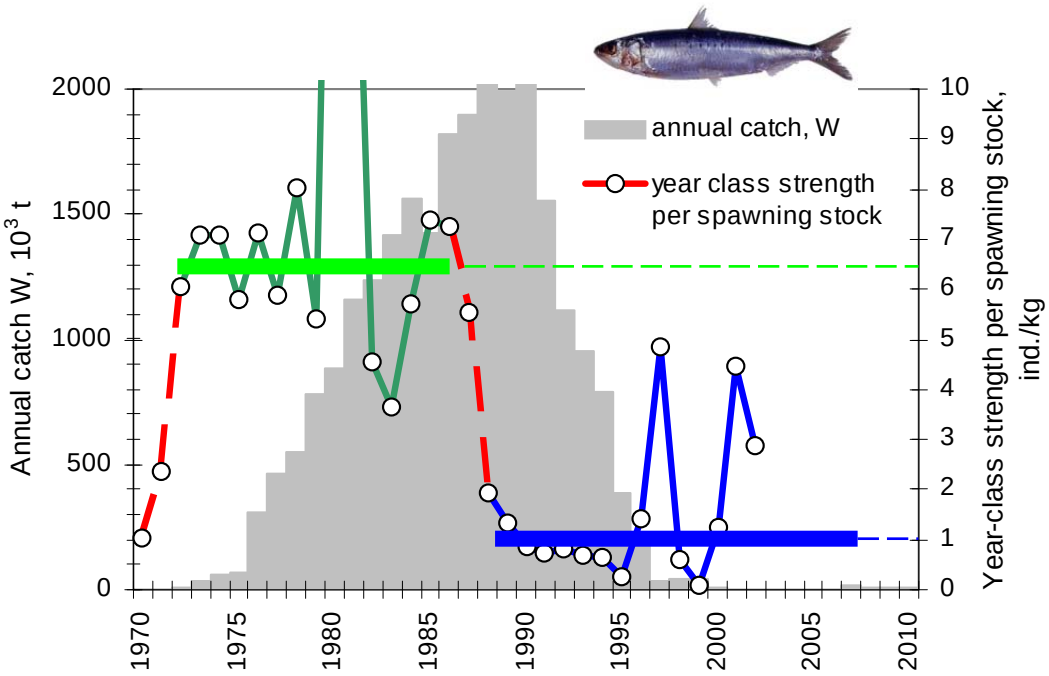
Yury Zuenko

Pacific Fisheries Research Center (TINRO)
Vladivostok, Russia

Resonance effect of spawning match with spring bloom for some fish species in the Japan/East Sea

Outline:

1. Tipping points for some fish populations in the Japan/East Sea
2. Cushing's match/mismatch hypothesis
3. Match/mismatch of winter-spawning species (saffron cod and japanese sardine) spawning with spring bloom
4. Resonance effect as the mechanism of tipping points formation, and its formalization

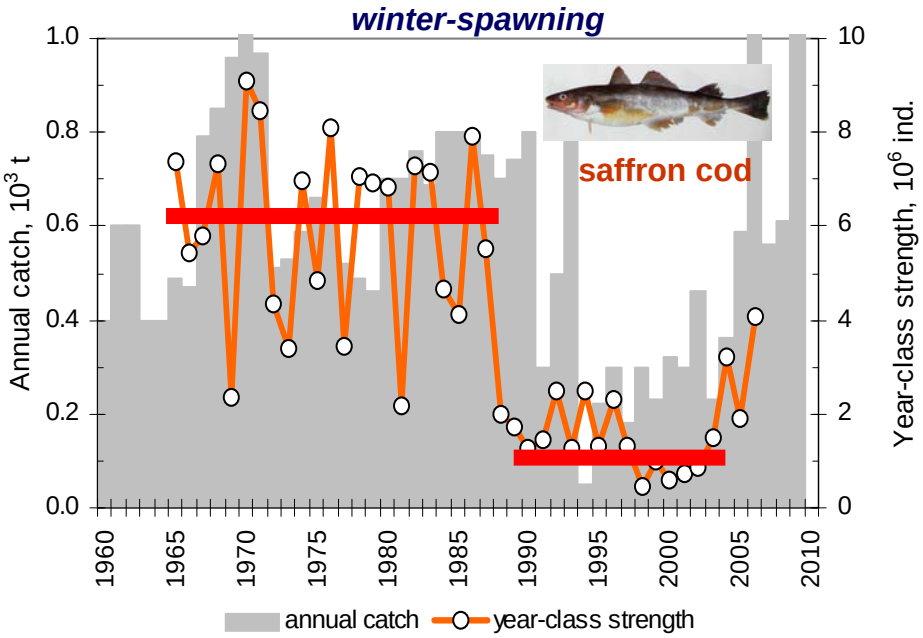


What happened in the middle 1980s that the extended reproduction of japanese sardine had stopped?

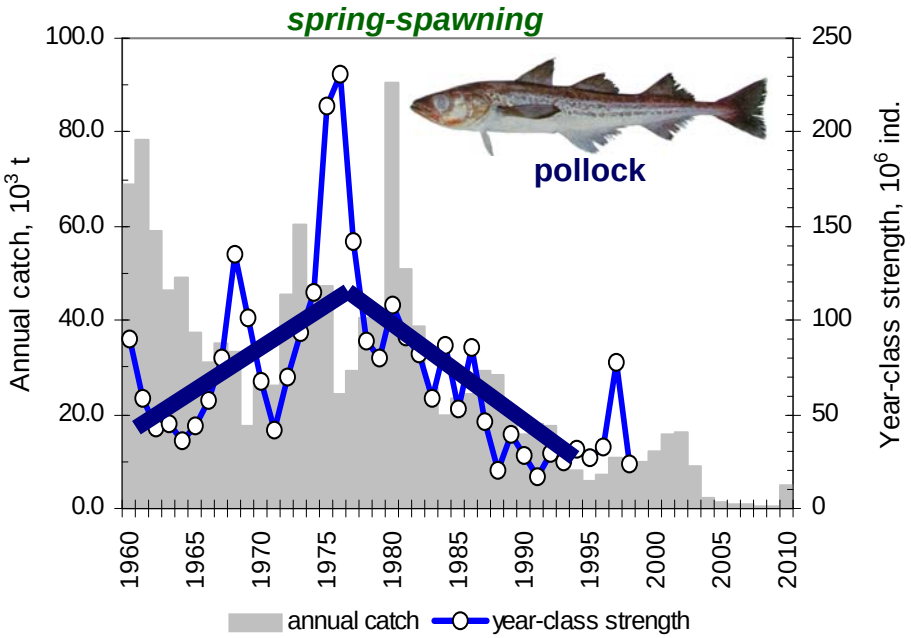
Do winter-spawning and spring-spawning species have similar dynamics?

The winter-spawning species, as japanese sardine and saffron cod, have a dynamics with prominent tipping points. The dynamics of spring-spawning species, as walleye pollock, is rather smoothed.

Possible reason: the winter-spawning species are evolutionary adapted to use for their reproduction the food resources of **spring bloom** that is very short, so their reproduction could be either very successful or unsuccessful.



Annual catch and year-class strength for saffron cod in Peter the Great Bay



Annual catch and year-class strength for walleye pollock in the northwestern Japan/East Sea

What are the tipping points in dynamics of winter-spawning species?

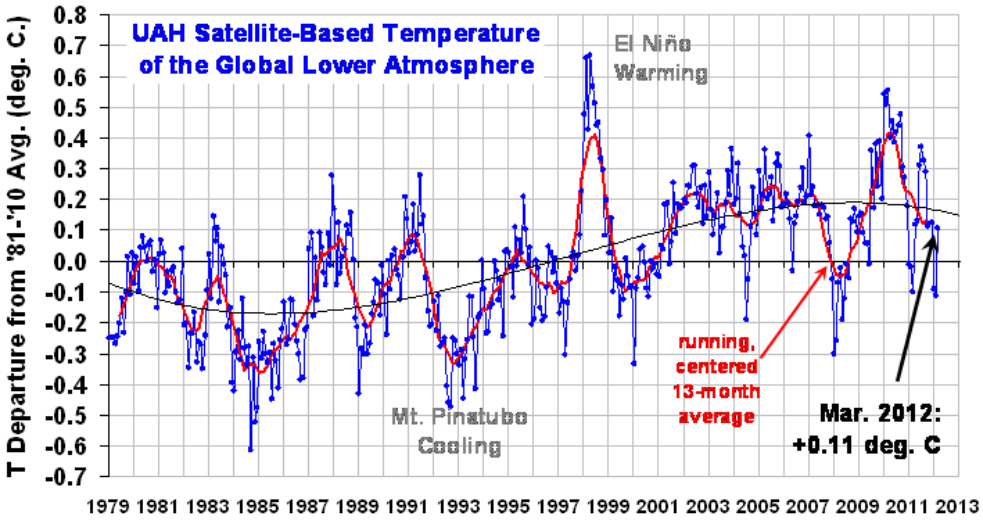
In the second half of the 20th Century, sardine had the tipping points in the early 1970s (rise) and late 1980s (fall), saffron cod – in the late 1980s (fall) and middle 2000s (rise).

Goal of the investigation – to understand:

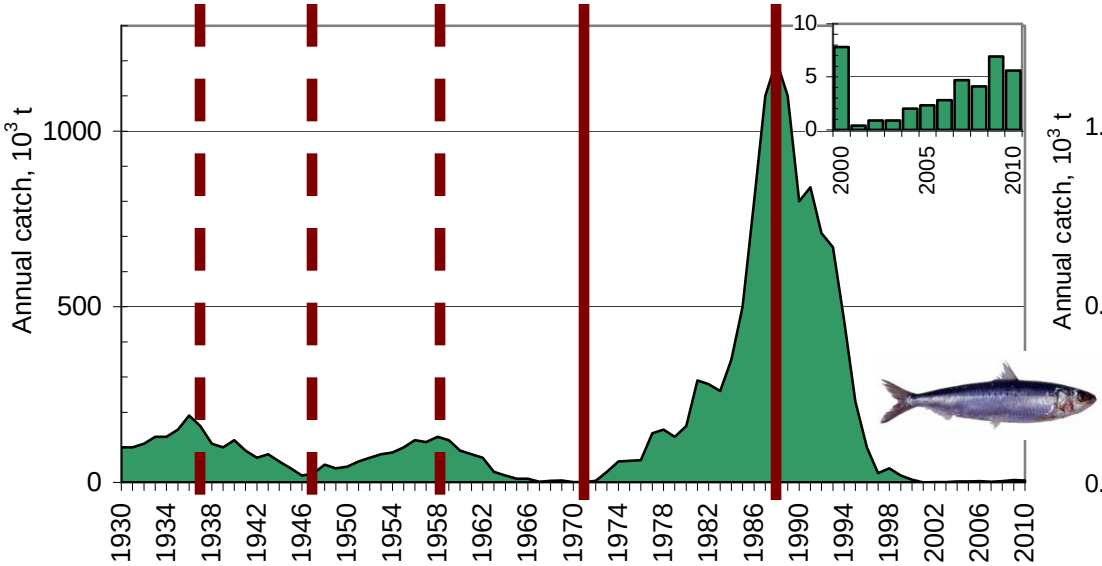
What happened in these tipping points?

