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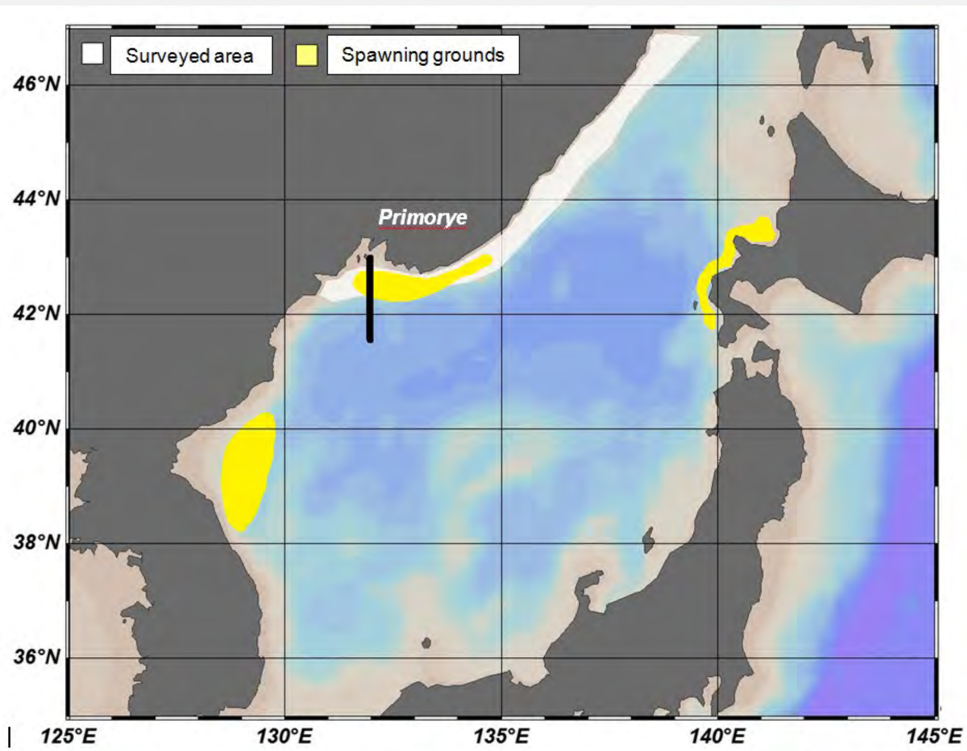
Dynamics of walleye pollock recruitment at Primorye (Japan Sea) under climate change

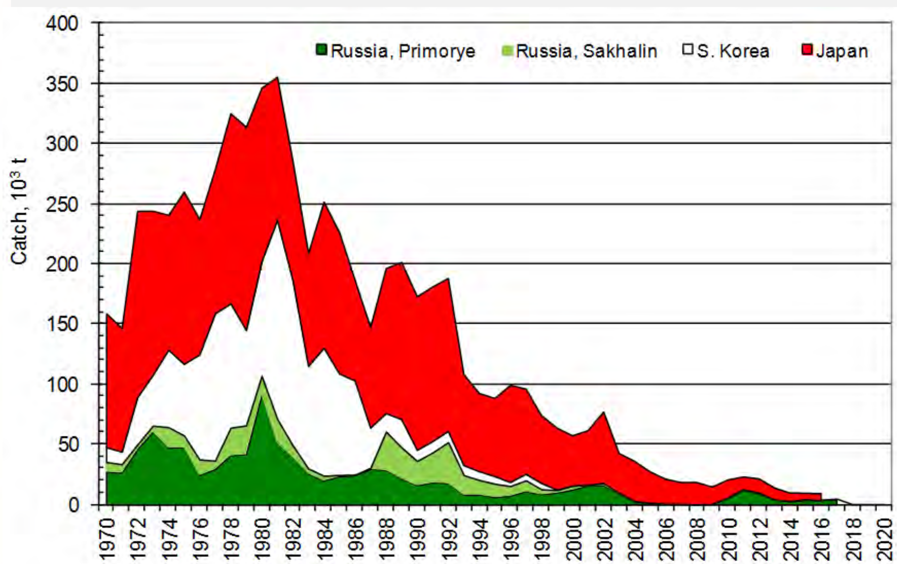
Preface

The main pollock populations in the Japan Sea are located in the East Korean (Chosonman) Bay, at Hokkaido Island and at Peter the Great Bay. The latter one is controlled by frequent surveys over the shelf of Primorye and oceanographic conditions are monitored at the standard section.

All pollock stocks have a tendency to decreasing recently. Annual caught in the S.Korean waters had lowered from $1.64 \cdot 10^6$ t in 1980s to 0.02-$0.06 \cdot 10^6$ t in 2000s, and the South Korean fishery had stopped. The population at Primorye coast had shrunk significantly since the 1980s, as well.



Scheme of the pollock spawning grounds in the Japan Sea. White area – quasi-annual bottom trawl surveys since 1973; thick line – standard oceanographic section since 1926



Walleye pollock annual landings in the Japan Sea, by country

Goals

- to understand reasons and mechanisms of the negative tendency in the pollock stock dynamics under environmental and intra-population factors.

