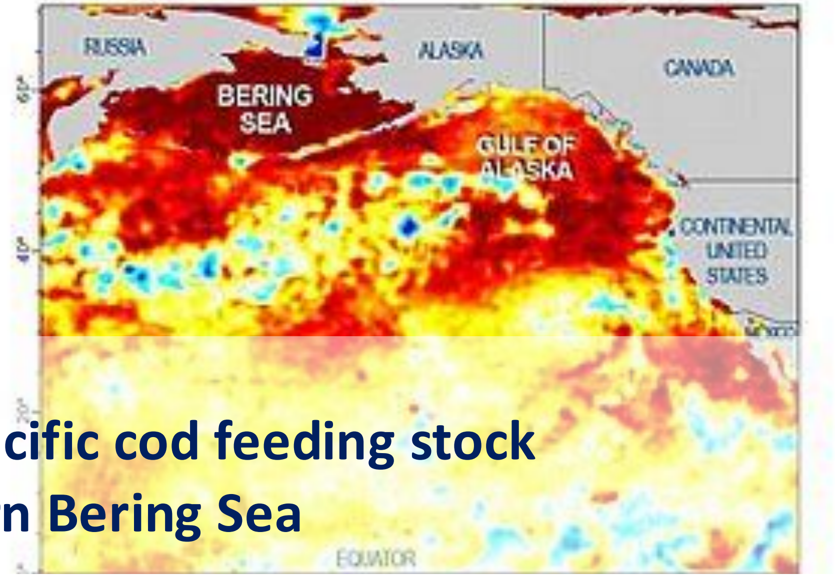
S12 FIS/BIO Topic Session
Understanding the linkages between forage species and top predators and how they may affect resilience in North Pacific Ecosystems



On recent increase of the pacific cod feeding stock in the northwestern Bering Sea

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Goal: to determine mechanisms of climate change influence on the cod fishery in Russian waters of northern Bering Sea

1. Instability of the cod fishery in Russian waters of northern Bering Sea

2. Recent environmental changes in the Bering Sea: their nature and consequences for the marine ecosystem

3. Conceptual model of climate change influence on the feeding stock of pacific cod in the northwestern Bering Sea and the Russian fishery of cod

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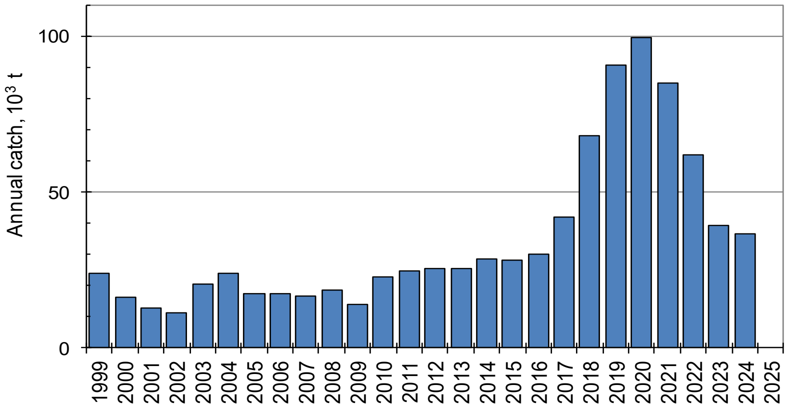
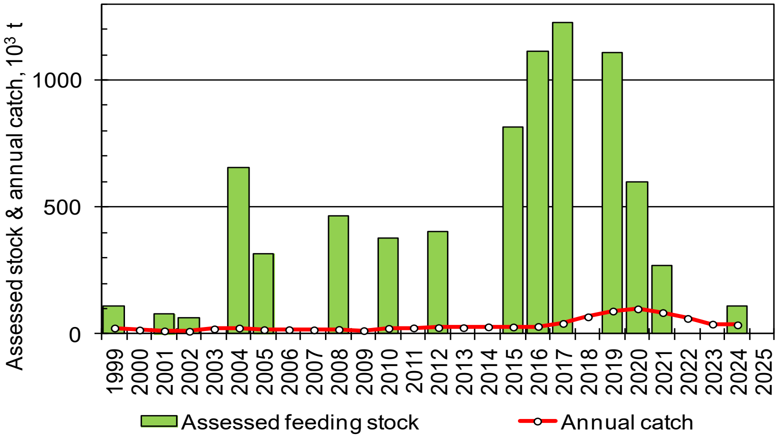
Instability of the Russian cod fishery

