Variability and change of the oceanographic conditions in the feeding migrations and reproduction areas of sardine, mackerels and saury in the Northwest Pacific

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Goal:

The purpose of the study was to assess the current state of the environment habitat of epipelagic subtropical migrants (sardine (Sardinops melanostictus), mackerels (Scomber japonicus and Scomber australasicus) and saury (Cololabis saira)) and to identify patterns of oceanographic conditions influence on the formation of possible migration routes and fishing grounds areas.

Acknowledgments:

The authors are sincerely grateful to TINRO R/V's crews and scientists who collected the important information used in the study.

We also thank Eu. Basyuk for the assistance with data on currents from OSCAR.

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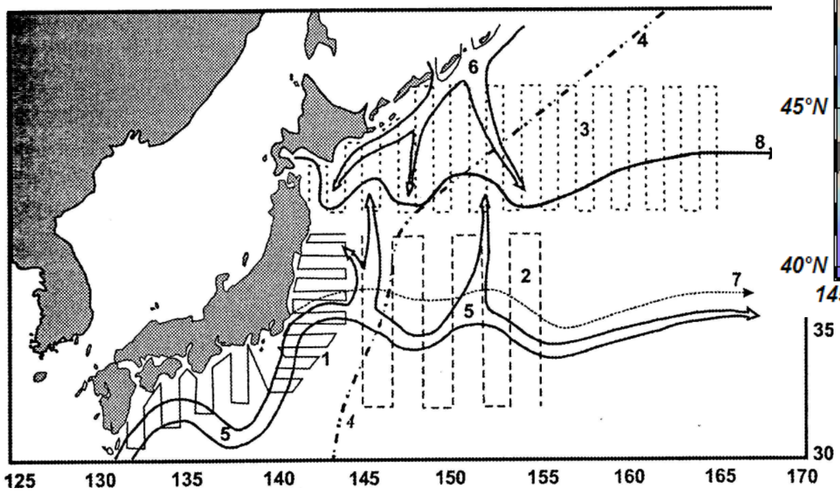
Data source

TINRO-Center fisheries independent surveys in 2014-2019: the complex scientific expeditions (CTD, hydrochemical sampling, plankton net, pelagic trawl, acoustic survey) from the databases “Oceanography” and “Marine Biology” (TINRO)

For comparison with previous «period without mackerel and sardine» we used the data of similar complex scientific expeditions in 2004-2013, June.

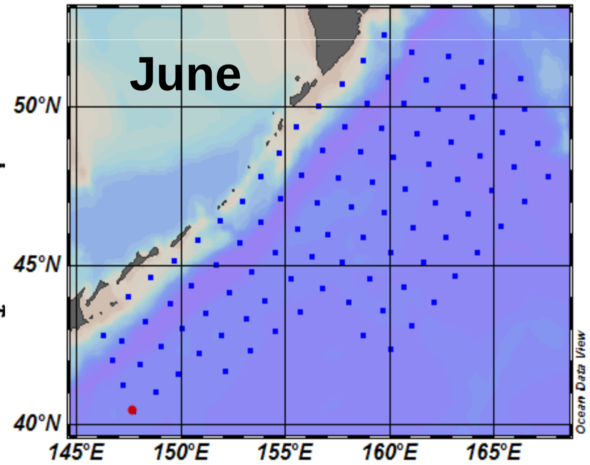
Besides, we used the data of complex scientific expeditions in the reproduction areas (1974-1995)

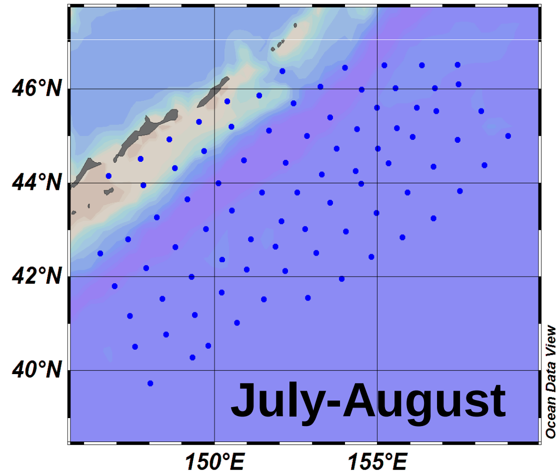
Scientific expeditions in 1974-1995:



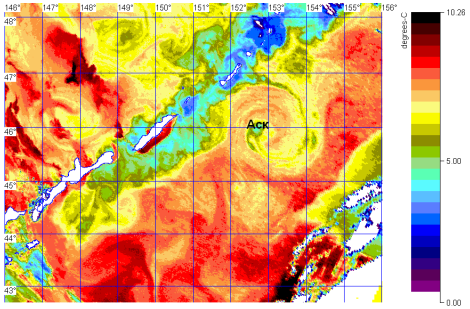
Belyaev, 2003

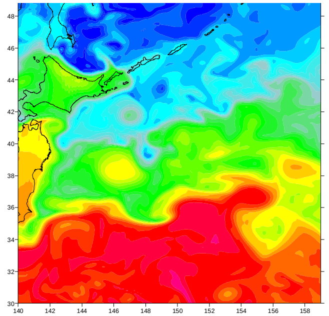
Scientific expeditions in 2004-2019:





Data source





Satellite information: **http://www.satellite.dvo.ru/**

We also use NEAR-GOOS gridded SST and temperature at 50, 100, 200, and 400 m

http://ds.data.jma.go.jp/gmd/goos/data/database.html

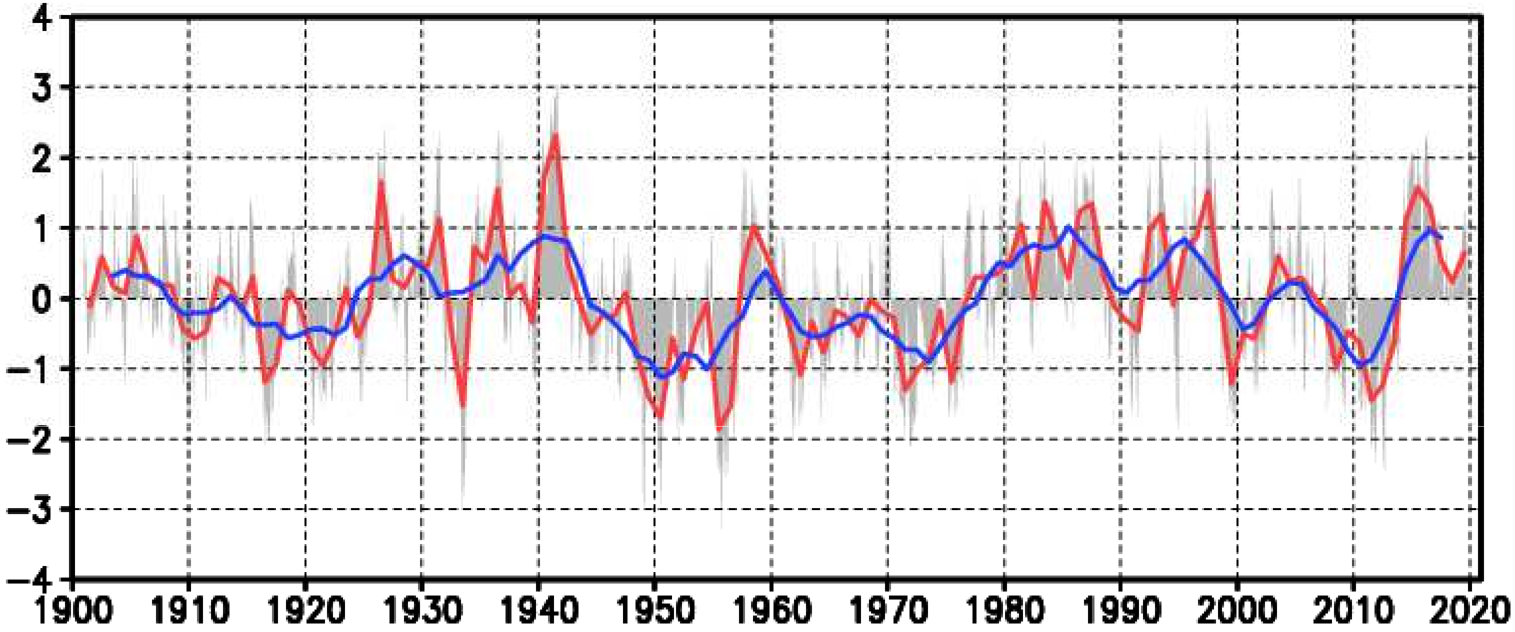
and currents from the Ocean Surface Current Analyses Real-time (OSCAR) project (by altimetry data, taking into account temperature anomalies transport as a passive tracer and wind).