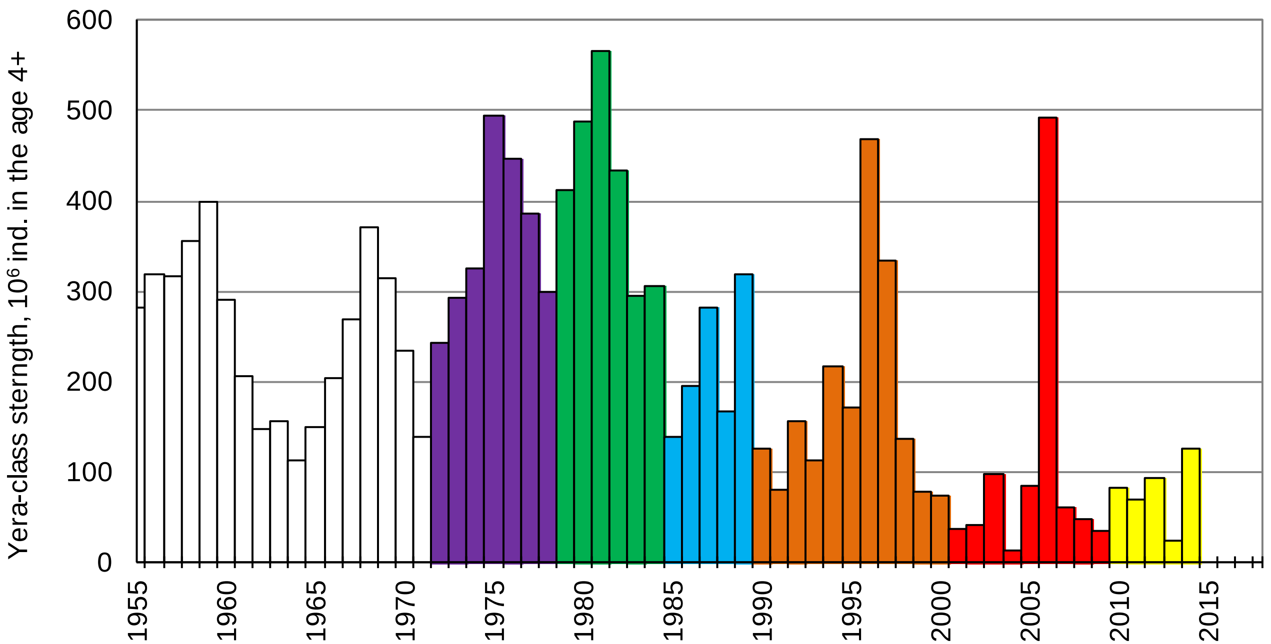
- to predict fluctuations of the pollock stock at Primorye in the nearest future, as the base for its fishery forecasting.

Data. Fish accounts

The pollock stock fluctuations at the coast of Primorye are conditioned mainly by its year-classes dynamics. Number of the fish at age 4+ (the most abundant age group in trawl catches) is calculated as the year-class strength and used as an index of reproduction success.

The calculation is made directly from the data of bottom trawl accounts or by extrapolation of elder groups number to the age 4+ using exponential function of the year-class abundance decreasing with age. The numbers for the period till 1972, when the southern part of the area was surveyed only, were restored from the accounts for Peter the Great Bay.

The year-class strength dynamics is distinguished by easy visible “waves” of successful reproduction with 1-2 strong year-classes and several weak year-classes between them.



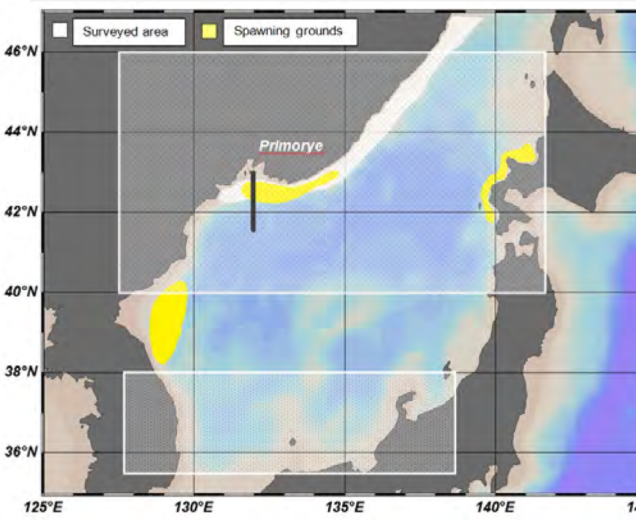
Dynamics of the year-class strength for walleye pollock at Primorye coast (northwestern Japan Sea). «Waves» of the recruitment fluctuations are shown by different colors, the classes restored on the data of partial surveys in Peter the Great Bay are unpainted