Are the synchronous falls in the late 1980s caused by climate shift to warming?

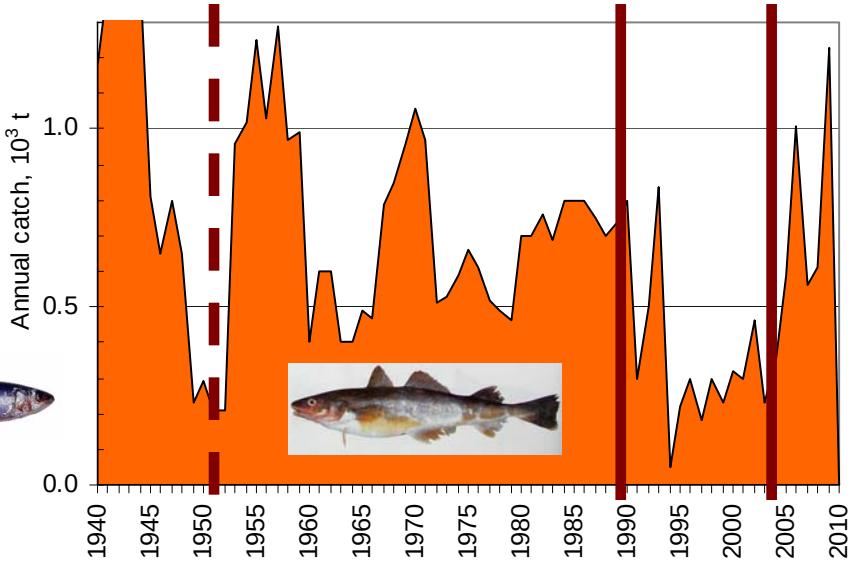
Is global warming good or bad for winter-spawning fish species?



from: http://www.drroyspencer.com/



Annual catch of japanese sardine in the Japan/East Sea by Japanese fleet

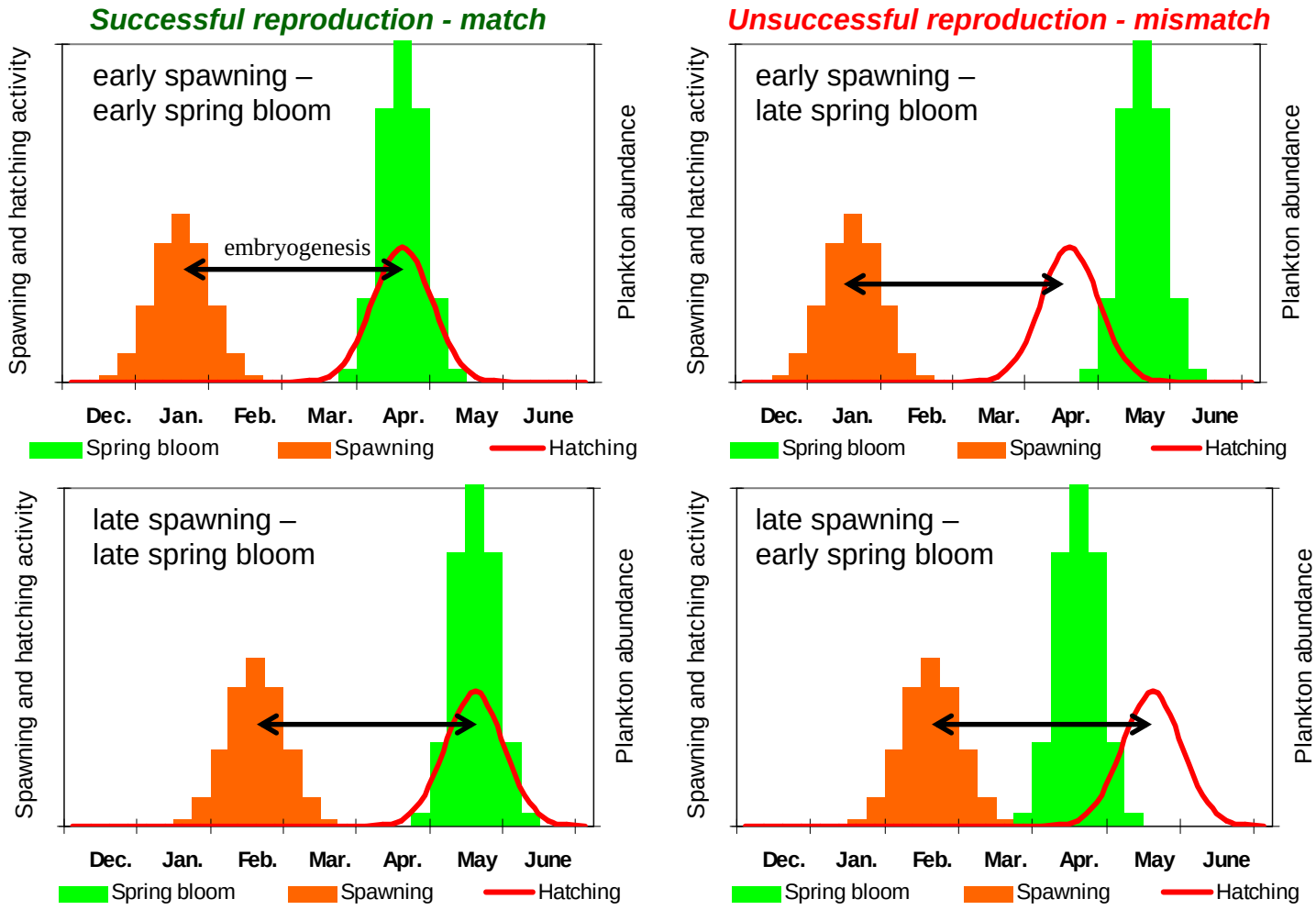


Annual catch of saffron cod in Peter the Great Bay

What is match / mismatch hypothesis?

For successful reproduction of winter-spawning species, the larvae should hatch from fish eggs directly in the time of spring bloom. Otherwise, if they hatch later or, in particularly, earlier – they have no food and die.

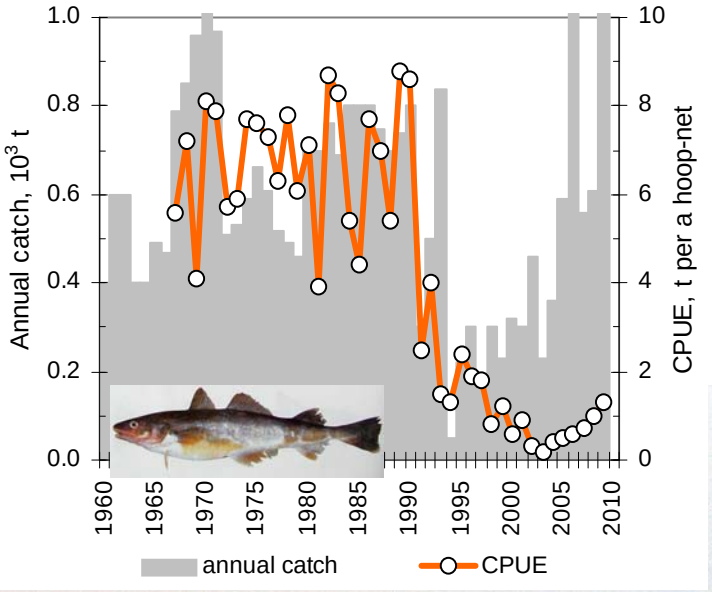
The time of hatching depend on the time of spawning and the time necessary for embryogenesis.



Saffron cod: what is the catch dynamics?

Saffron cod is caught mostly by hoop-nets in winter, under the sea ice, when it migrates to shallows for spawning.

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



T_a = –20°C

Hoop-net

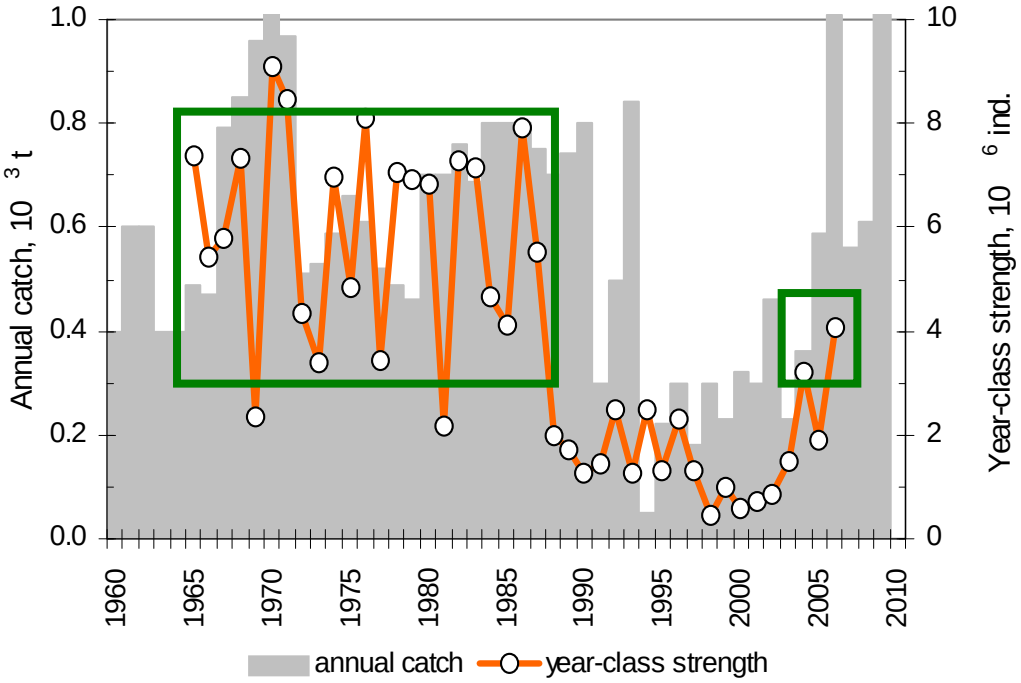
Fishing Tractor

Saffron cod: how to describe its reproductive success?

