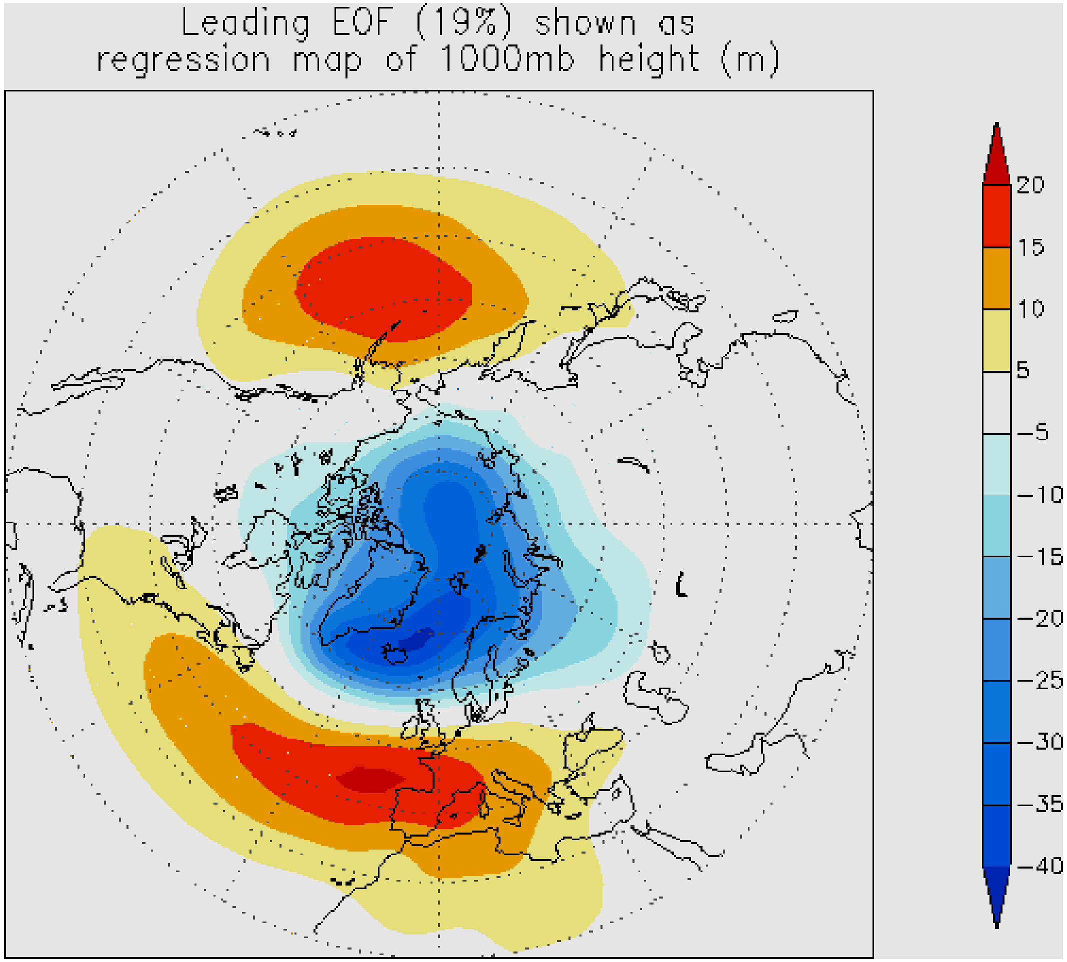


Conditions of sardine reproduction and landings of juvenile sardine

Scheme of climate change influence on the populations of winter-spawning fish species in the Japan Sea during the climate shift in the late 1980s



Possible mechanism of teleconnections between marine ecosystems of the Northern Hemisphere



Scheme of AO pattern

Arctic Oscillation determines air masses distribution over the whole Northern Hemisphere. That means that winter conditions over the Japan Sea which are dependent on regional process – winter monsoon, reflect the same atmosphere patterns of larger scale.

Ecosystems in other seas could be influenced by other regional processes, but those processes are related with Arctic Oscillation, too.

So, the Arctic Oscillation could drive changes of marine ecosystems in remote basins. There is revealed that principal components describing marine ecosystems of many subarctic seas, as for example the Baltic Sea, also correlate with AO and have prominent shifts in the late 1980s.

"Every thing is vibration, everything is resonance..."

Conclusions:

1. Decadal changes of winter environments in the Japan Sea are driven by Arctic Oscillation: its shift to positive phase in the late 1980s caused the winter monsoon weakening and warming. As the result, time of spawning of winter-spawning species shifted to earlier dates.

2. Strong generations of winter-spawning fish species, as sardine and saffron cod, form in the case of optimal period between the spawning and blooming that provides a **match** of its larvae hatching with the season of high abundance of their prey.

3. Species-specific reaction of winter-spawning fish species on climate change is determined by time of spawning (saffron cod spawns earlier, so prefers colder conditions, but too cold winters are unfavorable for sardine that spawns later).