ESR. 2009. OSCAR third degree resolution ocean surface currents. Ver. 1. PO.DAAC, CA, USA. Dataset accessed [YYYY-MM-DD] at **http://dx.doi.org/10.5067/OSCAR-03D01.**

For evaluation of anomalies there were used daily temperature and salinity climatic values calculated from World Ocean Atlas WOA2013.

PDO Index (1901-2019)

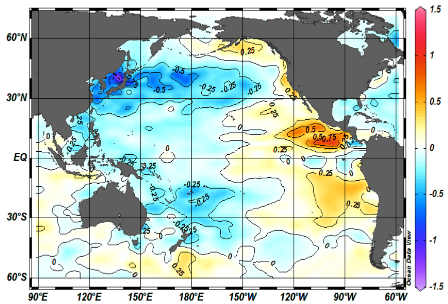
http://www.data.jma.go.jp/gmd/kaiyou/data/shindan/b_1/pdo/pdo.html



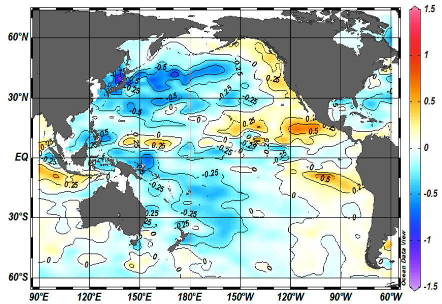
The red line is the annual average, and the blue line is the 5-year moving average. The monthly index is shown as a gray bar.

Common feature of the previous and current periods of the sardine high abundance is the predominance of the PDO positive phase when relatively cold conditions are observed in the reproduction zone

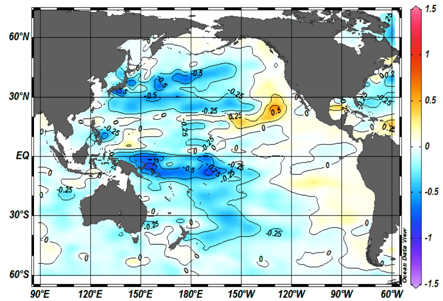
Water temperature anomaly in the previous "sardine era" and in recent years



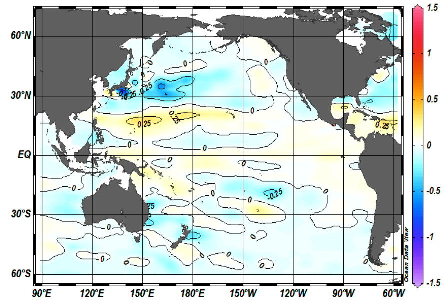
aT50 1981_1988



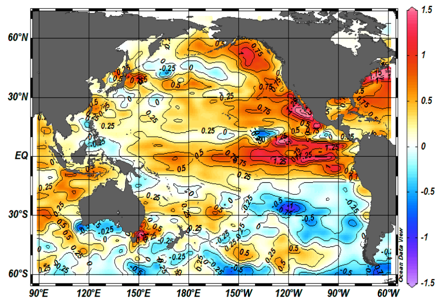
aT100 1981_1988



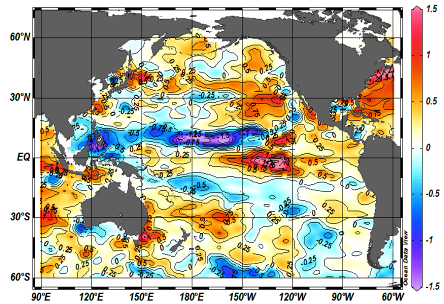
aT200 1981_1988



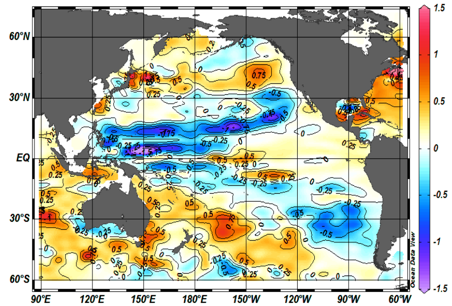
aT400 1981_1988



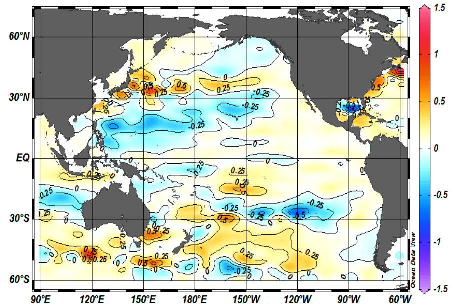
aT50 2014_2018



aT100 2014_2018



aT200 2014_2018

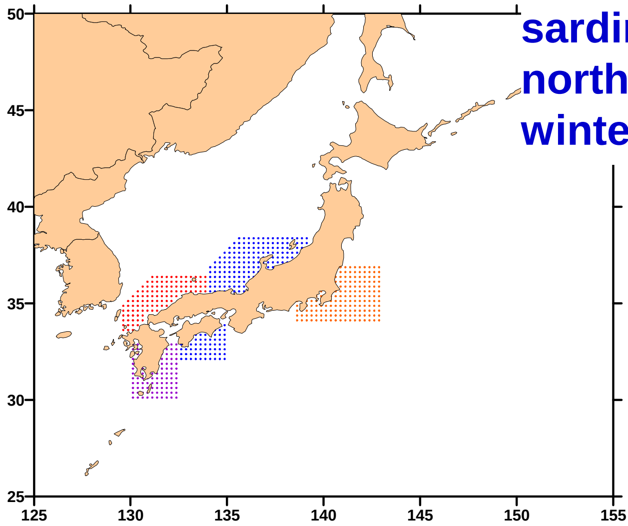


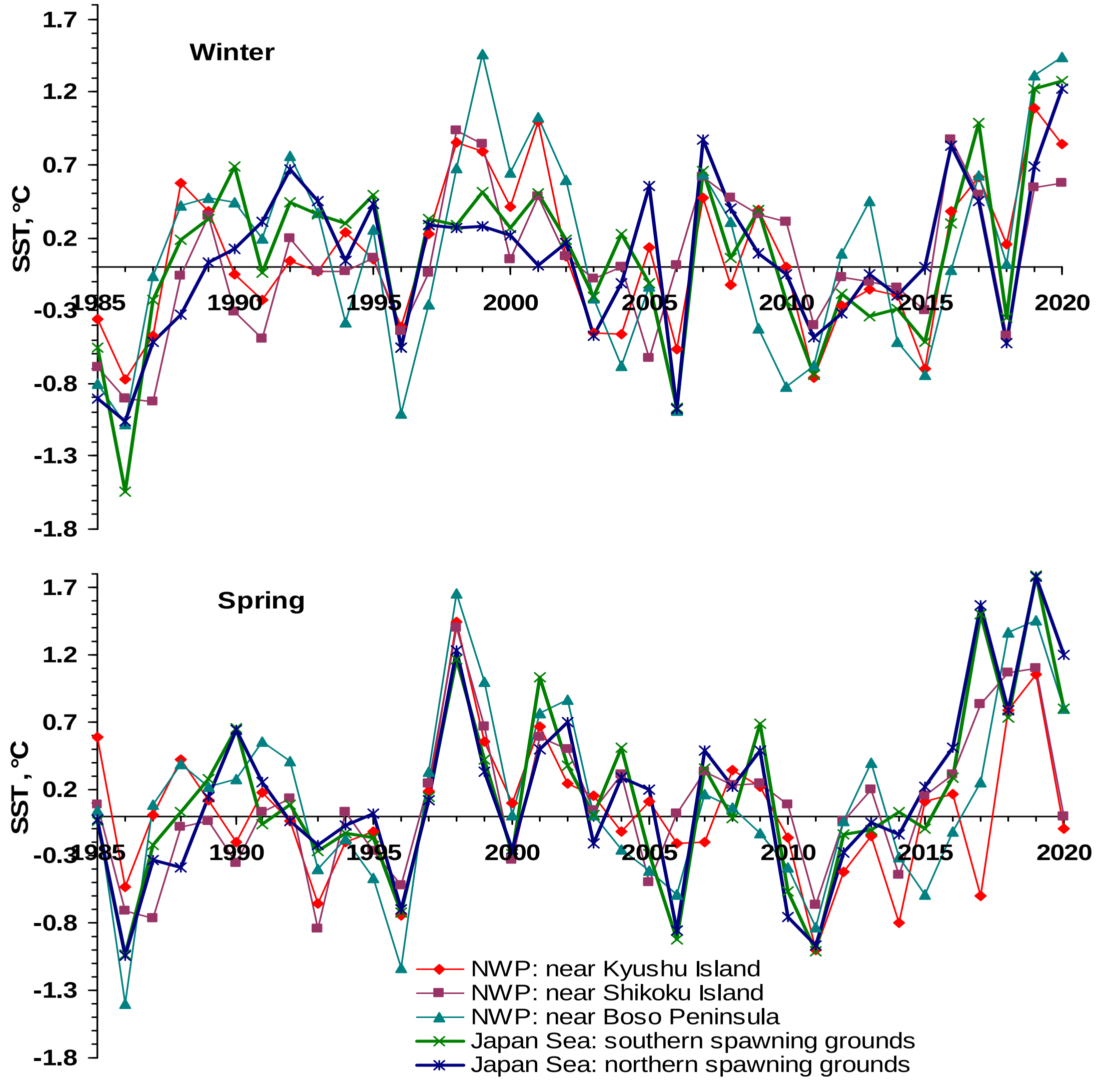
aT400 2014_2018

This “sardine wave” differs from the previous ones because it is coincident with positive temperature anomalies. When the “feeding area” reached northern subarctic area, positive temperature anomalies strengthened both at the surface and at the 50–100 m horizons and deeper. This “heat wave” may force, through feeding conditions, sardine migration for feeding far northward in the present period of the population growth.