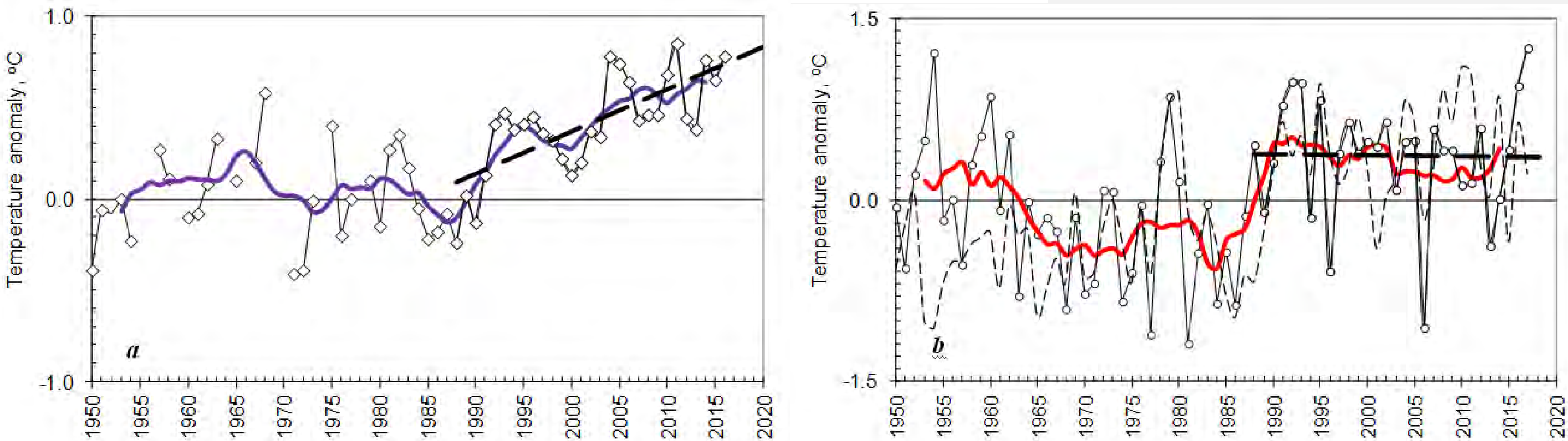
Data. Water temperature records

Data on water temperature at the sea surface and in the upper part of the intermediate layer (below the seasonal thermocline to 200 m depth) are used as indices of general thermal conditions in the Japan Sea and the thermal conditions of the pollock habitat.

The SST data for 0.5º-squares and 10-days intervals were received from JMA within NEAR-GOOS project; the anomalies were averaged for the southern (35-38ºN) and northern (40-46ºN) parts of the Sea for summer and winter seasons.

The upper intermediate layer temperature was measured at the standard section that was conducted by TINRO since 1926. The modal values for the layer from seasonal thermo-cline to 200 m were subjected to seasonal decomposition and the anomalies were averaged for summer and winter seasons.