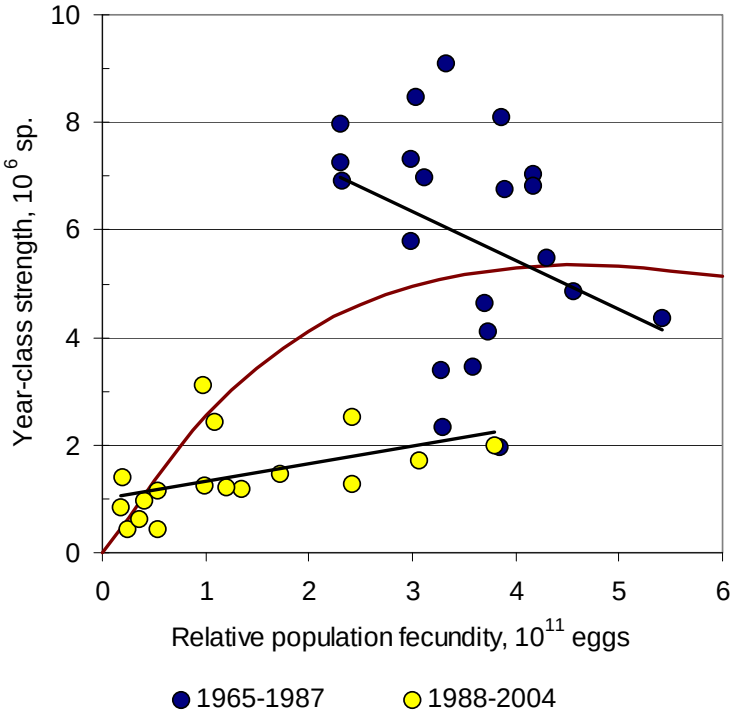
Year-class strength of saffron cod has similar changes, as the catches, with sharp decreasing between 1987 and 1988

The year-class strength of saffron cod does not depend on population fecundity, so this parameter could be used as an indicator of reproduction success.

The saffron cod reproduction was successful (>3 mln.ind.) in the period until 1987 and in 2004-2006



Year-class strength of saffron cod (summary catch of each generation in the age 2+ and elder normalized per standard fishing effort) on the background of annual catches

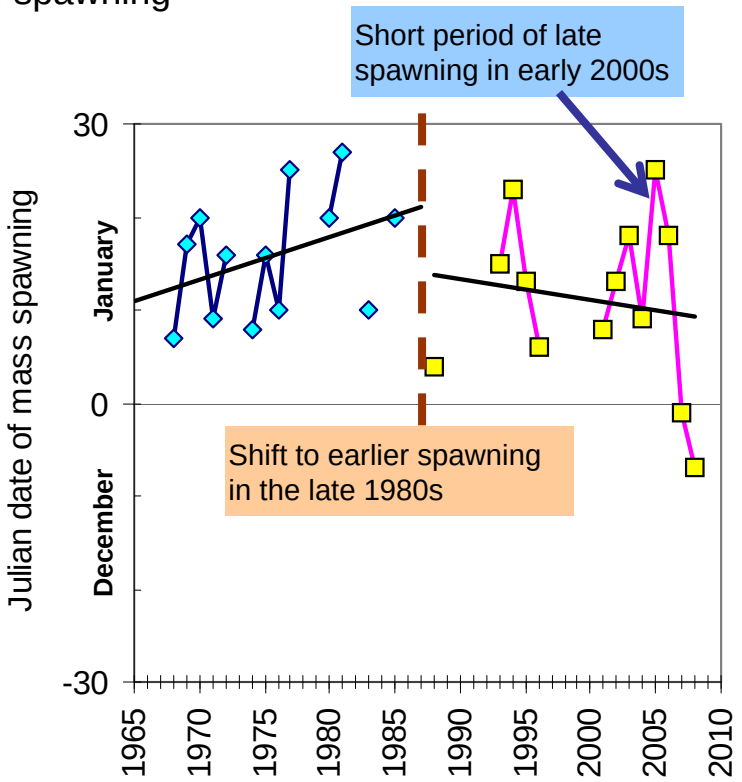


Dependence of the saffron cod year-class strength on its population fecundity

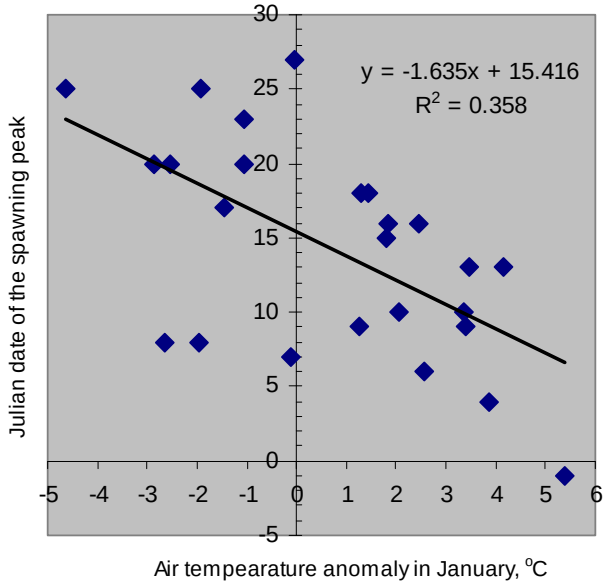
Saffron cod: how does the timing of spawning change?

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. The dates have a significant negative correlation with the air temperature in January (r = -0.60)

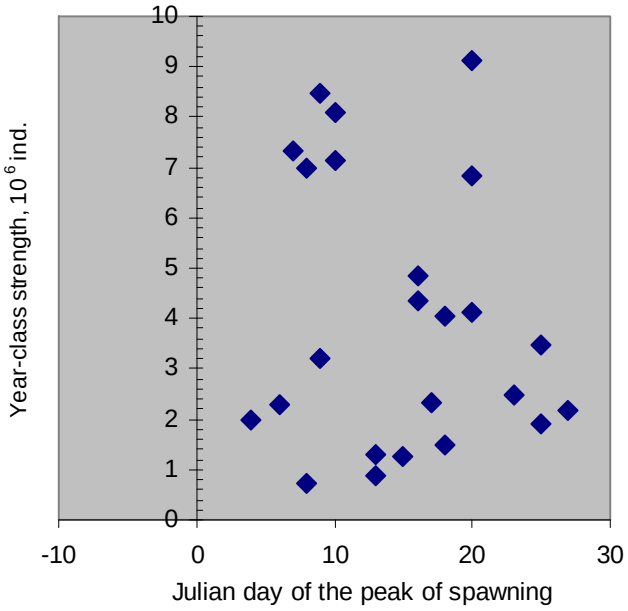
However, the year-class strength doesn't depend directly on the date of spawning



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



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

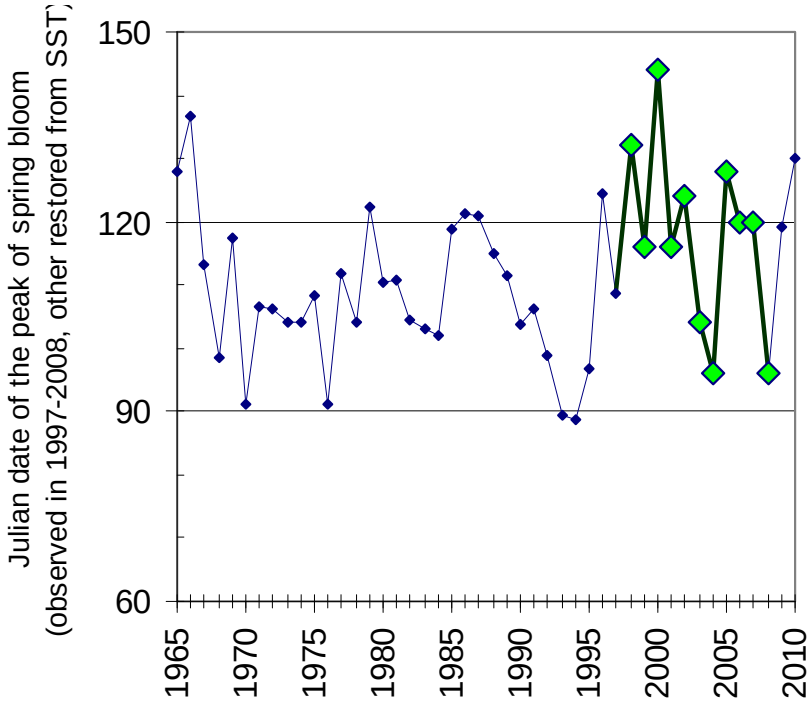


Dependence of the year-class strength on the date of the spawning peak for 1965-2006

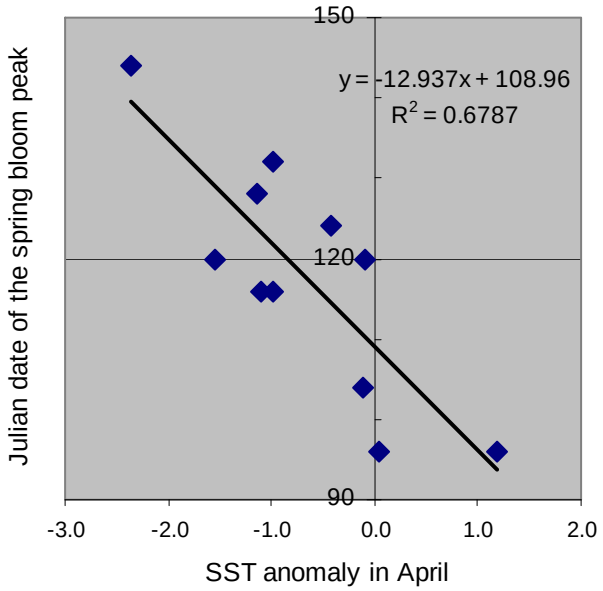
Saffron cod: how does the timing of spring bloom change?