Sardine

SST anomalies in in the northern (near the Boso Peninsula) **and southern** (near Kyushu Island and Shikoku Island, including Tosa Bay) **sardine spawning grounds in the Northwest Pacific and in the northern and southern spawning grounds of the Japan Sea in winter and spring, 1985-2020**





The long-term variations of winter-spring thermal conditions in the reproduction region are characterized by a tendency of near-surface (0-200 m) water temperature to decrease until 1986. A warming tendency was observed since 1987 (Ustinova et al, 2001).
Common feature of the previous and current periods of the sardine high abundance is the predominance of the PDO positive phase when relatively cold conditions are observed in the reproduction zone. However, in the series of relatively cold years were the exceptions.

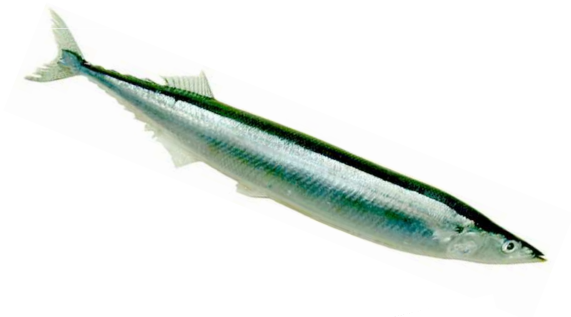
Large Kuroshio meander off south Honshu Island is observed in recent years similar to the previous period of high sardine abundance. The first low-abundance sardine generation was formed after the meander sharp decrease in the 1988 spawning season.

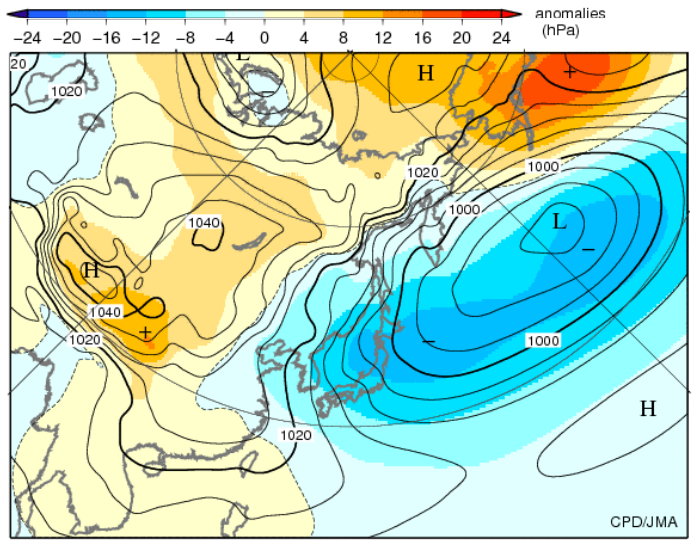
Fisheries effects

Example of the short-term impact of unfavorable factors leading to long-continued consequences is the extreme winter-spring cooling in 1963 in the Kuroshio-Oyashio system (Fujimori, 1964), which caused a mass mortality at early stage of small pelagic fish (Tsujita, 1966; Nakai et al, 1967), such as anchovy, saury and sardine.

Uda:

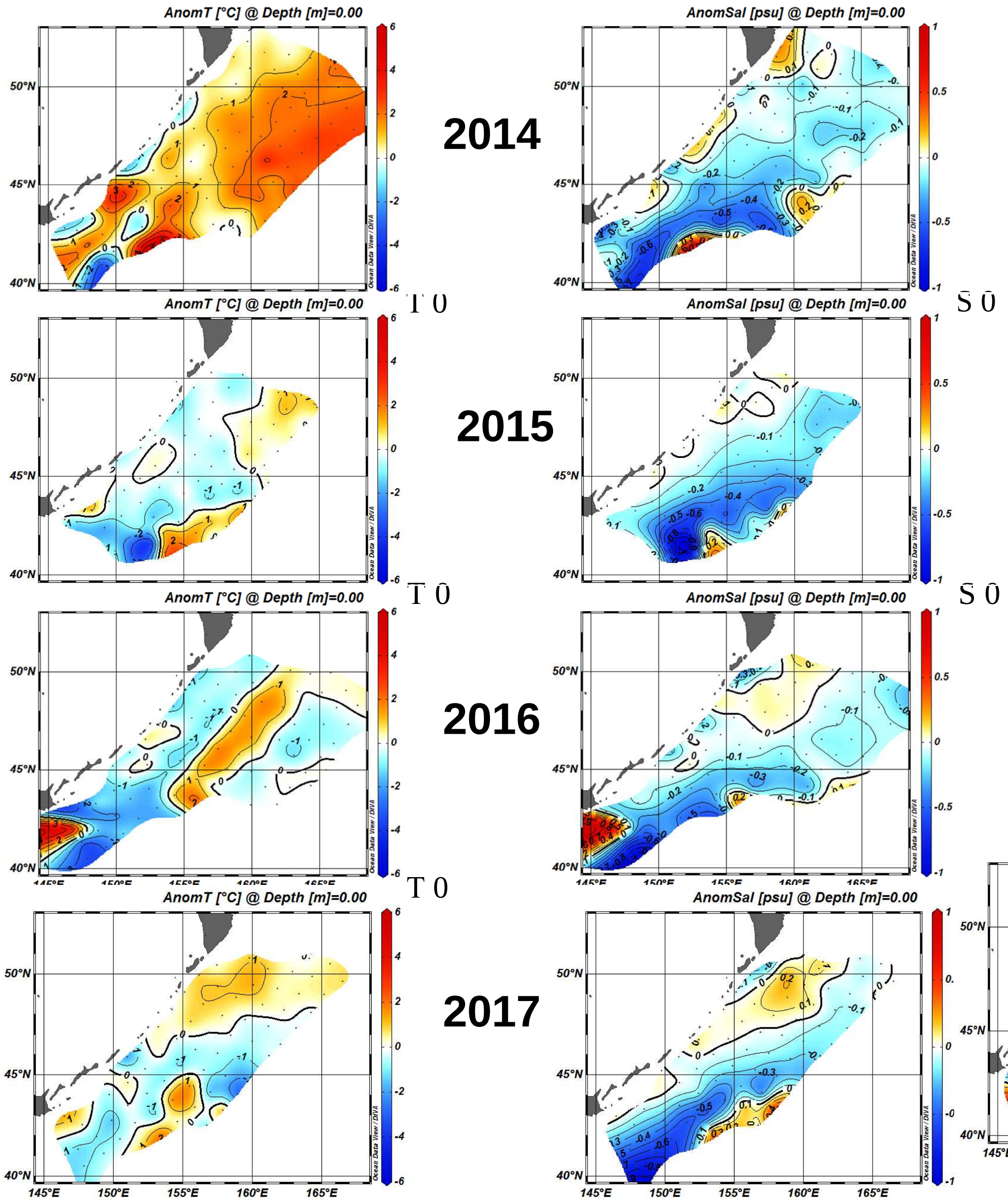
The saury catch reached a high of about 575,000 metric tons landed in 1958 and remained above 400,000 metric tons until 1963. After the abnormally cold year of 1963, the saury catches dropped off sharply to 200,000 metric tons or less after 1964.





Monthly mean sea level pressure and anomaly around Japan (Jan.1963)
The contours show sea level pressure at intervals of 4 hPa.
The shading indicates sea level pressure anomalies.
Anomalies are deviations from the 1981–2010 average.