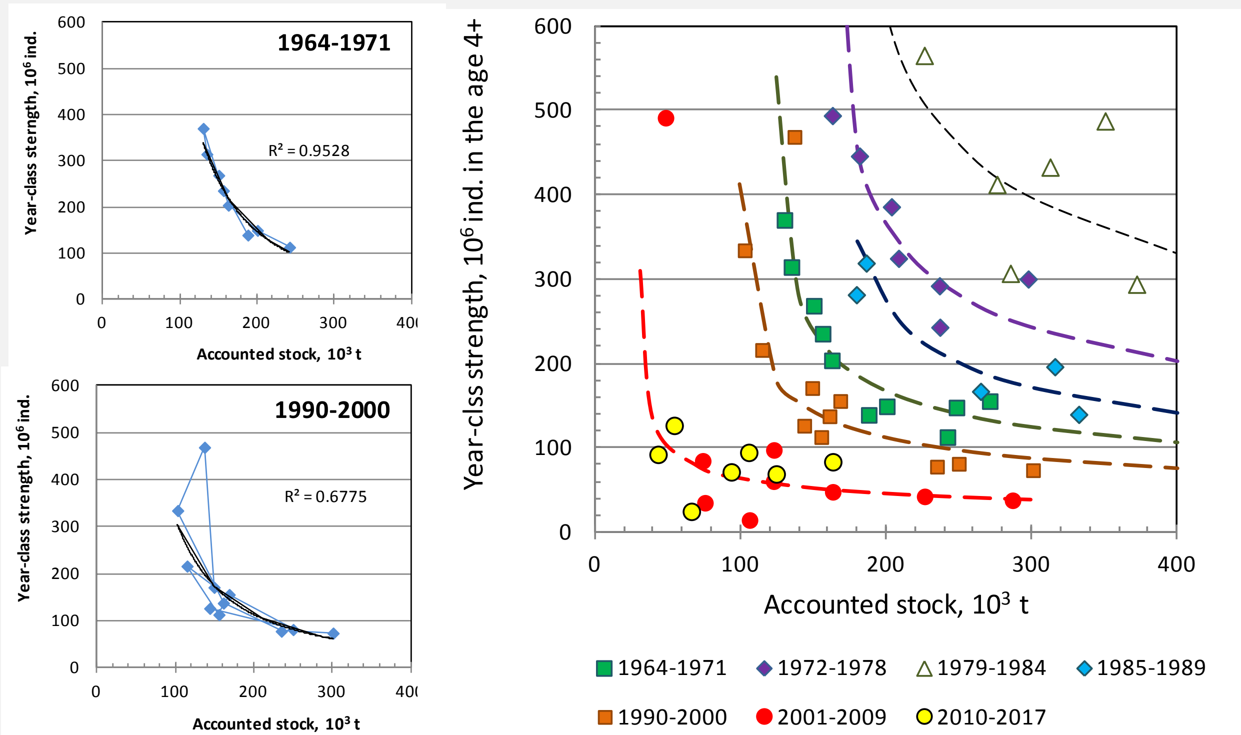




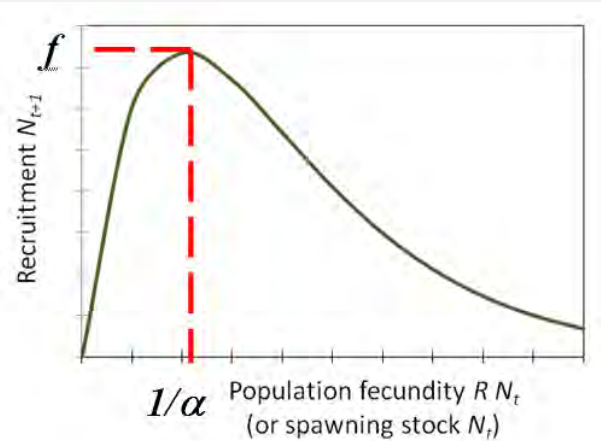
Mean summer anomalies of temperature in the upper intermediate layer at the continental slope (a) and mean winter SST anomalies in the southern (solid line) and northern (dotted line) Japan Sea (b). Running 7-year smoothing and modern linear trends are shown

Intra-population aspects of the stock fluctuation

For the Primorye pollock, there is no any statistically significant relationship between the year-class strength and spawning stock, that is typical for walleye pollock. However, a prominent cyclicity (“waves”) suggests that there is a self-oscillation in the population caused by periodic overloading of its optimal abundance. Considering the “waves” of recruitment separately, the statistically significant (> 0.95) negative power relationships with the coefficients of determination 0.65-0.95 are revealed for each “wave”. This negative dependence corresponds to the descending part of the Ricker curve , but its ascending part is absent for all “waves”, that means that carrying capacity of the pollock biotope is permanently overloaded in the modern times.



Examples of the pollock year-classes dependence on its stock for certain “waves” of their dynamics and general dependence for 1964-2017



Scheme of Ricker curve

$N_{t+1} = R\ N_t \exp(1 – aN_t)$,

illustrating theoretical dependence of recruitment (year-class strength) on spawning stock