The timing of spring bloom is detemined from SeaWiFS data. It depends on SST (negative, r = 0.82) that allows to reconstruct the dates of spring bloom for the years before SeaWiFS observations. This dates have no any significant trend.

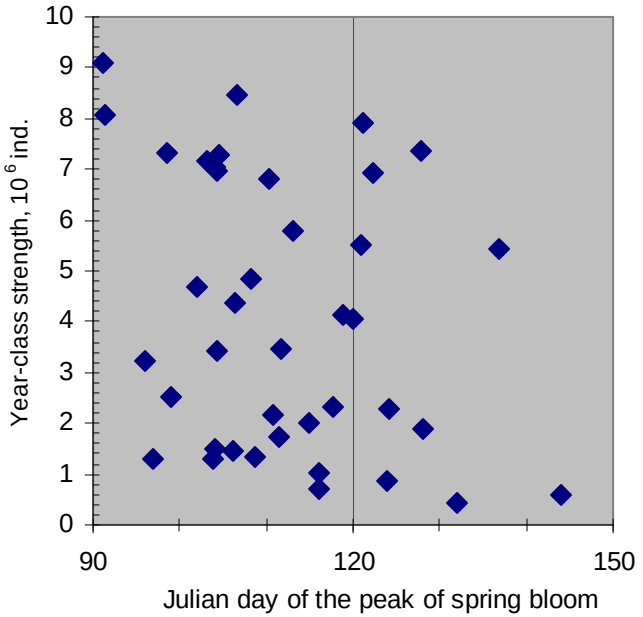
The year-class strength of saffron cod doesn't depend directly on the date of spring bloom.



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



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

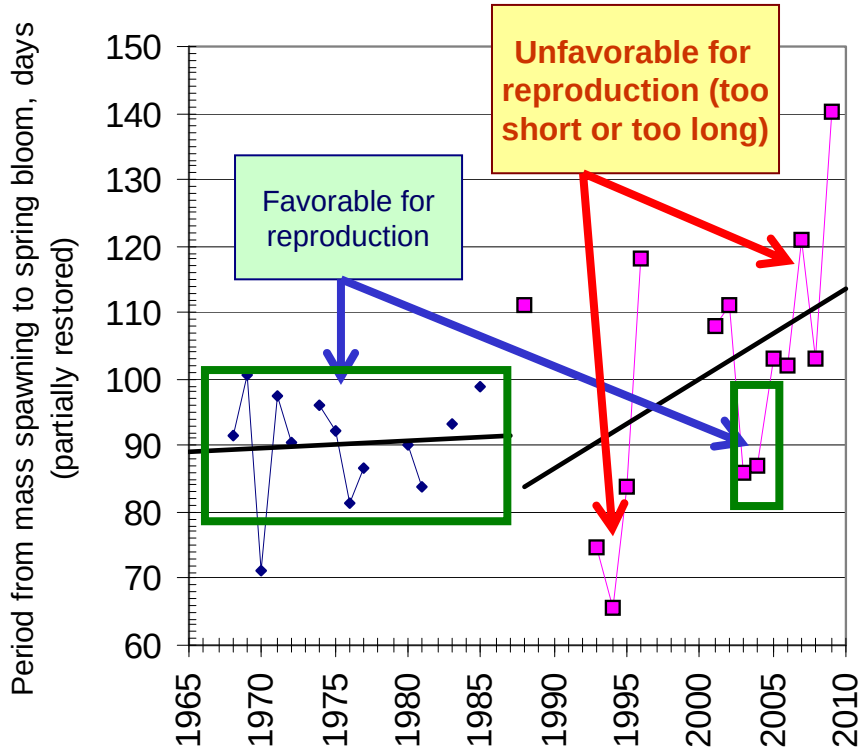


Dependence of the year-class strength on the date of the spring bloom peak (no relationship)

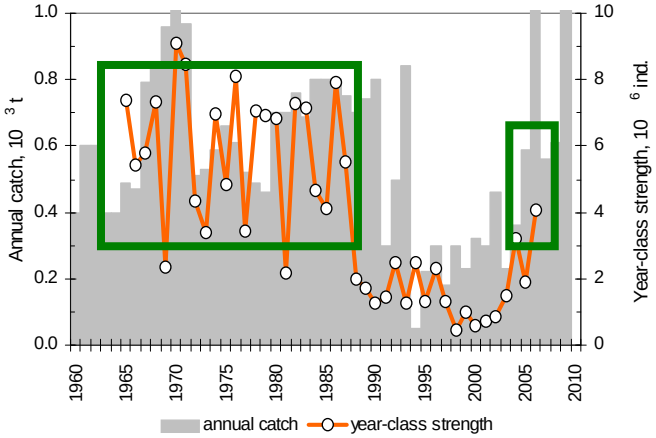
Saffron cod: when was the match and when was the mismatch?

So, neither the date of spawning nor the date of spring bloom are responsible for success of reproduction, but their match/mismatch is.

In the case of saffron cod, this interval has to be close to 90 days, as in 1970-1980s, when its reproduction was successful. When the interval became longer in 1990s (with exclusion of some years) – the reproduction became unsuccessful.



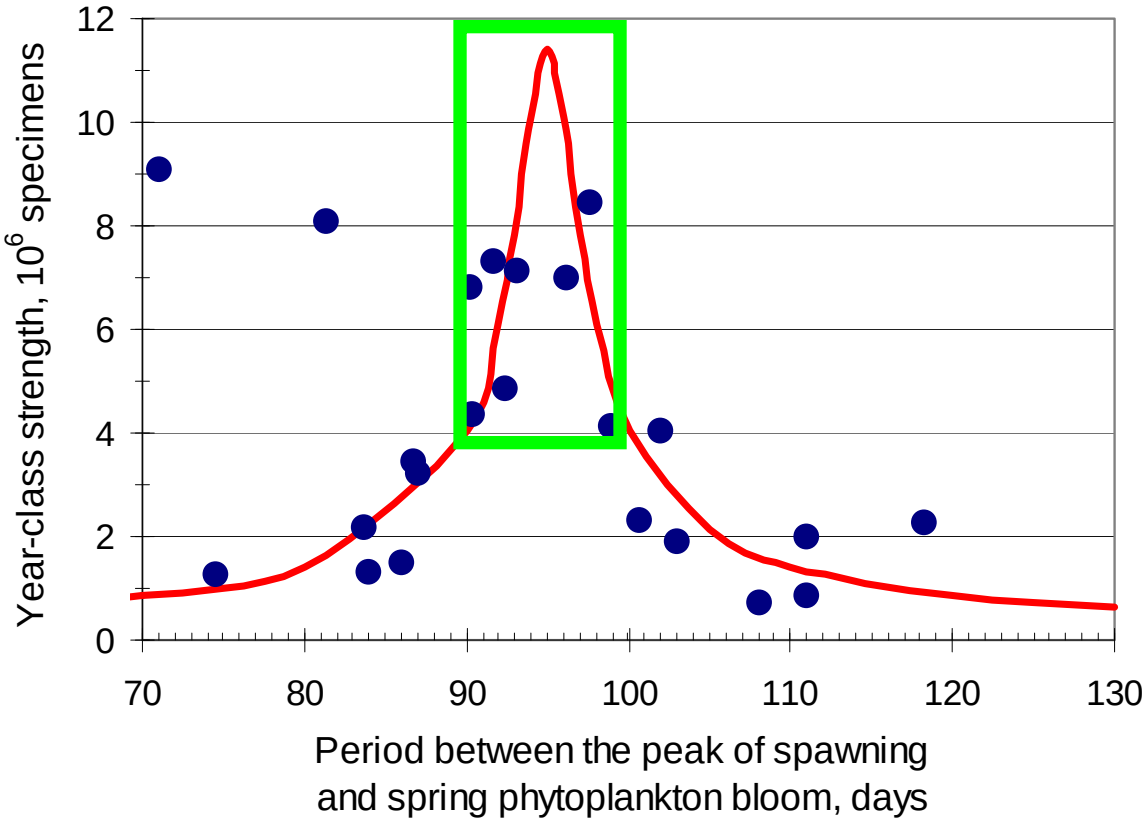
Year-to-year changes of the time interval between the peak of saffron cod spawning and the peak of spring bloom. Trends before and after 1988 are shown



Year-class strength of saffron cod on the background of annual catches

Saffron cod: does resonance work?

Dependence of the year-class strength on the time between spawning and blooming could be approximated by a resonance function. After tuning, the optimal interval is determined as 95 days. Almost all (80%) of strong generations (>4 mln.ind.) were formed when the spawning was in 90-100 days before the bloom, and all (100%) weak generations were formed when the spawning was <90 or >100 days before the bloom.



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.