Sea surface temperature (left) and salinity (right) anomalies in the Northwest Pacific in 2014-2018, June

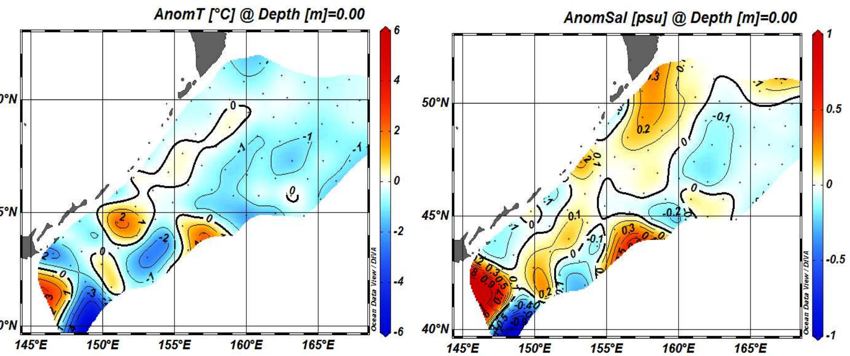


Compared with climatic values (World Ocean Atlas of WOA2013), the surface temperature during the surveys in 2014 was predominantly above the norm, but in 2015 both above and below the norm. Surface salinity during the surveys in 2014-2017 was predominantly below the norm.

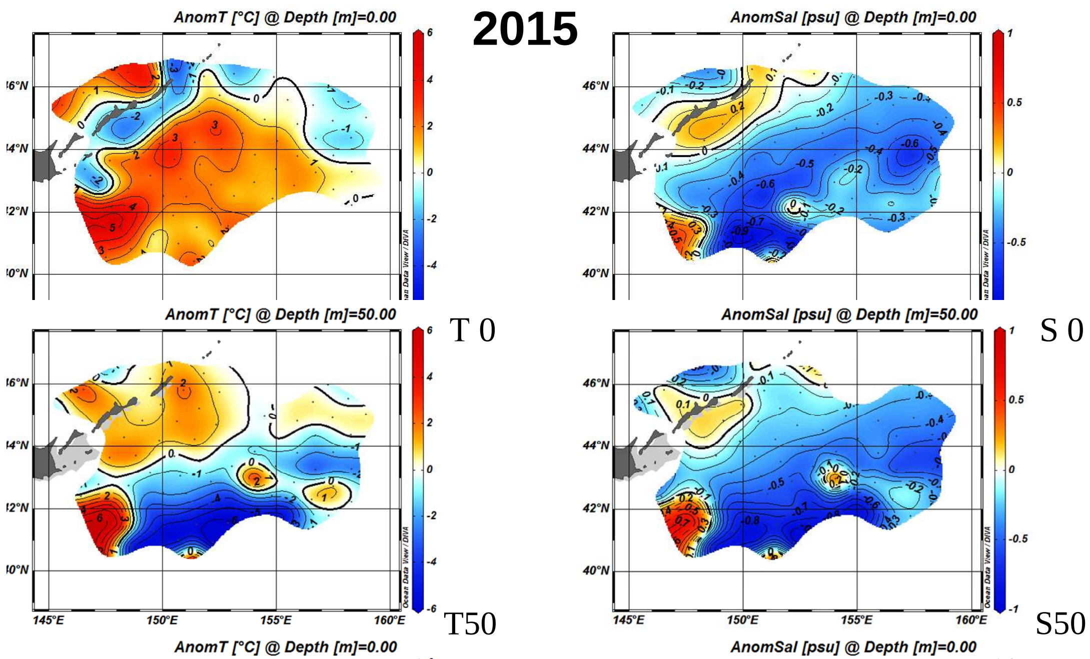
Positive anomalies of temperature corresponded to positive salinity anomalies only in regions with transformed subtropical waters inflows.

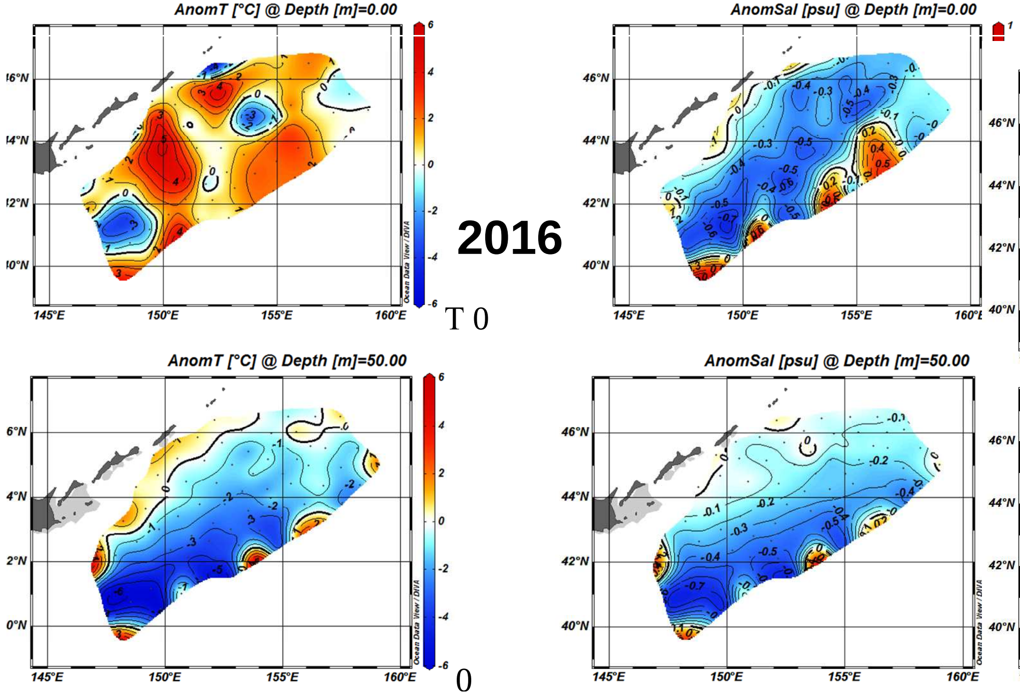
Ustinova et al, in press

2018



Temperature and salinity anomalies at 0 and 50 m depth in the Northwest Pacific 2015-2017, July-August