1/a – carrying capacity

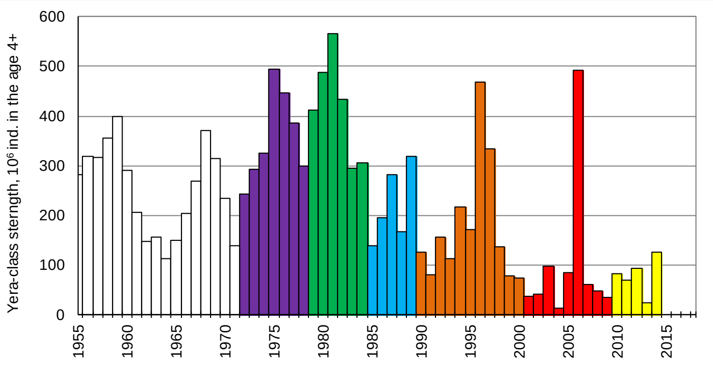
f – reproductive potential

Intra-population aspects of the stock fluctuation

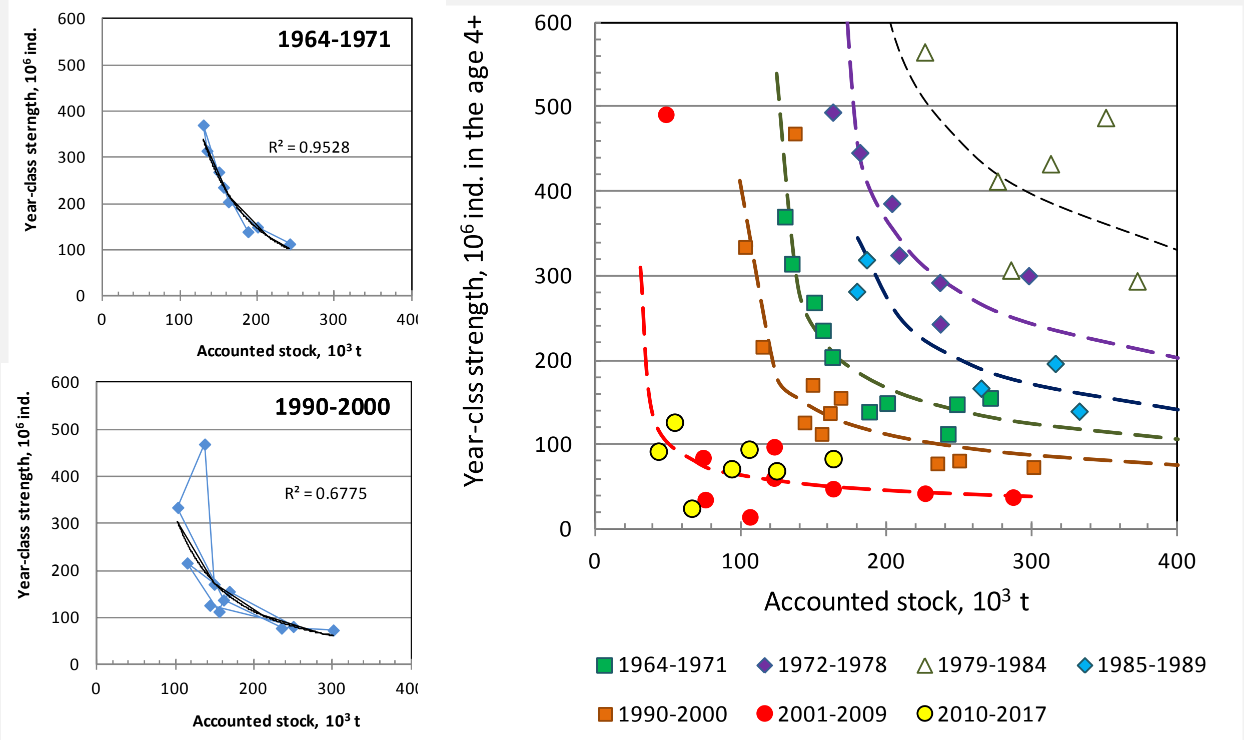
In this case of permanently negative dependence, the power function is closer to the real data and can be interpreted easier:

$$N = f\,(S - v)^{-b}$$

where N – year-class strength, f – reproductive potential corresponding to carrying capacity, S – spawning stock, v – carrying capacity of the biotope, b – empirical coefficient.



Using this equation and accounted values of year-class strength and stock, parameters f and v could be estimated for each "wave".



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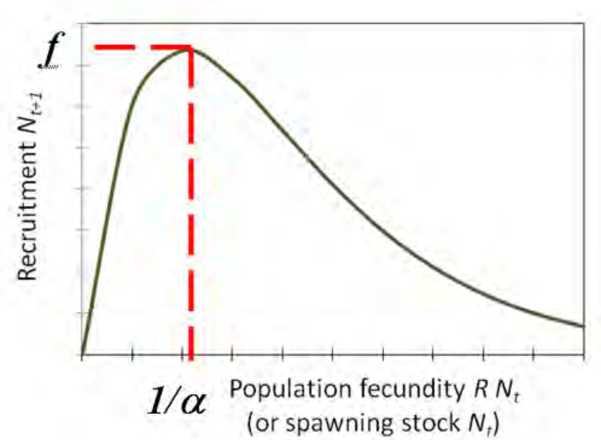

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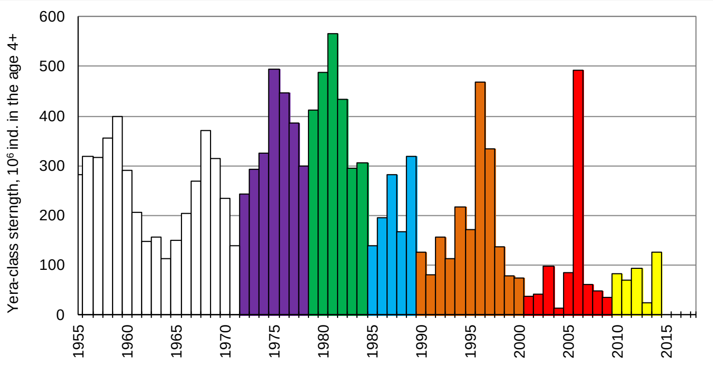
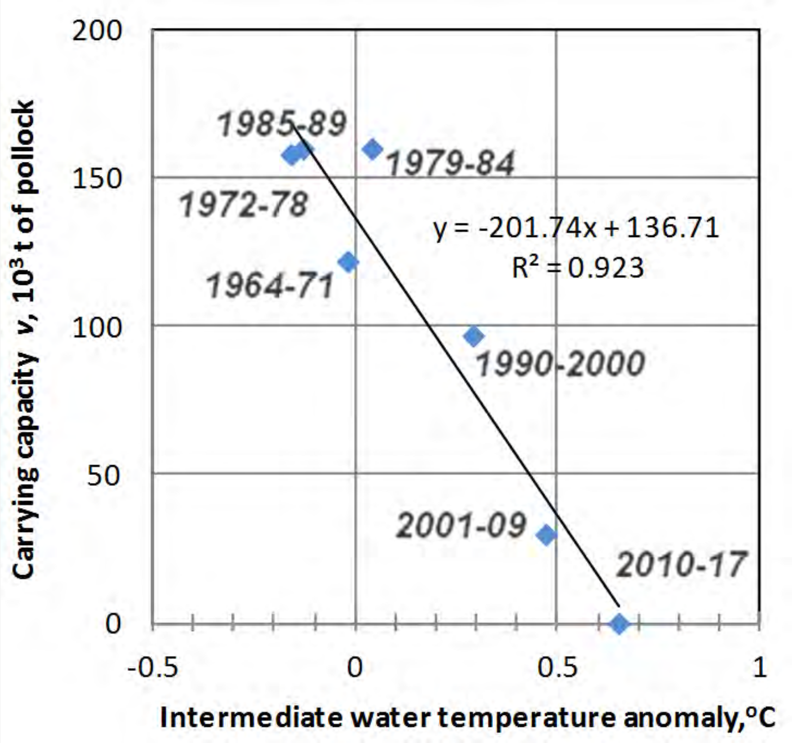
Environmental aspects of the stock fluctuation