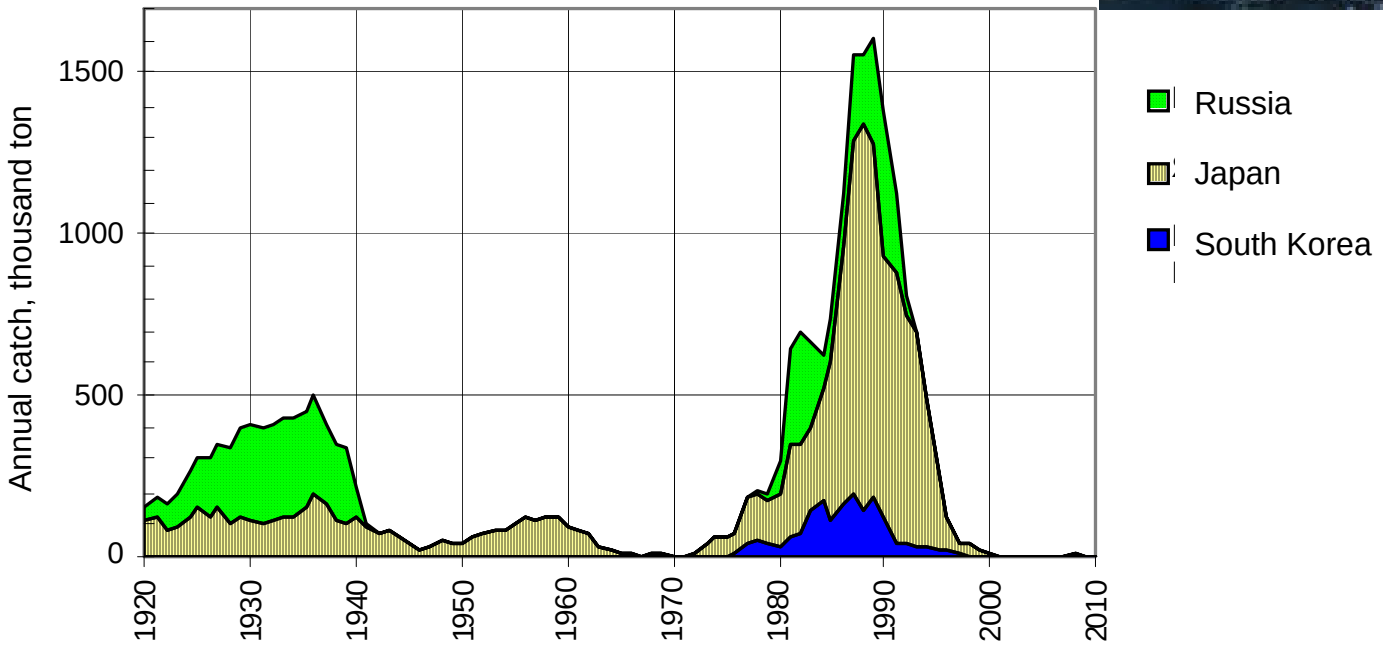
Parameters of this equation determined by its fitting to the data of observations:

T_R = 95 days;
Q = 0.53;
a = 11.4·10^6 specimens

Sardine: what is the catch dynamics?

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

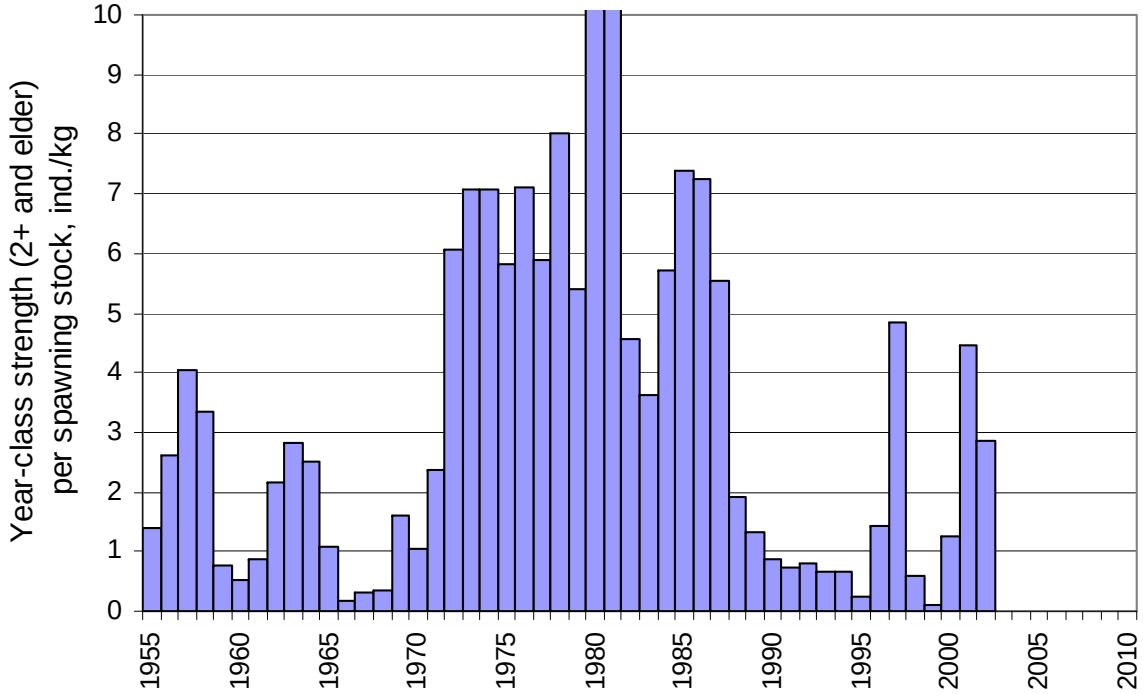
The last period of the sardine abundance was in 1970-1980s when its landing exceeded 5 mln t (1.6 mln.t in the Japan/East Sea). Since 2001, sardine is caught as a by-catch only.



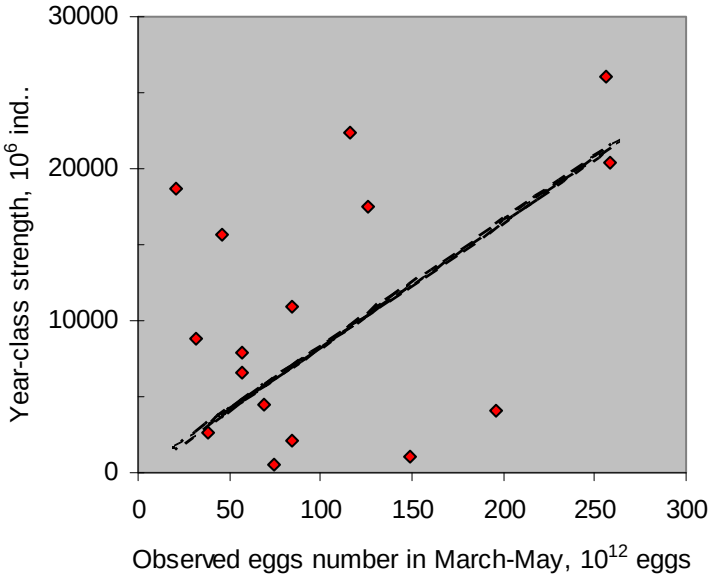
Annual catches of sardine in the Japan/East and East-China Seas by certain countries

Sardine: how to describe its reproductive success?

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 ind/kg that means successful reproduction) in 1971-1982 and 1984-1987.



*Quantitative parameter of sardine reproduction efficiency in the Japan/East Sea - the ratio **year-class strength / spawning stock*** [ind./kg]
(from the data published by Oshimo et al., 2009)

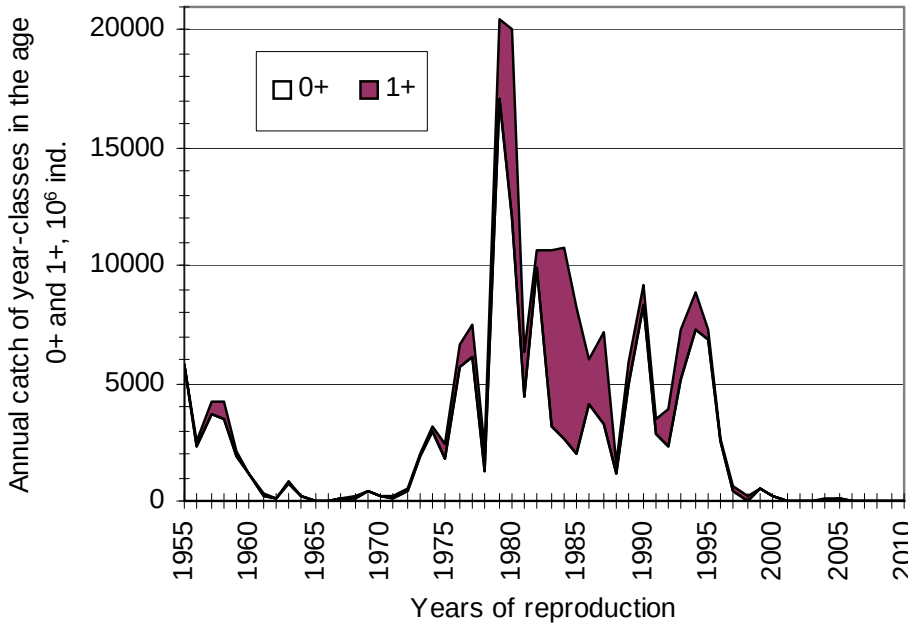


Dependence of the year-class strength of sardine (in the Japan/East and East-China Seas) on the number of sardine eggs counted in the Japan/East Sea in March-May of the years of reproduction (from the data published by Goto, 1998)

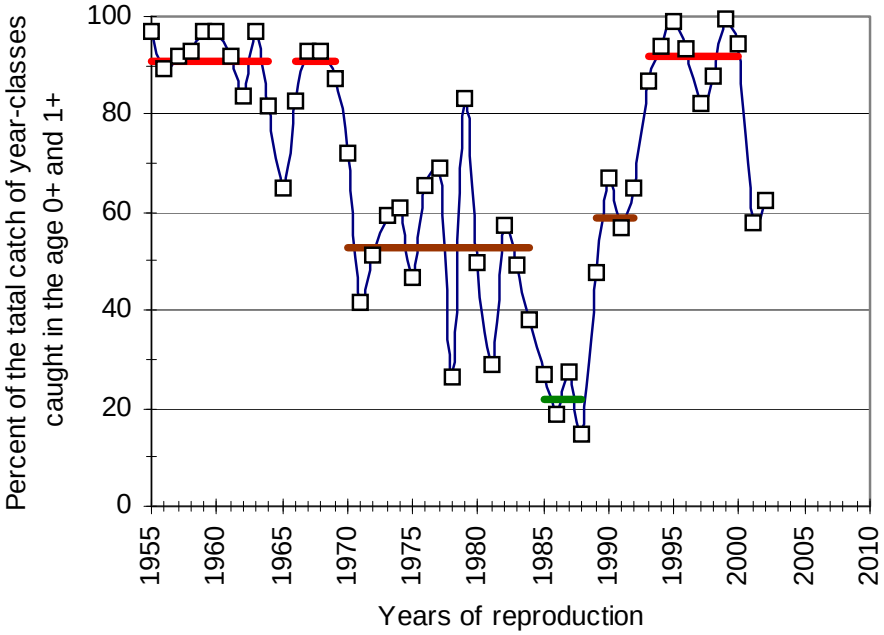
However, this parameter could be distorted by high catch of juveniles.