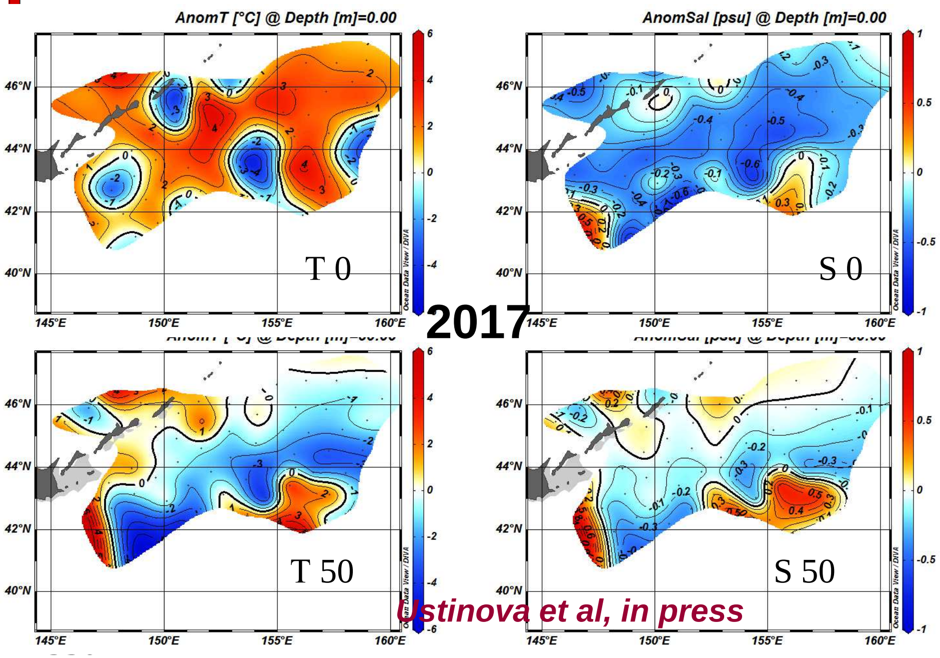




Salinity

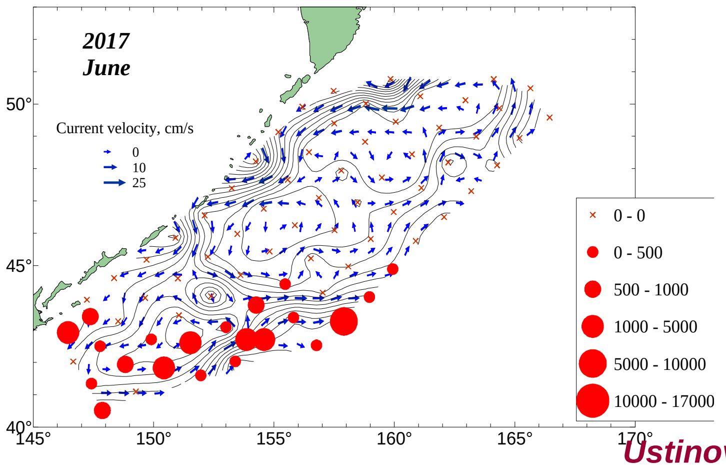
From 0 to 50 m depth below the norm

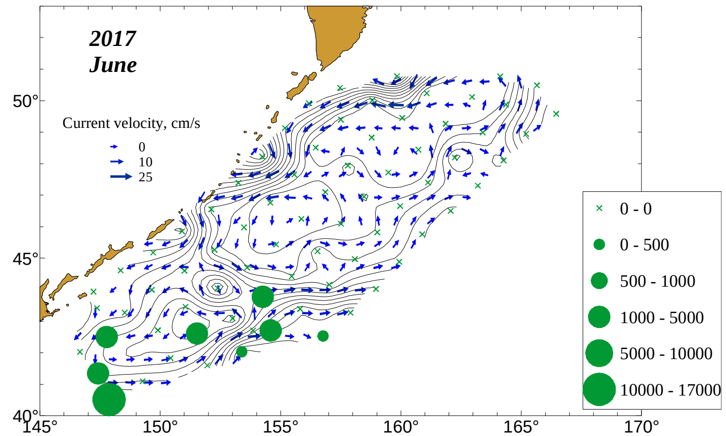
According to evaluation of temperature and salinity anomalies, in summers of 2014-2017, increased inflow of more productive low-salinity waters from the northeast region (in comparison with the previous period) in the Western Subarctic cyclonic Gyre is observed.



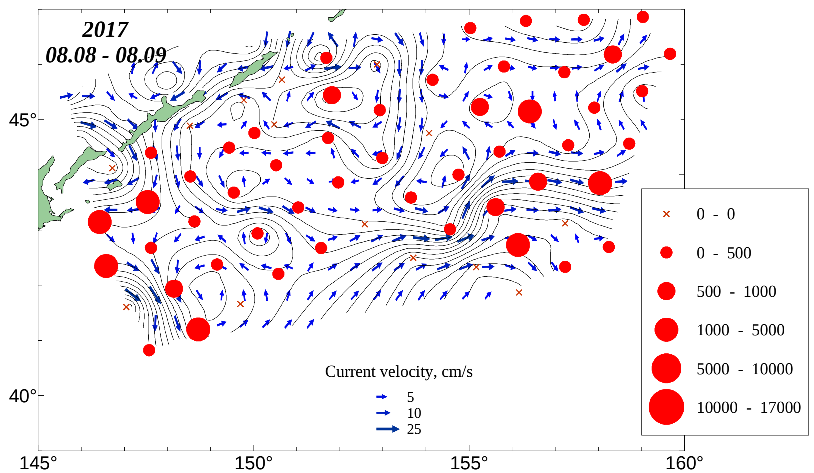
Ustinova et al, in press

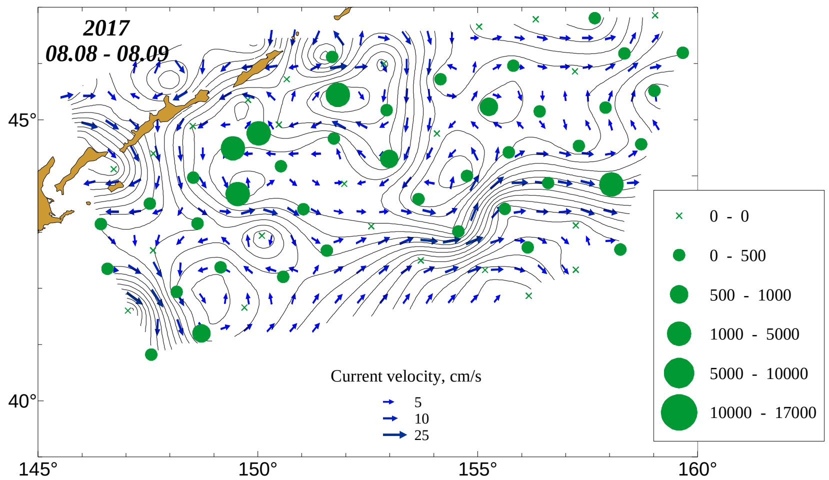
Geostrophic currents *(relative to 500 dbar)* **in the Northwest Pacific and distribution of mackerel (left) and sardine (right) catches** *(kg/hour of trawling)*





Ustinova et al, in press

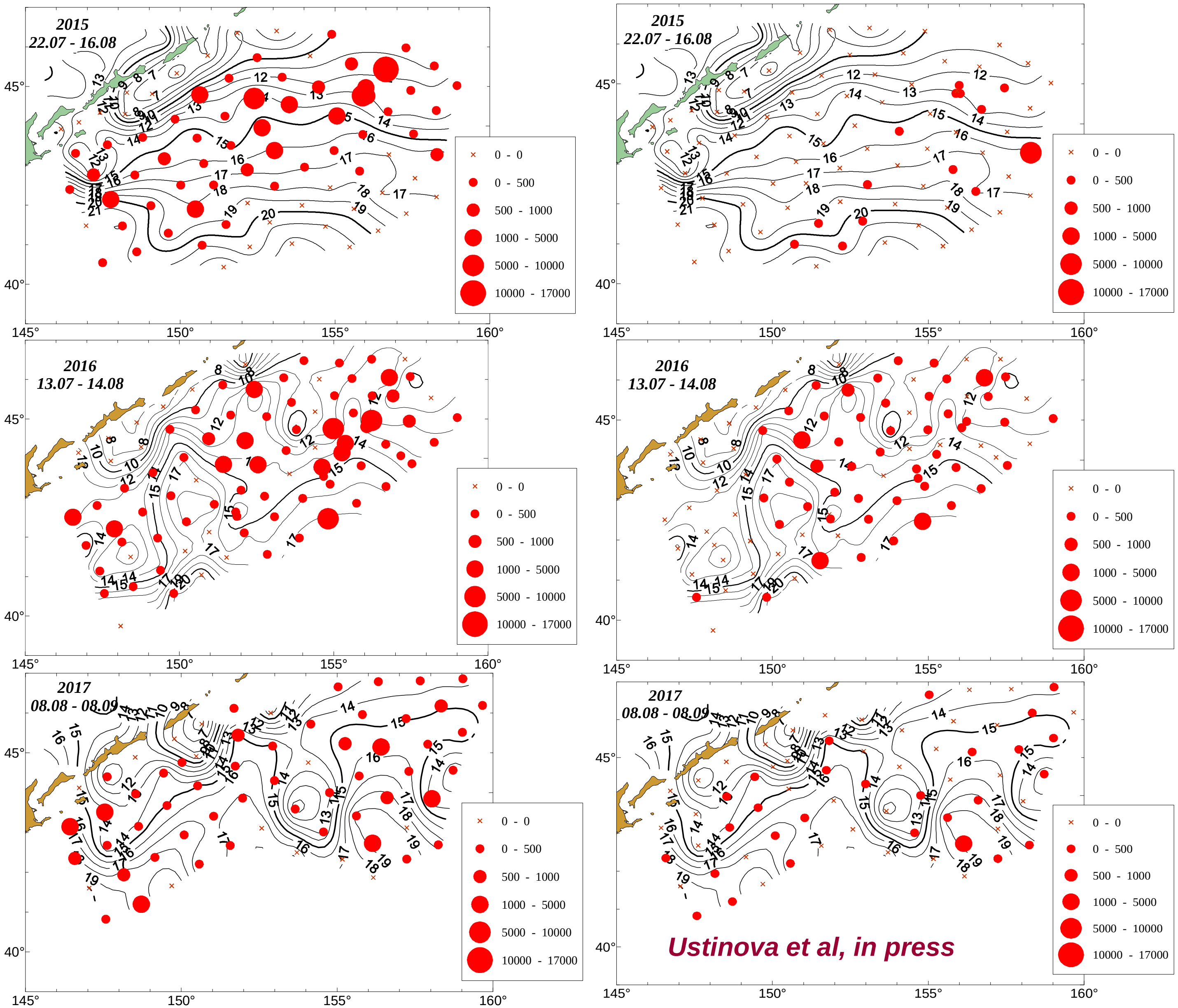




In June of 2014–2018, the main sardine aggregations as well as mackerel aggregations have been observed on the warmer water side in high-gradient zone of the North Subarctic Front. From July to September of 2015–2018, the maximum catches were recorded in the food-rich subarctic waters to the west from "third" Kuroshio branch or Isoguchi Jet. The relatively strong northeastward "third" Kuroshio branch (or Isoguchi Jet) was favorable for more intense northward migrations. Sardine aggregations were observed in coastal waters, too.