The parameters *f* and *v* (dependent on each other) change from "wave" to "wave" that reflects the environments changes. Generally, both carrying capacity and reproductive potential go down in the studying period that corresponds to a warming tendency observed in all layers of the Japan Sea. The best correlation with these parameters dynamics is found for the intermediate layer temperature – the pollock habitat.

Note that the recruitment dynamics within the last "wave" of 2010-17 corresponds to zero level of the carrying capacity that means that the ecosystem had changed so much that any number of pollock overloads the biotope now.



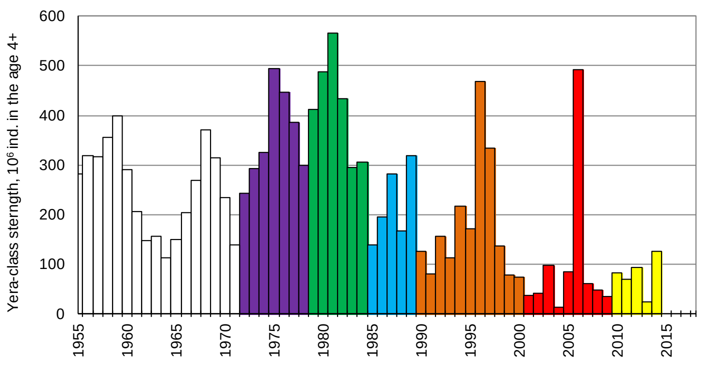
Dependence of carrying capacity v on mean summer anomaly of water temperature in the upper intermediate layer, by cycles of the pollock recruitment variations

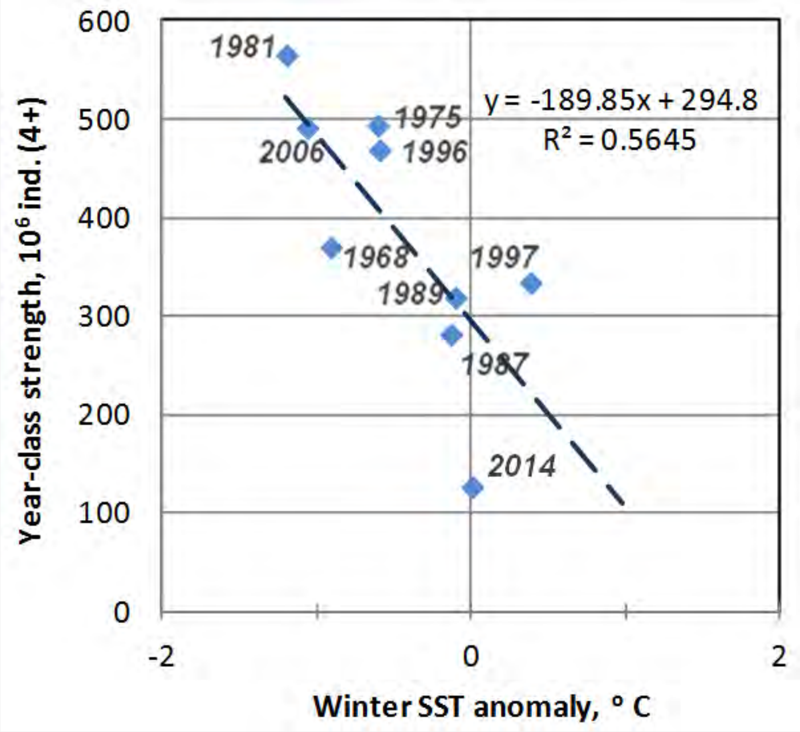
Environmental aspects of the stock fluctuation

Strong year-classes appear once or twice in each "wave", when the spawning stock is low. There is found that the strongest year-classes are formed in the years with low SST in winter, both in the northern and southern parts of the Japan Sea.

This negative dependence is possibly related with "match/mismatch effect" known for some species spawning in winter-spring, as japanese sardine or saffron cod: late timing of their spawning is better for reproduction in condition of warming environments.