Dynamics of annual catch of pacific cod in the Bering Sea by Russian fleet is distinguished by fluctuations caused by sharp year-to-year changes of the stock feeding in summer-fall in the northwestern Bering Sea, that is unusual for long-living species

Because of this instability, the cod stock is exploited irrationally, values of the total allowed catch (TAC) are not optimal – insignificantly small portion of the stock was landed in some years (< 3% in 2016), whereas about ½ of the stock was landed in other years (in early 2020s). Obviously, the annual catch dynamics lags behind the stock changes. For example, the catch increasing started in 2017, when the stock had reached its maximum, but the catch achieved its maximum in 2020, when the stock already decreased. This lag is caused by the fishery regulation with TAC value calculated with the models which assimilated the data of previous years but not a current year. As the result, the undercatch of cod happened in the late 2010s and danger of cod overfishing was averted by emergency measures in the early 2020s.



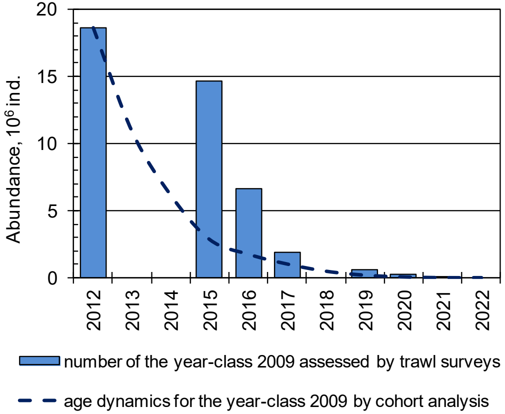
Annual catch of pacific cod in the Bering Sea by Russia



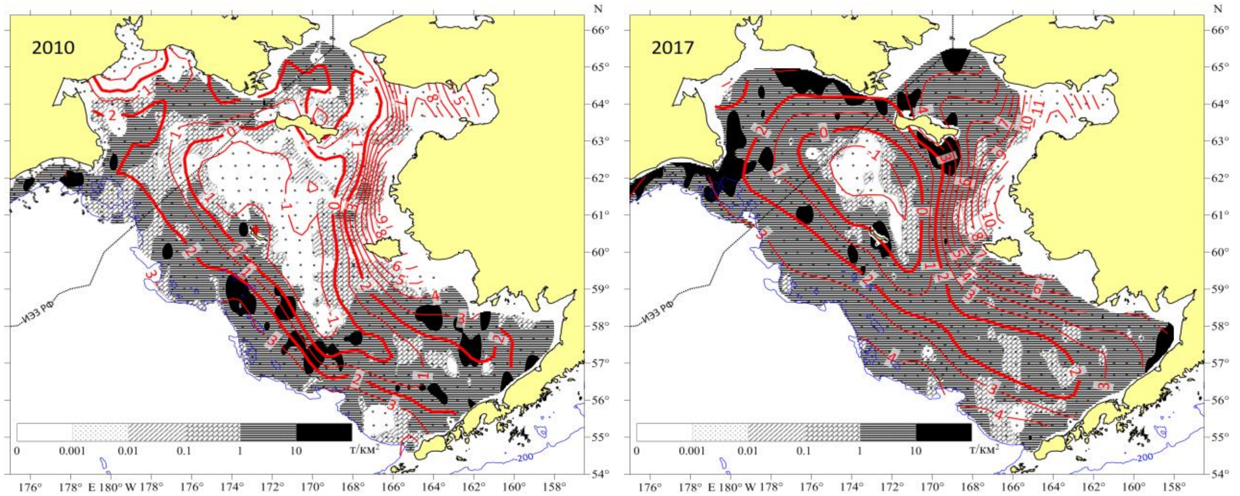
Feeding stock of cod assessed in the northwestern Bering Sea by trawl surveys relative to annual catch of cod by Russia

Instability of the Russian cod fishery

The stock of cod in the northwestern Bering Sea depends on abundant but irregular migrations of this species from the southeastern Bering Sea to the north for feeding. In the mixed feeding stock in Russian waters, the natural size composition of fish with age-by-age abundance decrease is strongly distorted because of the migrants input presented mostly by 4-7-year olds. The portion of migrants in the years of trawl surveys is determined for each year-class as a residual of the assessed abundance from the number of local population predicted by cohort analysis. This portion fluctuated from 72 to 94% that means that 6-48% of the southeastern population migrated annually from the US waters to the Russian waters for feeding.