Sardine: how to describe its reproductive success?

Landings of the sardine larvae, YOY, and yearlings (ages 0+ and 1+) were very high in some years (80-99 % of total catches of the year-classes). Obviously, the strength of these year-classes does not reflect the reproduction success. On the contrary, in some other years the juveniles landings were relatively low (<30% of total catch) so had abnormally light effect on reproduction - the strength of these year-classes also does nor reflect the reproduction success. Both these periods were excluded from the analysis. Natural reasons of the sardine reproduction success were considered for the years with moderate fishery press onto its early stages.



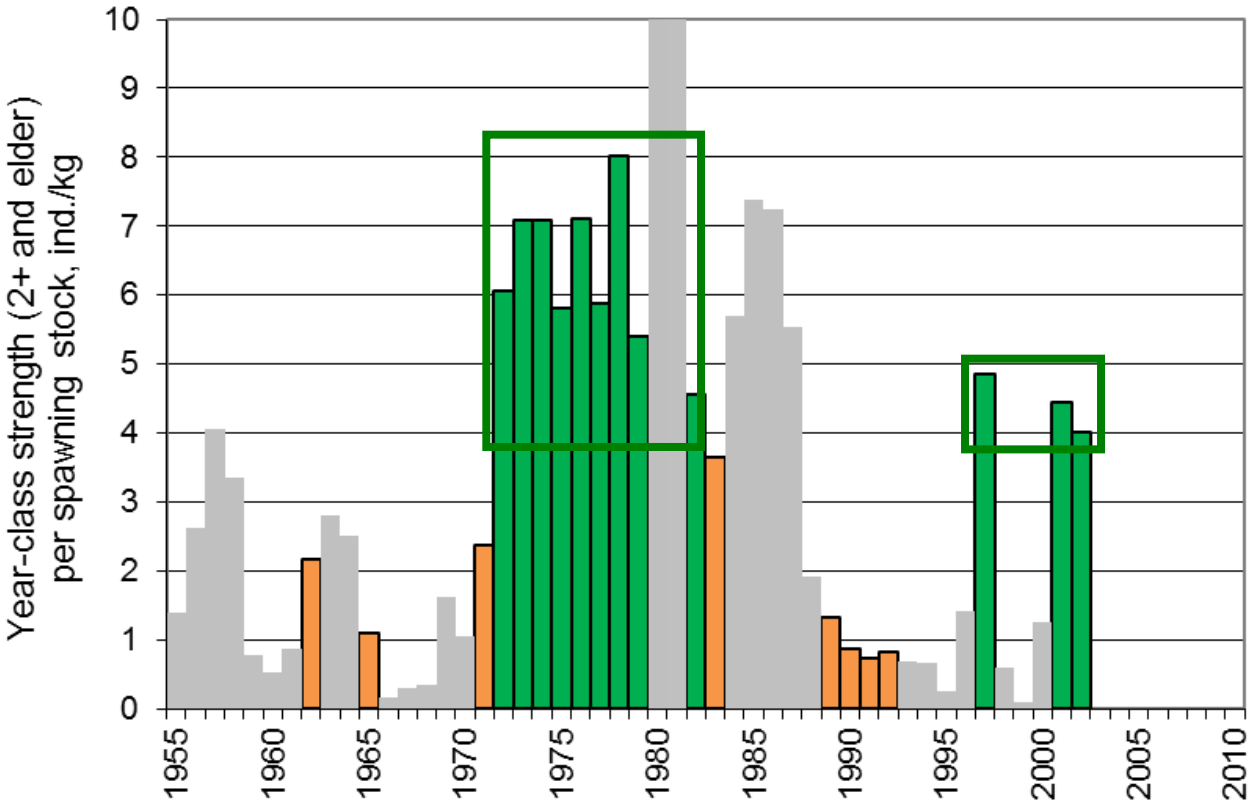
Japanese catches of larvae, YOY, and yearlings of sardine within the Japan/East and East-China Seas, by year-classes (from: Ohsimo et al., 2009)



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

Sardine: how to describe its reproductive success?

Taking into account only the years with moderate fishery press onto sardine juveniles, two periods of its successful reproduction (>4 ind./kg) could be found in the last half-century: in 1972-1982 and 1997-2002; in other years the reproduction was unsuccessful.



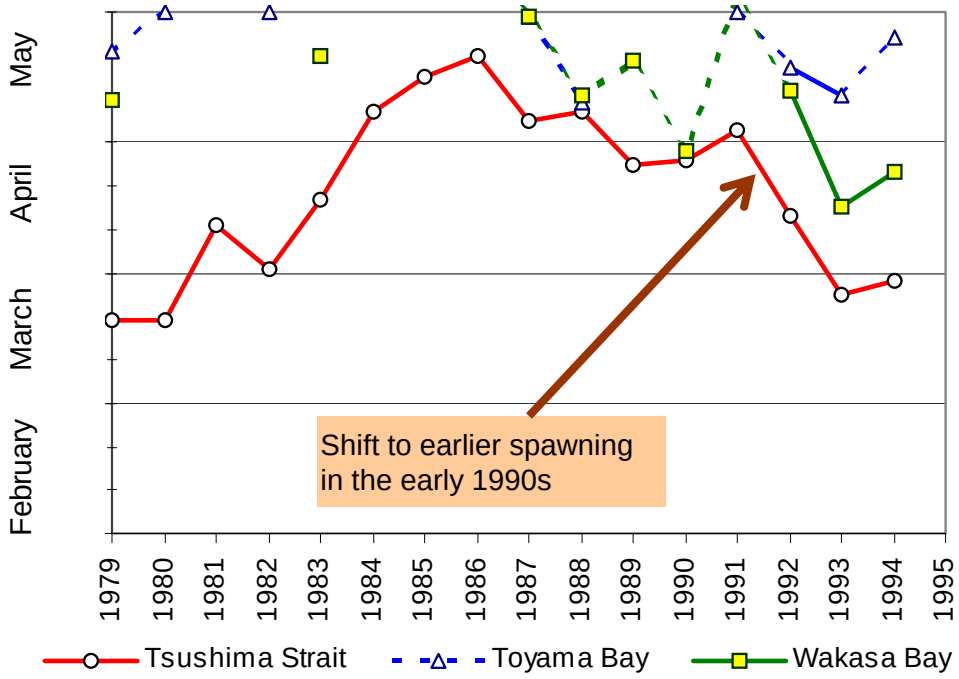
*Quantitative parameter of sardine reproduction efficiency in the Japan/East Sea - the ratio **year-class strength / spawning stock*** [ind./kg]
(from the data published by Oshimo et al., 2009)

Sardine: how does the timing of spawning change?

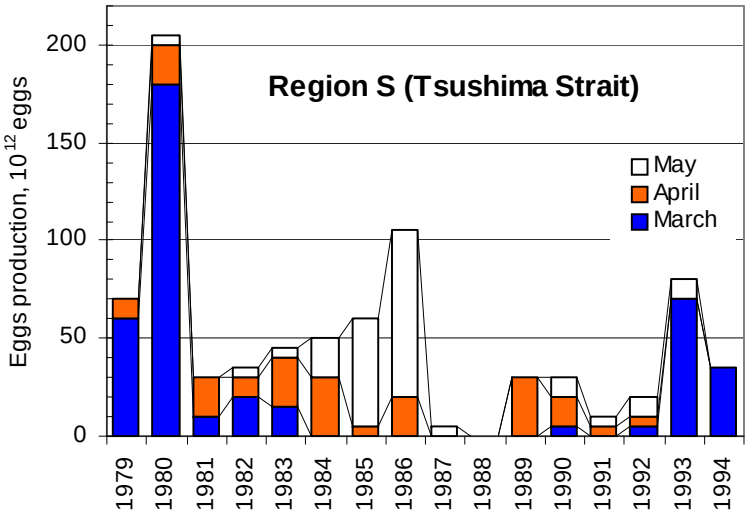
Sardine eggs production has a prominent year-to-year variation but was still very high even after the late 1980s, when the sardine stock decreased quickly.

Timing of the peak of spawning shifted to May in the early 1980s and back to March) in the early 1990s

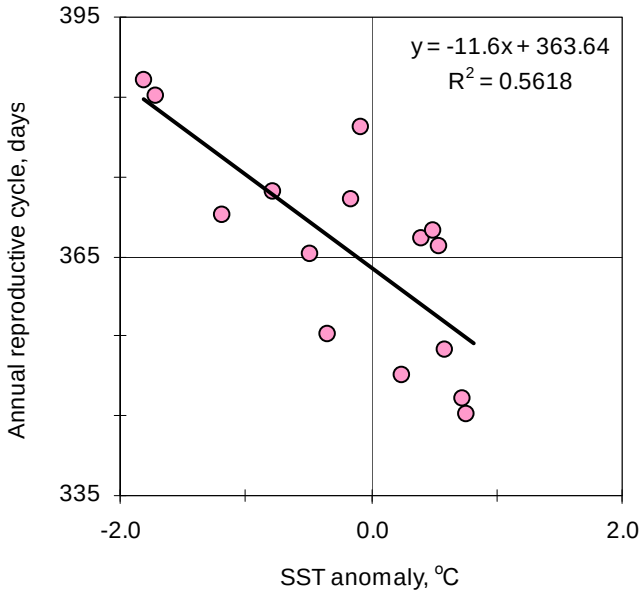
The dates of the spawning peak have negative dependence on winter SST in the area of spawning (r > 0.7)



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)