SST in the Northwest Pacific and distribution of mackerel catches:

Scomber japonicus (left) and *Scomber australasicus* (right), **(kg/hour of trawling)**



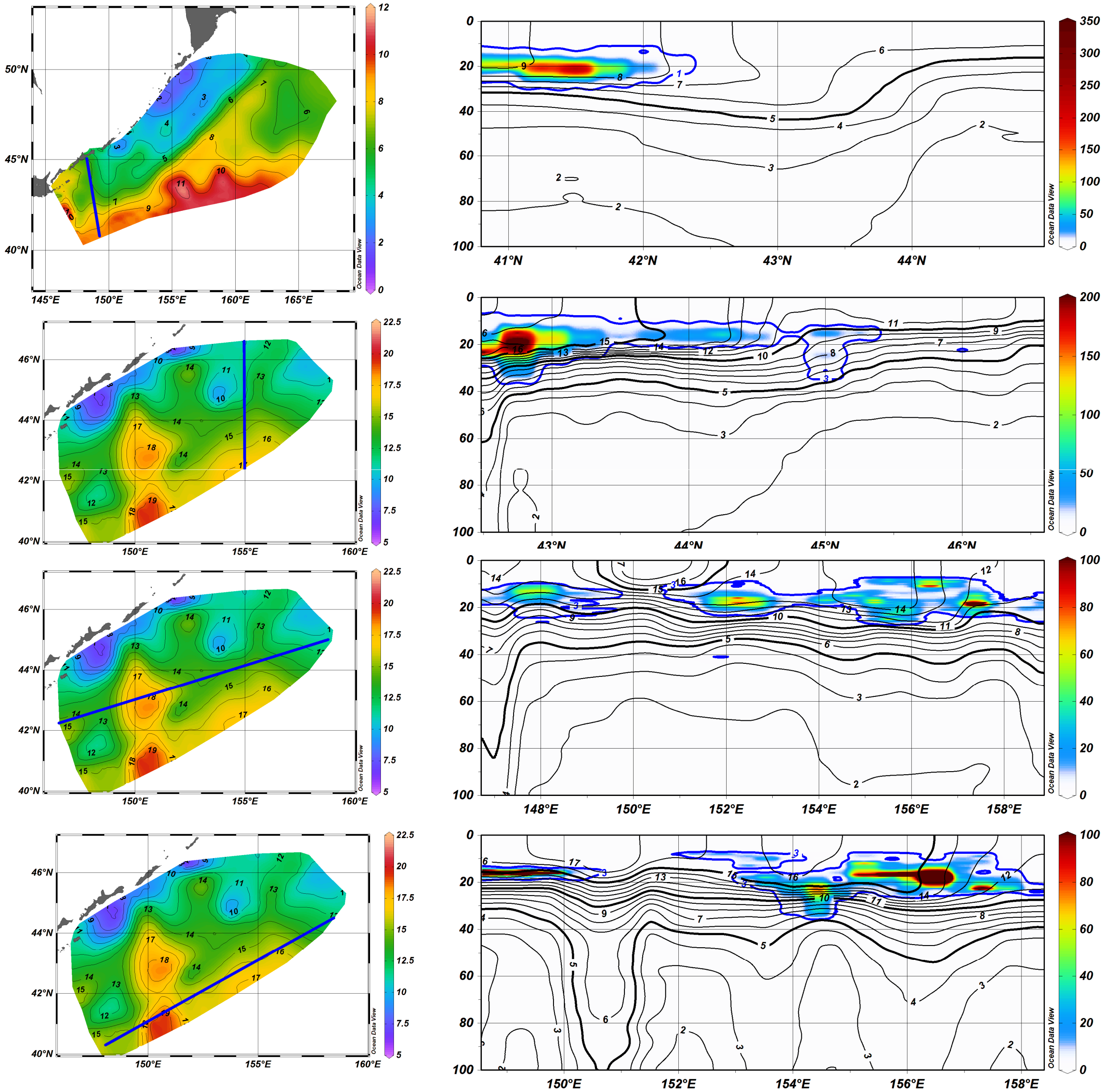
Ustinova et al, in press

Wide range of SST was for efficient trawl stations: 8.6-21.1°C

Higher concentrations were observed in waters with SST ranged from 12°C to 17°C.

Chub mackerel migrate into Russian waters during forage migrations and aggregate in the area off the southern Kuril Islands from July to November. Spotted mackerel (more southern species) was observed in the southeast area of the surveys in July and August.
The spotted mackerel is located offshore from the Oyashio current and its branches more than the Japanese mackerel.
This species was noted in 2 cases in transformed subtropical waters.

Vertical distribution of mackerels density aggregations s_A ($m^2/n.mi^2$) and temperature (°C) in the Northwest Pacific



June 2016

Isothermal surface of 8°C is their northern and deep habitat limit.

July-August 2016

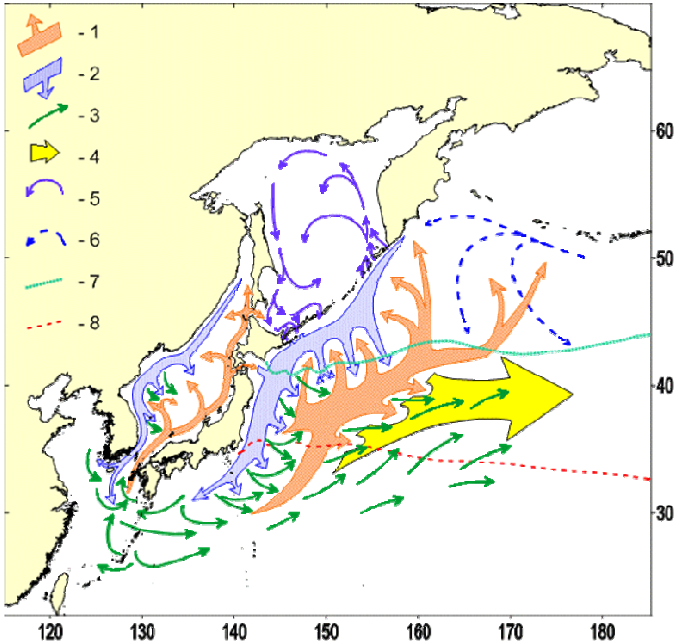
The sardine and mackerels spatial distributions during their feeding migration are substantially affected by mesoscale fronts and seasonal thermocline topography. The limiting role of the seasonal thermocline in the vertical distribution is clearly visible on these sections.

In two lower figures, mackerel avoids warm water inflow from the south: the central part with anticyclonic rotation in the upper 18-meter layer in the north area and eastern part of the deeper anticyclonic meander in the south area.

Ustinova et al, 2019

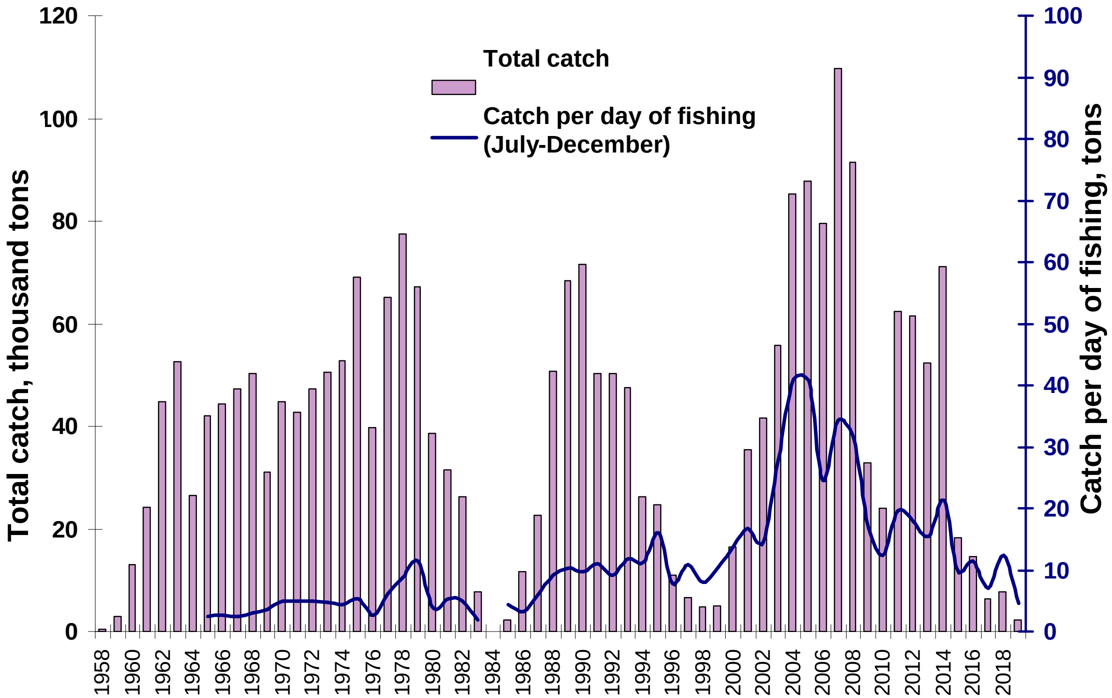
Saury

Since 2014, mackerel and sardine have been observed en masse in the waters available for Russian fishery, and since 2015 the main concentrations of saury have shifted to the east and north. The abundance of saury decreases.