Number of fish belonged to the year-class 2009 in the northwestern Bering Sea assessed by trawl surveys (bars) and predicted with cohort analysis (dotted line)



Examples of pacific cod distribution in the Bering Sea by the data of trawl surveys in summer of 2010 and 2017.

Dots indicate sites of trawling; isolines, water temperature at the sea bottom, °C

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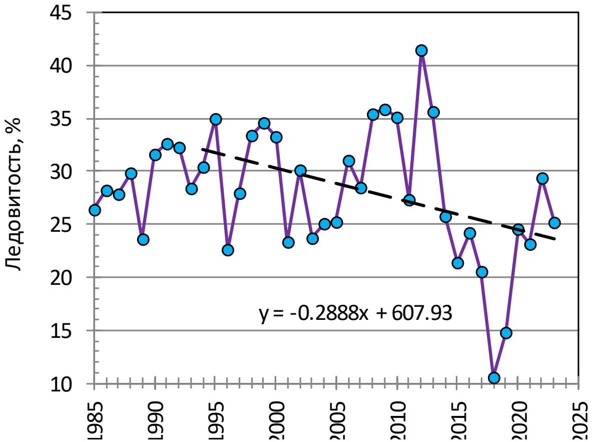
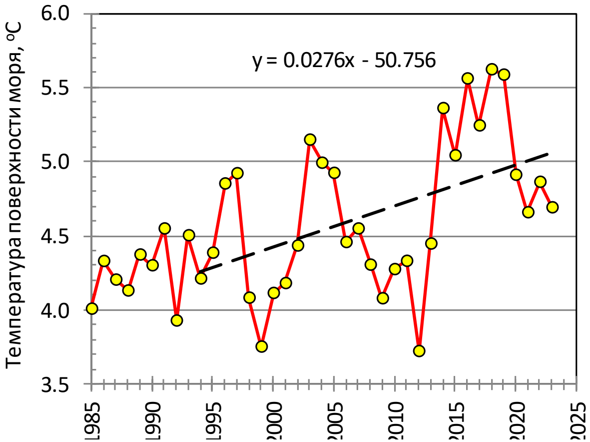
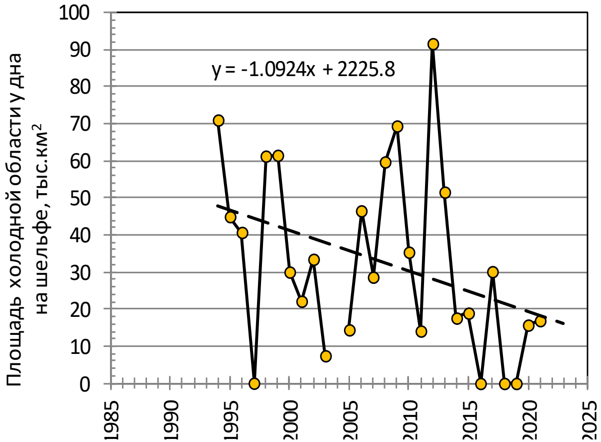
Recent environmental changes

The cod migrations occur on the background of fast climate changes in the North Pacific. Particularly in the Bering Sea, dynamics of all environmental parameters is determined by winter processes, generally explained by the ice cover. That's why all the main environmental indices have here the same tendency – to warming, and similar cyclic dynamics.
The most extreme warming happened here in 2016-2019, and relaxation after this "heat wave" is observed recently.