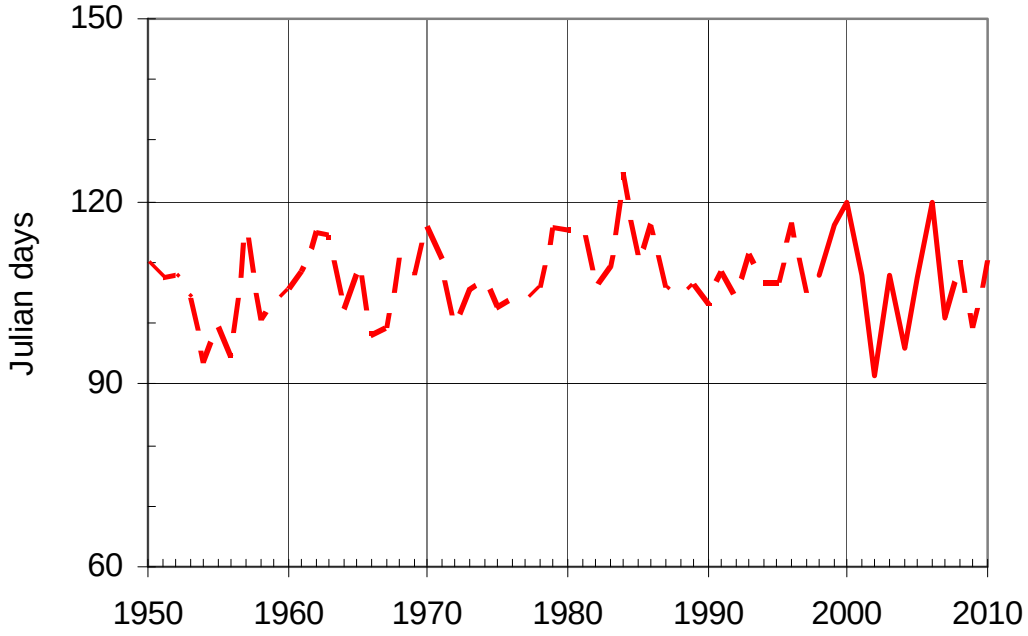
Annual estimations of the sardine eggs production in the main spawning grounds in the Japan/East Sea at the Tsushima Strait (from: Goto, 1998)



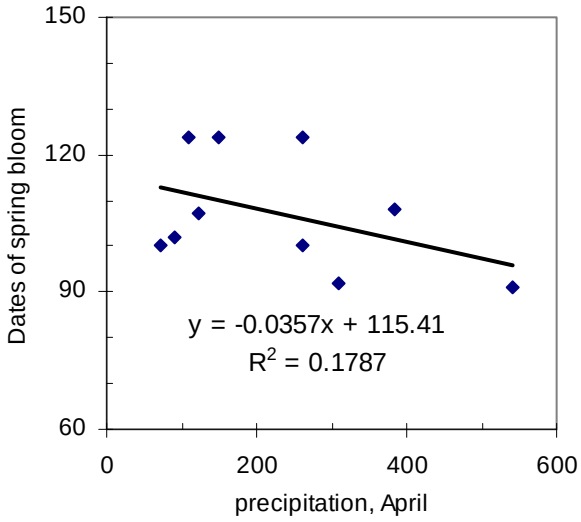
Dependence of the annual reproductive cycle length (from spawning to spawning) on winter SST for the main spawning ground of sardine in the Japan Sea

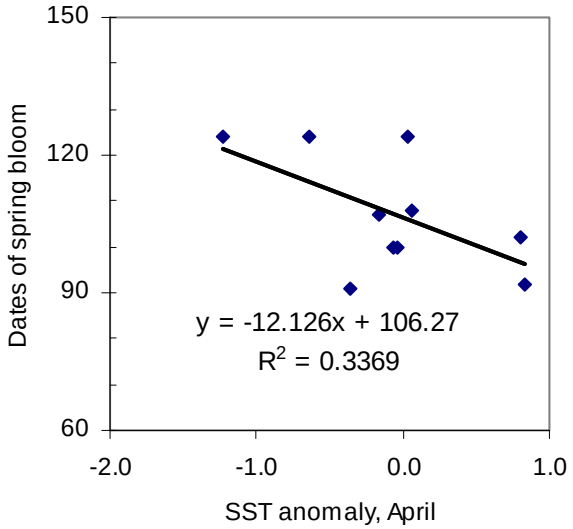
Sardine: how does the timing of spring bloom change?

Sardine larvae hatch in spring, during spring bloom of plankton and prey mainly on early stages of copepods. Timing of spring bloom in the sardine spawning grounds is determined from SeaWiFS observations; their variations for the times before the observations are reconstructed, as well. Generally, the timing of the peak of blooming in the main spawning grounds of sardine was 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)

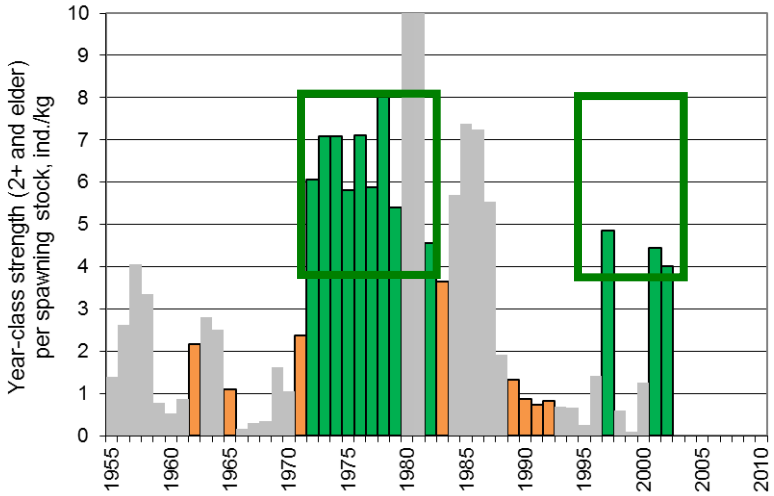




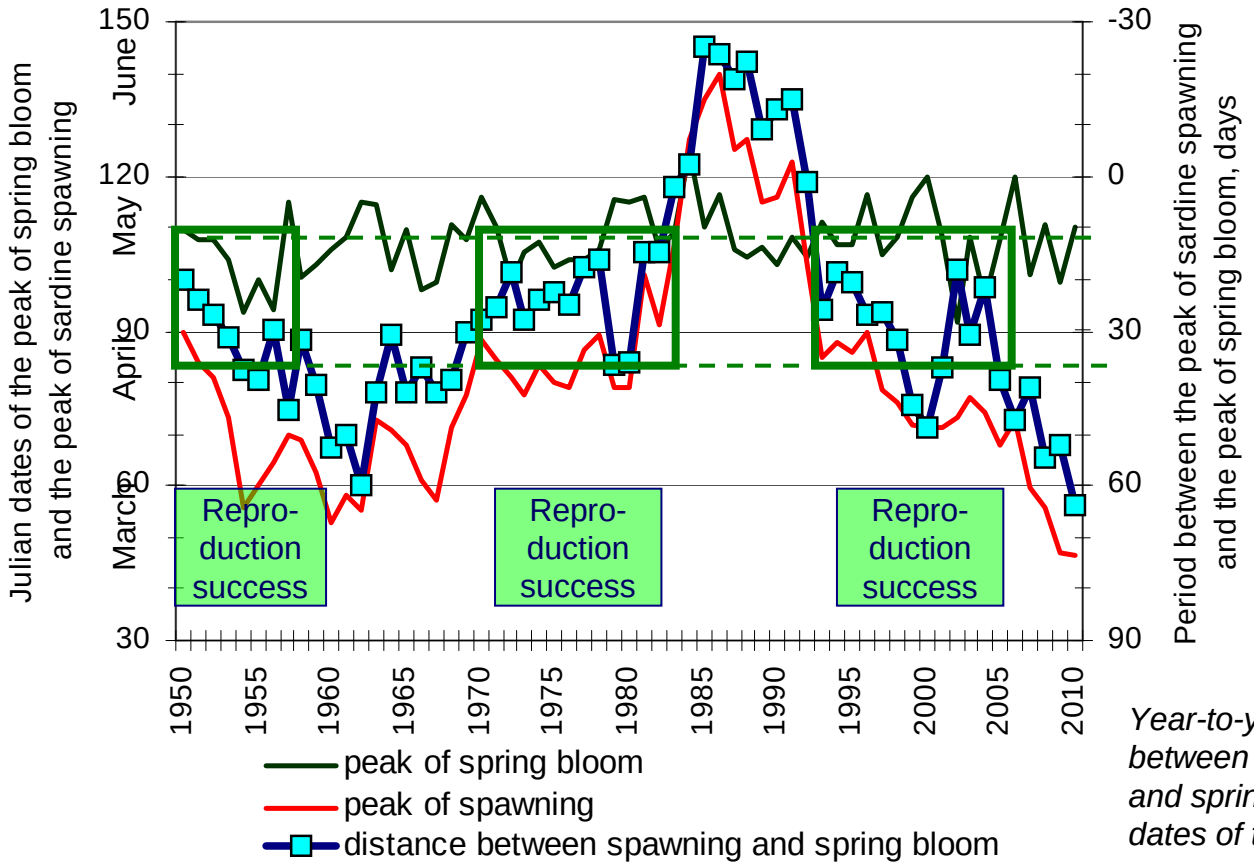
Dependence of the date of spring bloom peak on the main spawning grounds of sardine on SST and precipitation

Sardine: when was the match and when was the mismatch?

In the years with successful reproduction of sardine, the time interval between the spawning and spring bloom was 10-40 days. It was optimal in the 1970s and in the early 1950s and late 1990s – early 2000s. However, only slight increase of catch occurred in the latter periods because of extremely heavy fisheries press on juveniles. When the interval was shorter (as in 1980s) or longer (as in 1960s and nowadays) – the reproduction was unsuccessful.