However, this negative relationship is not typical for the main populations of walleye pollock in the Okhotsk and Bering Seas





Dependence of the strong year-classes abundance on mean winter SST anomalies in the southern Japan Sea

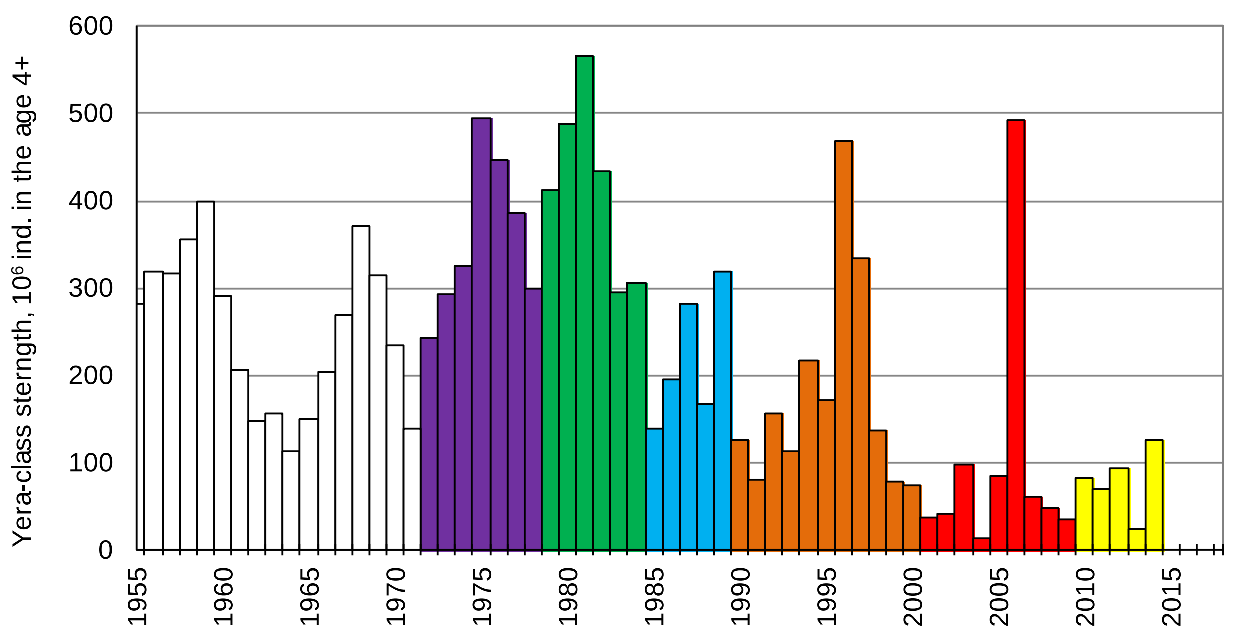
Pollock stock fluctuations: interpretation

Each “wave” of pollock reproduction at Primorye starts from 1-2 strong year-classes . Their strength depends on winter SST (the colder, the better).

In succeeding years of a “wave”, success of reproduction is regulated by intra-population factors and depends on the stock (the lower, the better). Length of the “waves” is determined by the time of strong year-classes domination, their temporal scale corresponds to the life span of pollock (9 years).

Factual length of “waves” is very various (5-11 years). Each “wave” ends and new strong year-classes appear when the previous ones are eliminated enough. If the carrying capacity is high, rather slight elimination is enough, so the “waves” are short. If the carrying capacity is low – almost total elimination of previous strong classes is necessary, so new “wave” comes in longer times.

So far as the carrying capacity depends on the Intermediate water temperature, the “waves” of reproduction are shorter and strong year-classes appear frequently in colder conditions (as in the 1970-1980s), but long “waves” with seldom strong classes are typical for modern environments.