Interannual dynamics of the main environmental indices for thermal regime of Bering Sea:

Average ice-cover in January-April, %

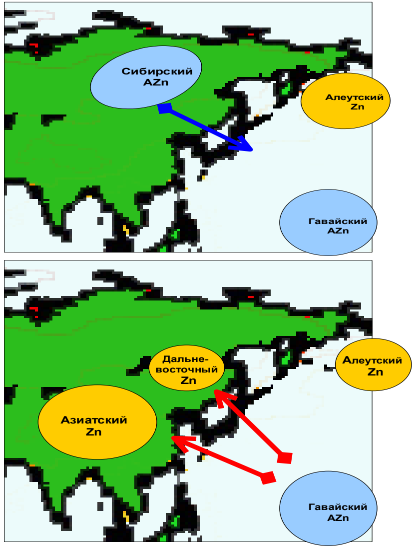
Mean annual SST, °C

Area of the cold (< 0°C) water pool at the bottom on shelf in summer (within EEZ of Russia)

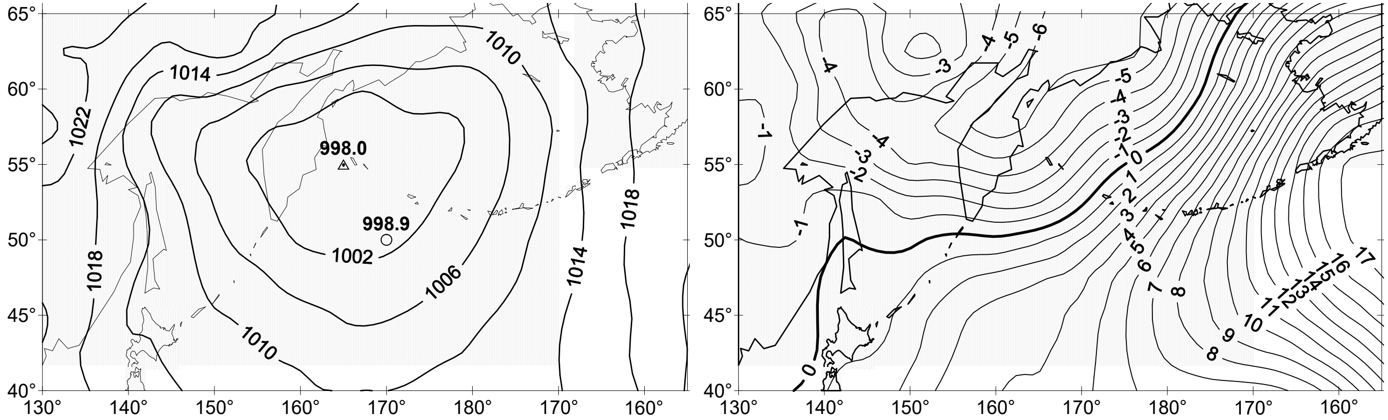
Recent environmental changes

Cyclic fluctuations in environments in the Bering Sea are caused by shifts of the Aleutian Low. When it moves eastward – north winds prevail in winter over the western Bering Sea and south winds over its eastern part, that is normal situation, but if it moves westward – southerlies prevail over the entire Bering Sea that provides anomalously warm winter and influences correspondingly on environments in other seasons.

Beyond these cyclic changes, a climatic trend to warming was not noted in the Bering Sea until 21st century, but became apparent recently because of the Hawaiian High strengthening in conditions of active transport of air from equatorial zone to subtropics in macroscale circulation cells. If the spur of this anticyclone spreads to Alaska – it pushes the Aleutian Low to the west, sometimes to Kamchatka, as happened in 2016-2019.



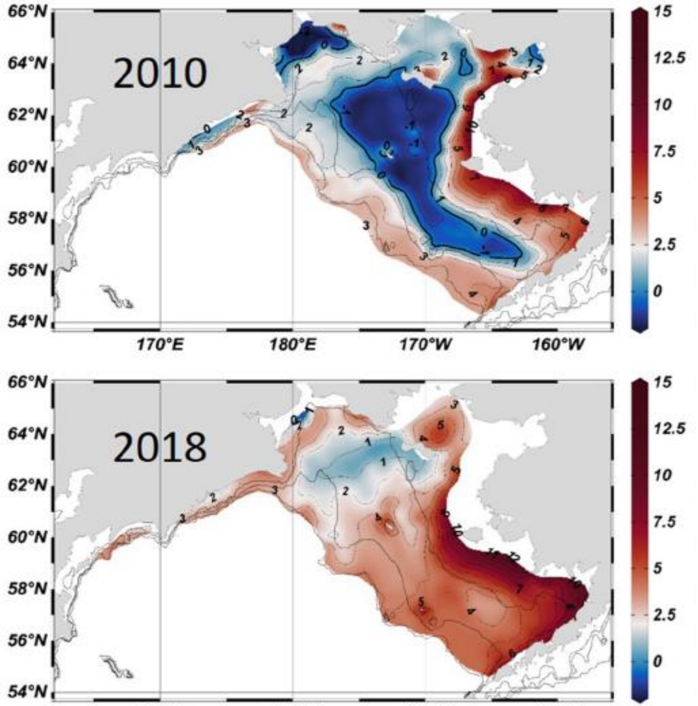
Schemes of winter and summer monsoon circulation over East Asia and North Pacific