Japanese sardine year-class strength per spawning stock in the Japan/East Sea. Periods of successful reproduction are shown

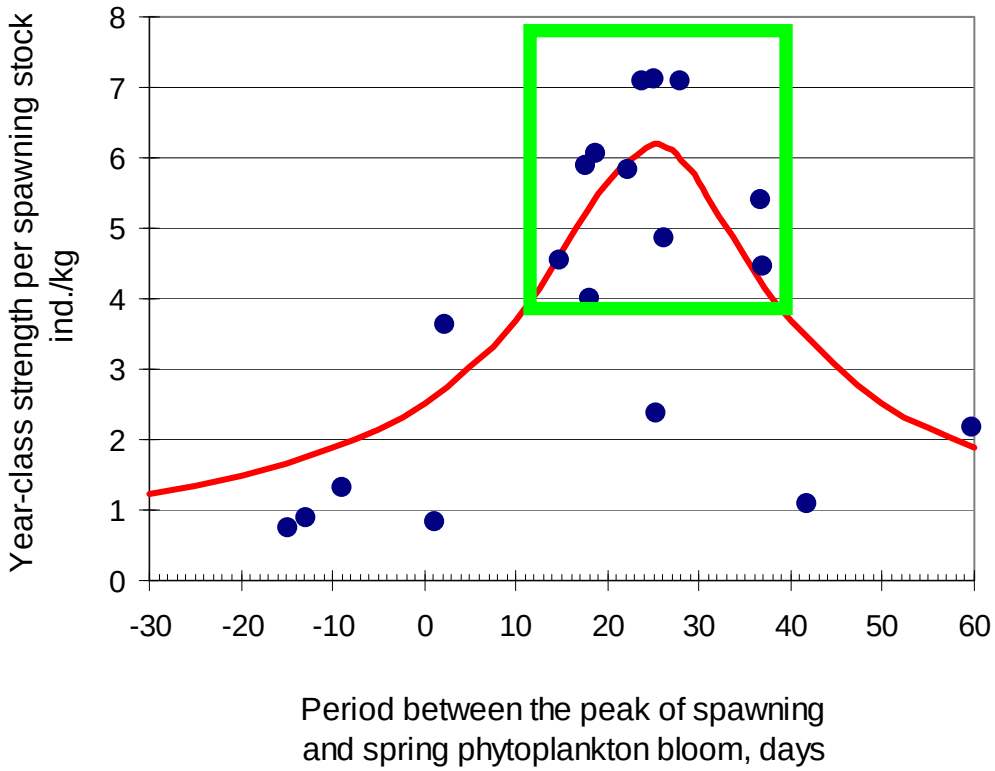


Year-to-year changes of the interval between the peaks of sardine spawning and spring bloom (thick blue line). The dates of the peaks are also shown

Sardine: does resonance work again?

Dependence of the sardine year-class strength on the time between spawning and blooming could be approximated by a resonance function, as well ($R^2 = 0.67$).

The optimal interval is determined as 25 days. All strong generations (>4 ind./kg) were formed when the spawning was in 10-40 days before the bloom, and 90% of weak generations were formed when the spawning was <10 or >40 days before the bloom.



Dependence of the ratio year-class strength per spawning stock for sardine 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.

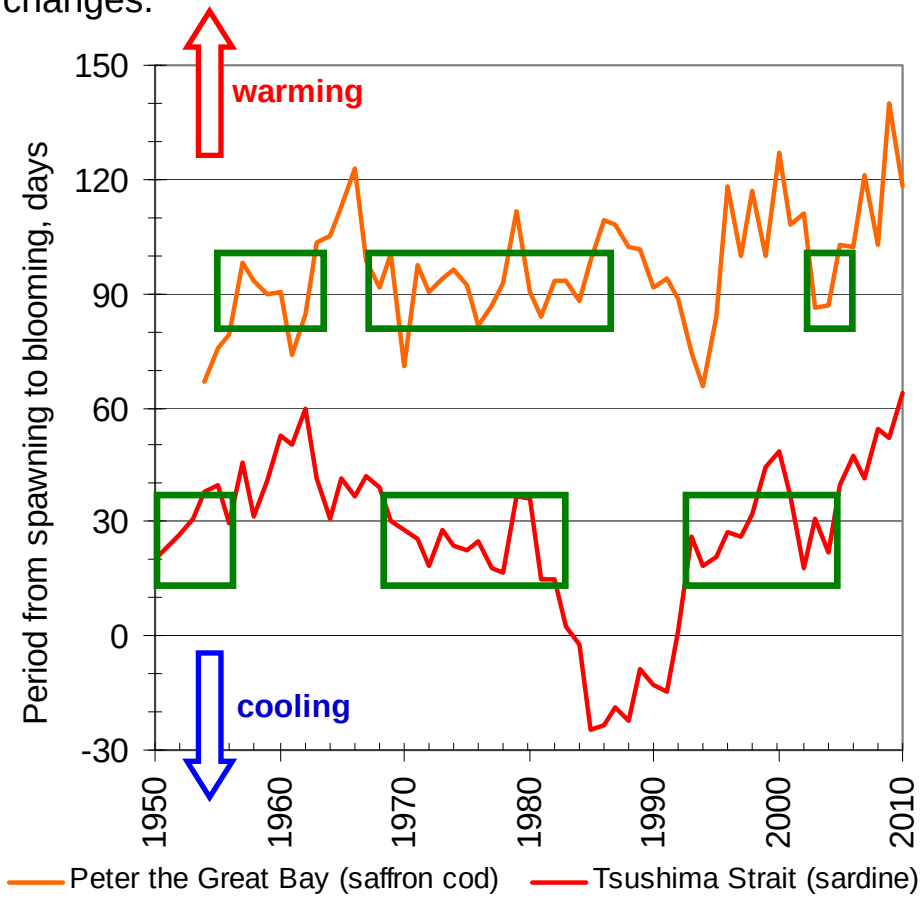
The sardine reproduction is successful and strong year-classes form in the years with T_i close to T_R that provides the best match of the larvae hatching with their prey abundance, but the years with extremely long and extremely short T_i are unfavorable for reproduction.

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

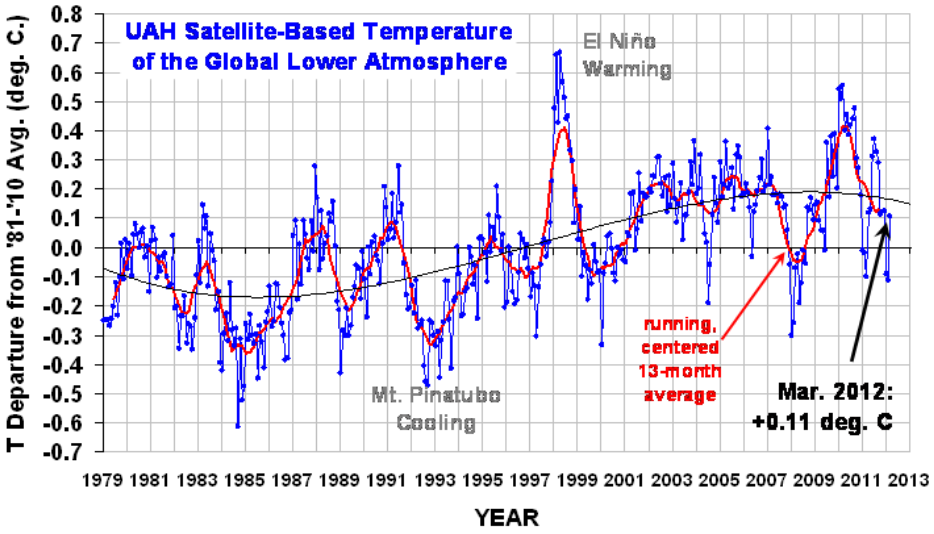
T_R = 25 days;
Q = 0.09;
a = 6.2 ind./kg

How does climate changes influence on saffron cod and japanese sardine reproduction?

Nether warming nor cooling itself is favorable for the saffron cod and sardine reproduction, but conditions of match or mismatch depend on these changes.



Length of period between spawning and blooming for saffron cod in Peter the Great Bay and for sardine at the Tsushima Strait



For example, cooling in the 1970-1980s was at first favorable for the sardine reproduction but after the coldest winters in the middle 1980s it spawned too late. So both tipping points in changes of the sardine abundance were reasoned by the process of cooling. Warming in the 1990s was favorable for sardine, but it did not use this chance because of overfishing.

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

Conclusions:

1. In the case of winter-spawning fish dynamics, tipping points bound a "window" of environmental conditions combination that provides match of their larvae hatching with the spring bloom that is necessary for their successful reproduction.

2. The match is conditioned mainly by the time of spawning that depends on water temperature in the period of maturing.

3. Reproduction success of saffron cod and japanese sardine has non-linear dependence on water temperature that could be described by resonance function. It has no direct dependence on climate warming or cooling.

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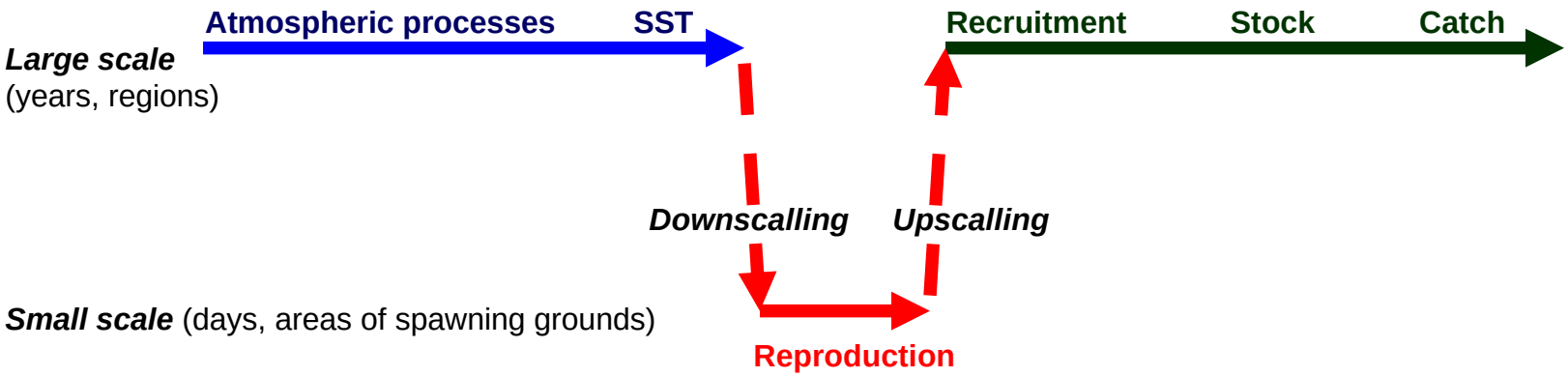

Data sources:

Index	Period	Brief description	Source
Catch of saffron cod	1942-2009	Annual commercial catch in Peter the Great Bay, mainly by hoop nets	Fishery 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/