Filatov et al., 2011

Dynamics of the Russian catch of Pacific saury

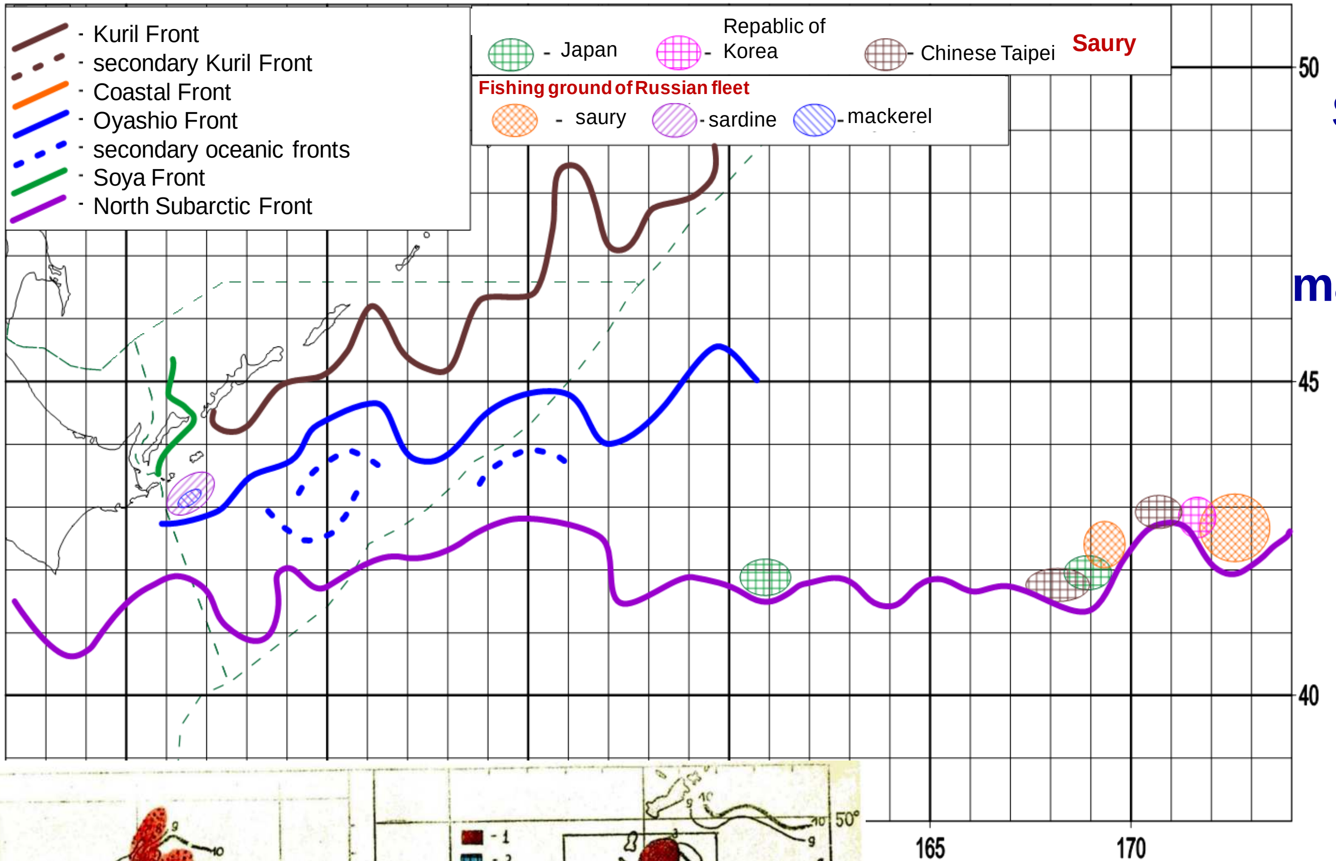


General scheme of saury migrations in the North-West Pacific:

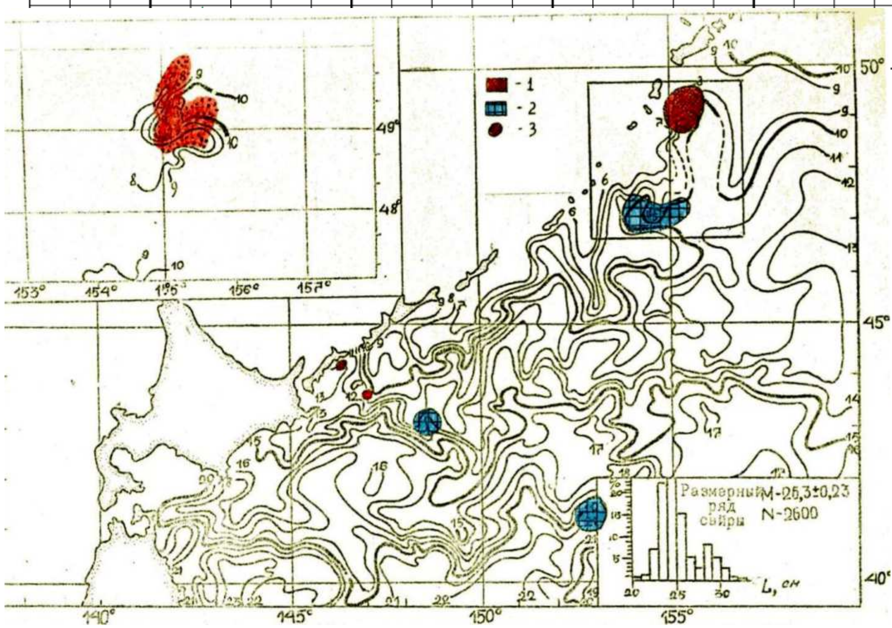
1 – spring-summer migrations; 2 – autumn migrations;
3 – transport of eggs and larvae;
4 – transport of juveniles (for winter spawning);
5 – unstable migrations in the Okhotsk Sea;
6 – migrations from «north ocean water»;
7 – North Subarctic Front; 8 – Kuroshio Front

Surface oceanographic fronts and saury, sardine and mackerel fishing grounds

21-30 June, 2019

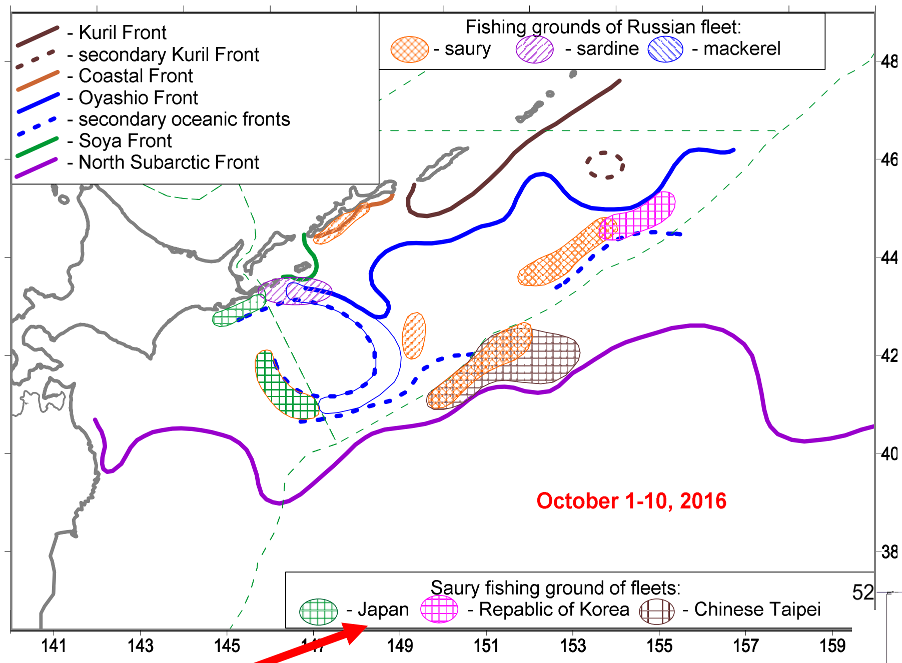


In 2019, saury fishing was carried out east of 170°E. This is the most eastern position of the fishery areas for all years.



SST and accumulations of Pacific saury (September 1-5, 1987)
1 - fishing area of the USSR fleet,
2 - fishing area of the Japanese fleet,
3 - places of detection of schools by search vessels.