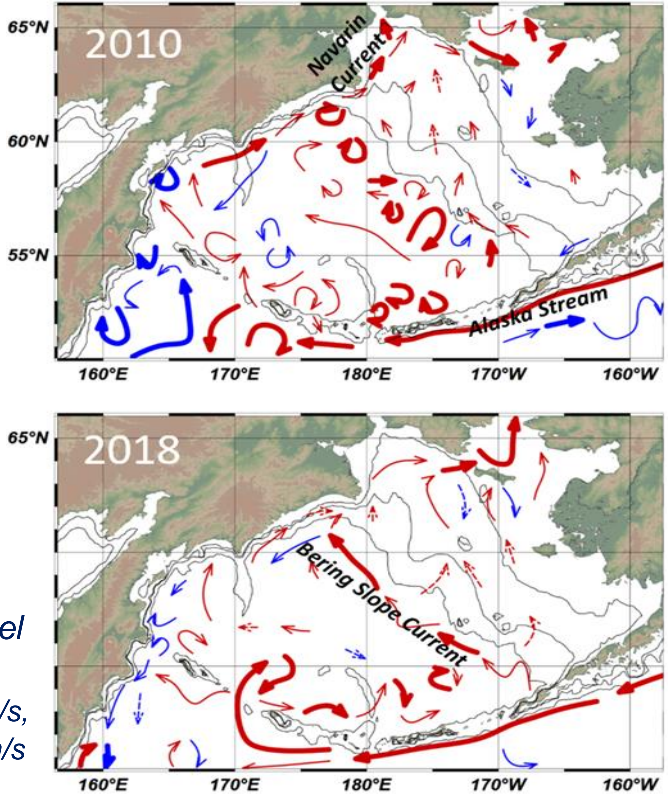
Mean atmospheric pressure at the sea surface in February 2018 (left panel) and its anomalies (right panel), hPa. Triangle – the center of Aleutian Low, circle – its mean climatic position in February

Recent environmental changes

The anticyclonic gyre forms on the Bering Sea shelf around the near-bottom St. Lawrence Cold Water Pool with low salinity. A part of this gyre is the northward Navarin Current across the northern shelf. It became weak and unstable in warm years. On the contrary, the Bering Sea Slope Current became stronger supported by south winds and stronger density gradient.



Water temperature at the bottom of the Bering Sea shelf

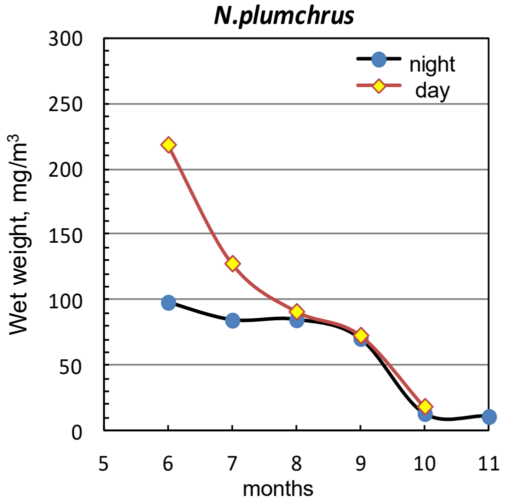


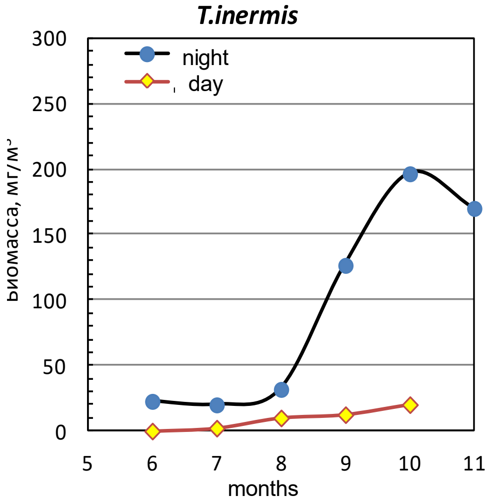
Generalized schemes for the water circulation at the Bering Sea surface calculated by on-line model OSCAR.