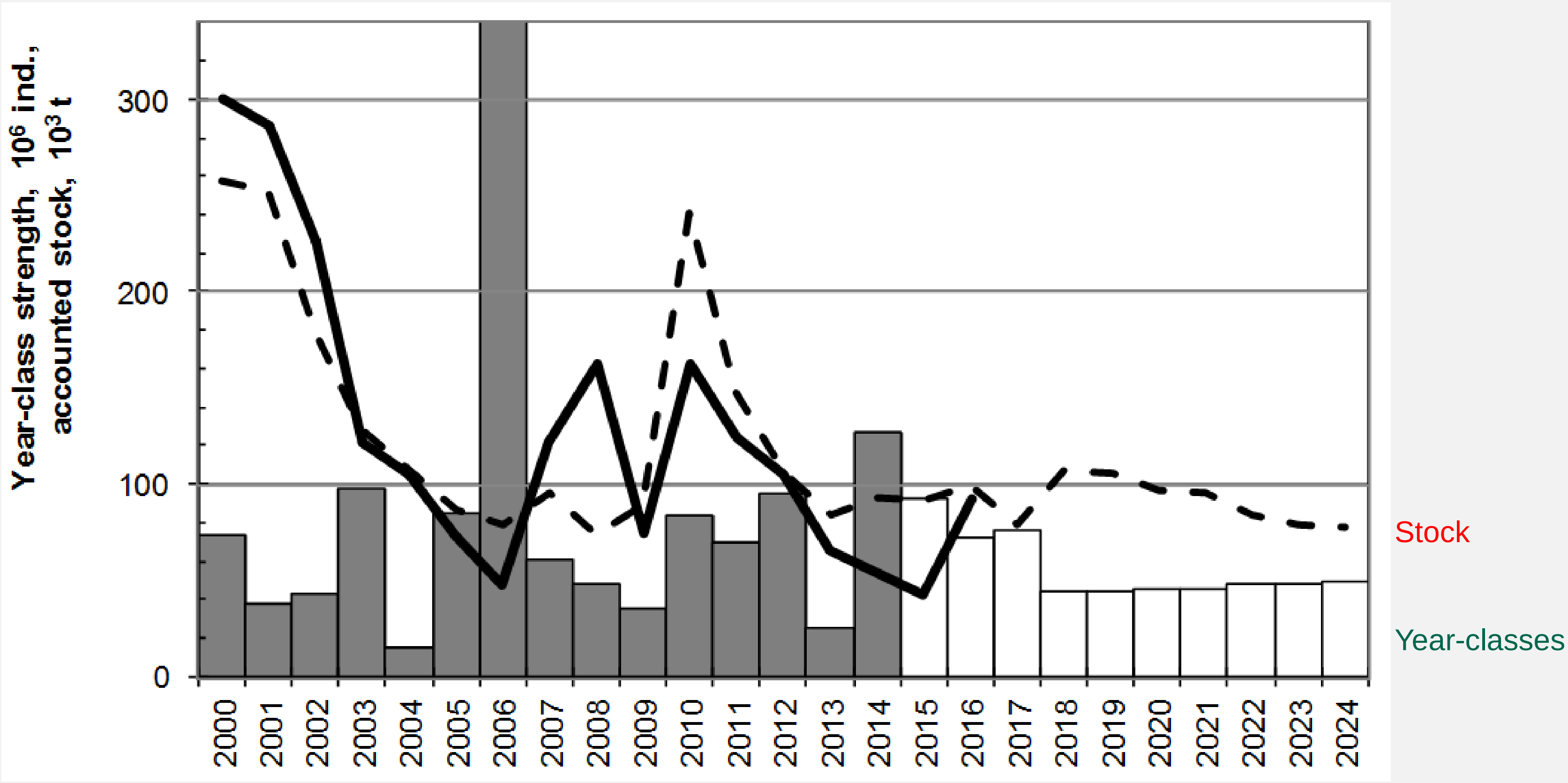
Dynamics of the year-class strength for walleye pollock at Primorye .
«Waves» of the recruitment fluctuations are shown by different colors

Forecasting of the Primorye pollock stock

Using the model $N = f\,(S - v)^{-b}$ and f , v dependence on environmental conditions, the year-classes strength could be forecasted for the nearest future.

Summarizing the year-classes, taking into account their annual mortality ($S_i = \sum_{j=0}^{10}[w \cdot N_{i+j-4} \cdot (1-m)^j]$) the pollock stock change is predicted till 2014. Its stabilizing on a a low level is expected, because the carrying capacity of this biotope for pollock will not change, so far as it cannot be below zero.

N – year-class strength
w – individual weight
m – annual mortality



Recent changes of the year-class strength (bars, real data till 2014, then forecast) and stock (real data – solid line, forecast – dotted line) for Primorye pollock

Conclusions

1. Carrying capacity of the Primorye biotope for walleye pollock is permanently overloaded during the last several decades that determines stable negative relationship between its spawning stock and recruitment.

2. Carrying capacity for the Primorye pollock and reproductive potential of this population change in dependence on environments, in particular on temperature of the upper Intermediate layer where the pollock dwells: the lower the temperature, the larger the carrying capacity and the potential. Mechanism of this relationship is not clear but reconstructions of the entire ecosystem are supposed.

3. Cyclic oscillations develop in the system "stock-recruitment" in the process of the pollock population adaptation to changes of the carrying capacity. Once in each cycle, in the years with minimal stock, 1-2 strong year-classes appear, in other years the high stock prevent the strong year-classes. Frequency of the strong year-classes appearance increases with large carrying capacity and decreases with its low level.

4. Abundance of the strong year-classes depends on thermal conditions in preceding winter: the lower SST, the stronger the year-class. Possible mechanism of this relationship is match/mismatch of the larvae hatching with the spring plankton bloom.

5. Thermal conditions of the Japan Sea in the last decades and in the forecasted future are characterized by warming in all areas and layers that causes lowering of the carrying capacity for the pollock, so unfavorable for its reproduction.

6. New "wave" of reproduction begins in 2018; short rising of the Primorye pollock stock is expected in 2018-2019 on the base of the strong year-class of 2014, then the stock will decrease again. The stock oscillations will possibly attenuate in the 2020s on a very low level because of lowering of the carrying capacity to zero. Recovering of the Primorye population of pollock to conditions of its high stock typical for 1970-1980s is impossible in modern environmental conditions