Fisheries effects



Oceanographic fronts and saury, sardine and mackerel fishing grounds

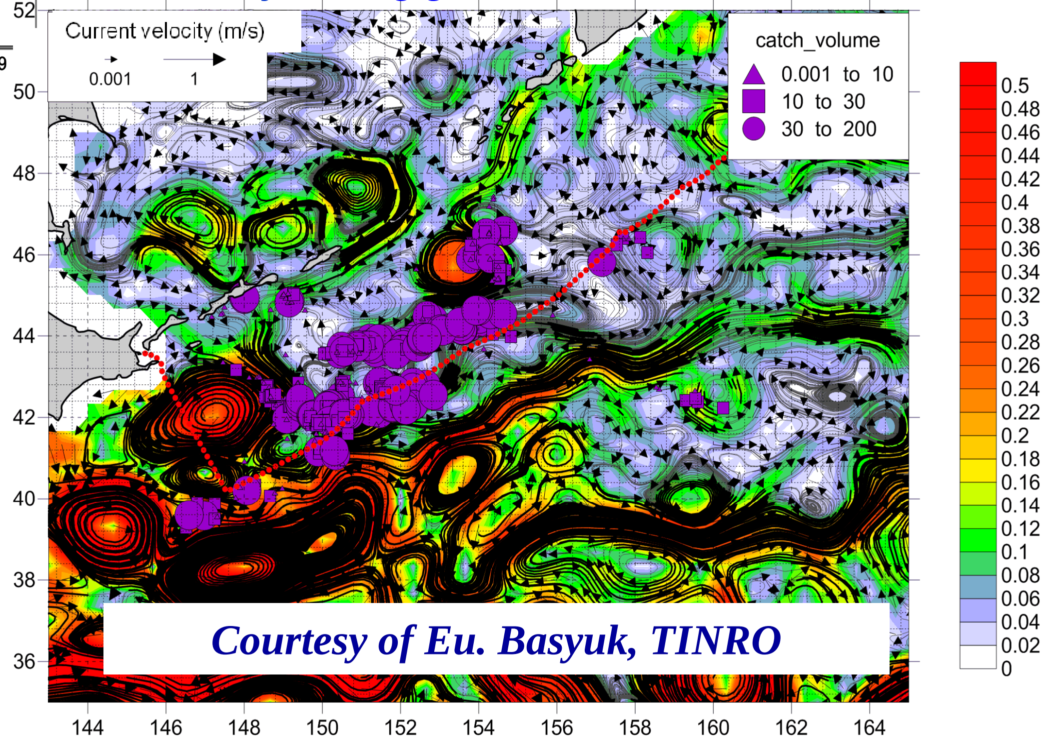
Large anticyclonic eddies are observed in: 1975, 1979, 1983, 1987, 1991, 1995, 1999 (Bulatov, 2002). After this period, large eddies began to be observed more often. Extreme large anticyclonic eddy: 2015-2016

We are still working for understanding the how large-scale warm eddies influence on abundance of species such as saury.

2016: large anticyclonic eddy near islands

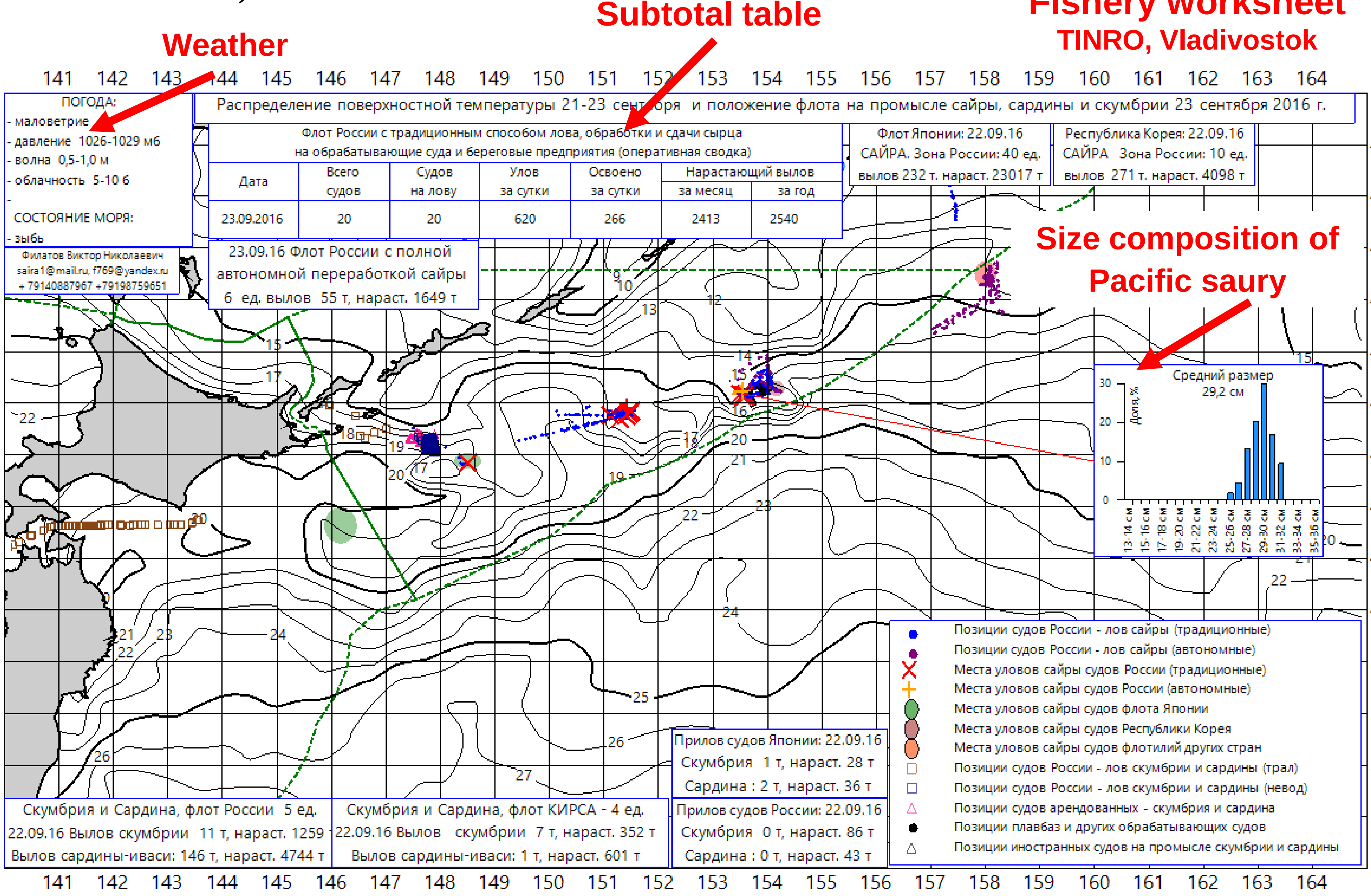
The region of the Russian fishery of the subtropical migrants (sardine (Sardinops melanostictus), mackerels (Scomber japonicus and Scomber australasicus) and saury (Cololabis saira)) is characterized by strong mesoscale variability associated with the Oyashio branches, anticyclonic and cyclonic eddies, and related processes of frontrogenesis and frontolysis.

Surface currents (vectors / background contour and current streamlines) in the Northwest Pacific according to OSCAR project and saury fishing grounds areas



Operational fisheries oceanography: example of Fishery worksheet

Ustinova et al, 2019



Summary

Last 7 years, significant changes in the spatial distribution of these species have occurred in the Northwest Pacific. Since 2014, mackerel and sardine have been observed en masse in the waters available for Russian fishery, and since 2015 the main concentrations of saury have shifted to the east and north. In 2019, saury fishing was carried out east of 170°E. This is the most eastern position of the fishery areas for all years.

Changes in the water dynamics contributed to this redistribution: more northerly propagation of subtropical origin waters and weakening of the Oyashio current. The penetration of sardine and mackerels into the northern regions is associated with increase in their abundance, which is formed in the reproduction zone near the Honshu, Shikoku and Kyushu islands.

Common feature of the previous and current periods of the sardine high abundance is the predominance of the PDO positive phase when relatively cold conditions are observed in the reproduction zone. However, in the series of relatively cold years were the exceptions.

Large Kuroshio meander off south Honshu Island is observed in recent years similar to the previous period of high sardine abundance. The first low-abundance sardine generation was formed after the meander sharp decrease in the 1988 spawning season.

Seasonal and mesoscale processes affecting the migration patterns and fishing ground of small pelagic fish influences on the interannual variability, especially in the Subarctic frontal zone. Obvious example is the impact of the Kuroshio and Oyashio branches seasonal dynamics and the presence and position of the large anticyclonic eddy east off Hokkaido Island in summer and autumn.

Another type of the short-term impact of unfavorable factors leading to long-continued consequences is the extreme winter-spring cooling in 1963 in the Kuroshio-Oyashio system, which caused a mass mortality at early stage of small pelagic fish.

Regime shifts played "dramatic" role too, because of abrupt change.