Bold allows – streams >10 cm/s, thin arrows – streams 5-10 cm/s

Recent environmental changes

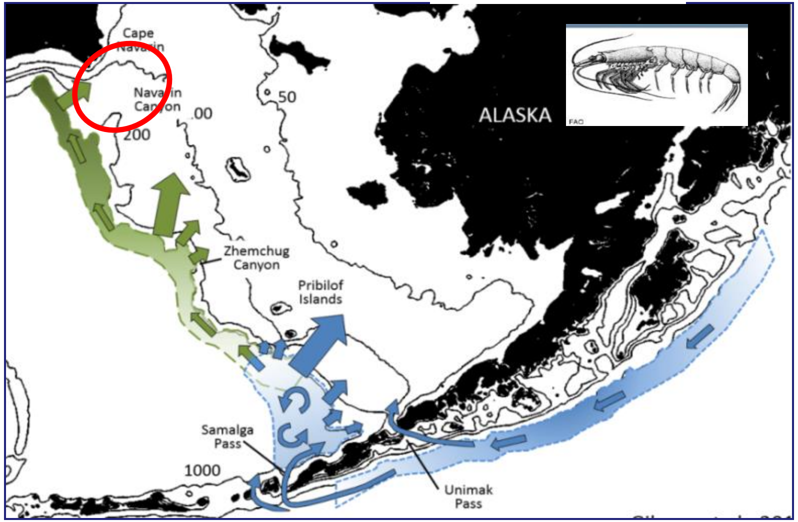
These changes in water circulation are important for spatial distribution of large-sized zooplankton, as the crucial species for fish feeding – the krill *Thysanoessa inermis*. They spawn mainly in Zhemchug canyon at the eastern continental slope and the progeny is transported by Slope Current to Cape Navarin. This food resource attracts mass fish species from the eastern Bering Sea populations, including pollock, in the fall season when large-sized copepods sink to the depth for spawning. Cod follows to migrations of their prey. Activity of this migrations corresponds to intensity of the Slope Current.





Mean seasonal variation of mass Copepoda and Euphausia species in the shelf area at Cape Navarin [Zuenko, Basyuk, 2017].

In the fall season the copepods are replaced by krill that provides the feeding resource for fish until December



Scheme of krill T.inermis transportation by currents from their spawning grounds [Gibson et al., 2012].

The area at Cape Navarin is marked

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Цель работы: понять механизм влияния климатических изменений на промысел трески в доступной российским рыбакам акватории Берингова моря

1. Неустойчивость трескового промысла в Беринговом море и её причина

2. Современные климатические изменения в Беринговом море, их природа и последствия для экосистемы

3. Концептуальная модель влияния климатических изменений на нагульный запас трески в западной части Берингова моря и её промысел

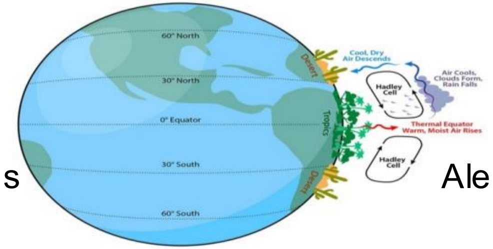
4. Практические рекомендации по регулированию промысла трески

Conceptual model

All found interrelations in the ecosystem of Bering Sea concerning the cod migration to the Russian waters could be generalized as a scheme of 2 scenario:

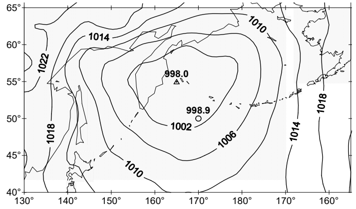
[Earlier] normal atmosphere circulation

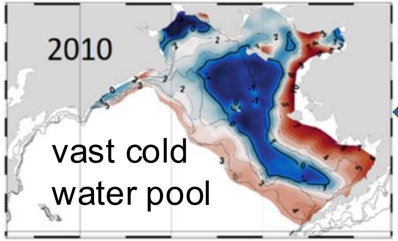
Aleutian Low over Aleutians



Active atmosphere macrocirculation

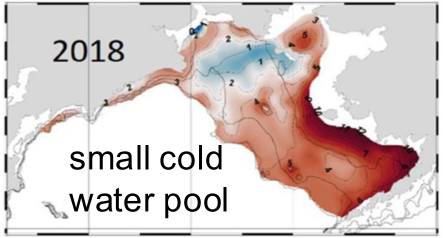
Aleutian Low at Kamchatka





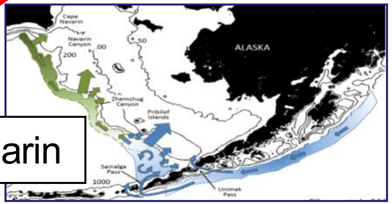
severe winter in the northwestern Bering Sea

Soft winter in the northwestren Bering Sea

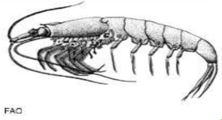


weak Bering Sea Slope Current, strong Navarin Current

strong Bering Sea Slope Current, weak Navarin Current



Unstable feeding at Cape Navarin



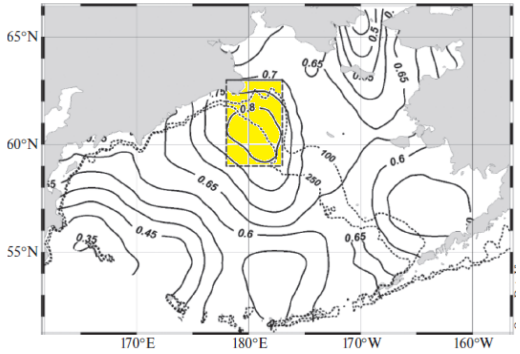
Stable feeding at Cape Navarin

inactive migrations of pollock and cod from SE Bering Sea to Cape Navarin area

active migrations of pollock and cod from SE Bering Sea to Cape Navarin area

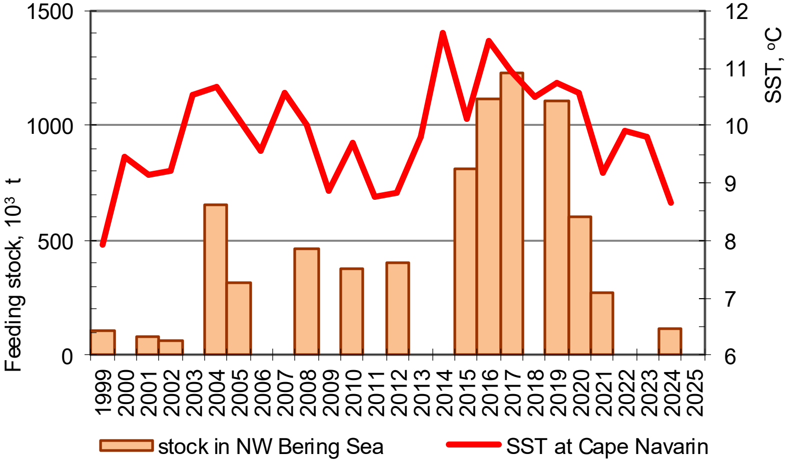
Conceptual model

So, we link the dynamics of stock for demersal species (cod) stock with changes is circulation at the sea surface. This paradoxical assumption is confirmed by the closest correlation of this dynamics with SST but not with the cold water pool are a. This relationship is explained by the proposed mechanism of environmental influence that is based on conditions of migration concerned to water dynamics but not on conditions of reproduction or wintering.

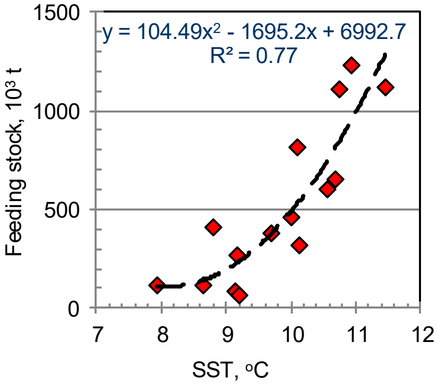


Coefficients of linear correlation between interannual variations of SST in in August and the stock of feeding cod in northwestern Bering Sea (trawl surveys data).

Informative area at Cape Navarin with the highest correlation is shaded. Isobaths of 100 and 250 m are drawn.



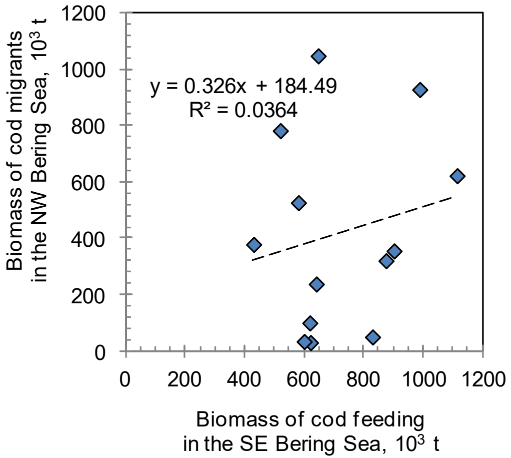
Interannual dynamics of SST at Cape Navarin in August and the mixed feeding stock of cod in the northwestern Bering Sea (EEZ of Russia)



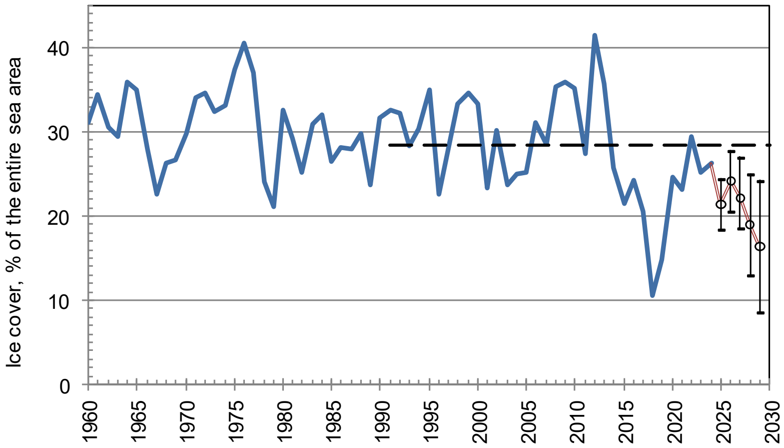
Dependence of the cod feeding stock in the Russian waters of Bering Sea on SST in the informative area at Cape Navarin in August, approximated by a second-degree polynomial

Conceptual model

So, we link the dynamics of stock for demersal species (cod) stock with changes is circulation at the sea surface. This paradoxical assumption is confirmed by the closest correlation of this dynamics with SST but not with the cold water pool are a. This relationship is explained by the proposed mechanism of environmental influence that is based only on conditions of migration concerned to water dynamics but not on local conditions in the northwestern Bering Sea or on abundance of cod in the southeastern Bering Sea.



Statistically insignificant relationship between variations of biomass for the cod continued feeding in the SE Bering Sea and migrated to the NW Bering Sea



Interannual dynamics of ice cover in the Bering Sea averaged for January–April and its Fourier prediction for 2025–2029 on the basis of interannual variability in 1979–2024.

Dashed line – climatic mean value for 1991–2020; whiskers – mean squared error of prediction

Conclusions:

1. **Composition of the cod feeding stock in NW Bering Sea** – The mixed stock includes both local fish and migrants; the portion of migrants (mostly 4-5-years aged fish) in total biomass of cod in this area varied between 72-94%.

2. **Recent increasing of the cod feeding stock in NW Bering Sea** – The increasing in 2016-2019 was caused by active seasonal migrations of cod from the southeastern shelf to the northwest, mostly to the area at Cape Navarin, in conditions of extreme warming and strong Bering Sea Slope Current.

3. **Environmental influence to cod migrations** – Active transport of krill *Thysanoessa inermis* with the Bering Sea Slope Current is considered as the main reason for the active cod migration to the north-west. This phenomenon could be predicted on the data of ice cover in winter, so far as the winter conditions determine patterns of water circulation in Bering Sea in summer. The conditions favorable for active migration can be expected again in the end of current decade