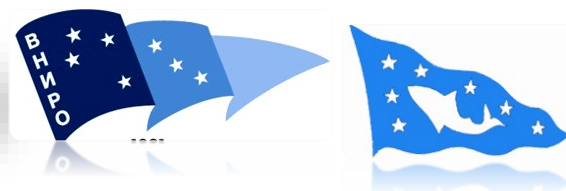
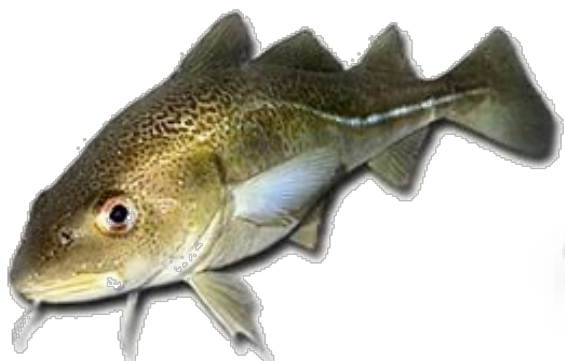


# **Influence of external environmental factors on the dynamics of the number of Pacific cod and saffron cod of the Eastern part of the sea of Okhotsk**

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# Objective:

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**And many others.**

# Objective:

## GOAL:

Assessment for the complex effects of the climatic factors on the stock abundance of Pacific cod and saffron cod in the eastern part of the Sea of Okhotsk.

## TASKS:

- to evaluate correlations of the population dynamics of the studied fish species;
- to analyze the direct and complex influence of climatic factors on the fish population at different stages of ontogenesis;
- to select the most significant climatic factors affecting the population dynamics of the studied species.

# Data and methods

Biomass of *Gadidae*,  
*Pleuronectidae* and *Cottidae*  
(1971-2018)

Abundance of Saffron cod (1987-2018)

Abundance of Pacific cod (1971-2018)

Data of summer trawl  
surveys  
GIS «CartMaster»  
(Bizikov et al., 2007)

Obtained with the method of  
the cohort model «Sintez»  
(Ilyin et al., 2014)

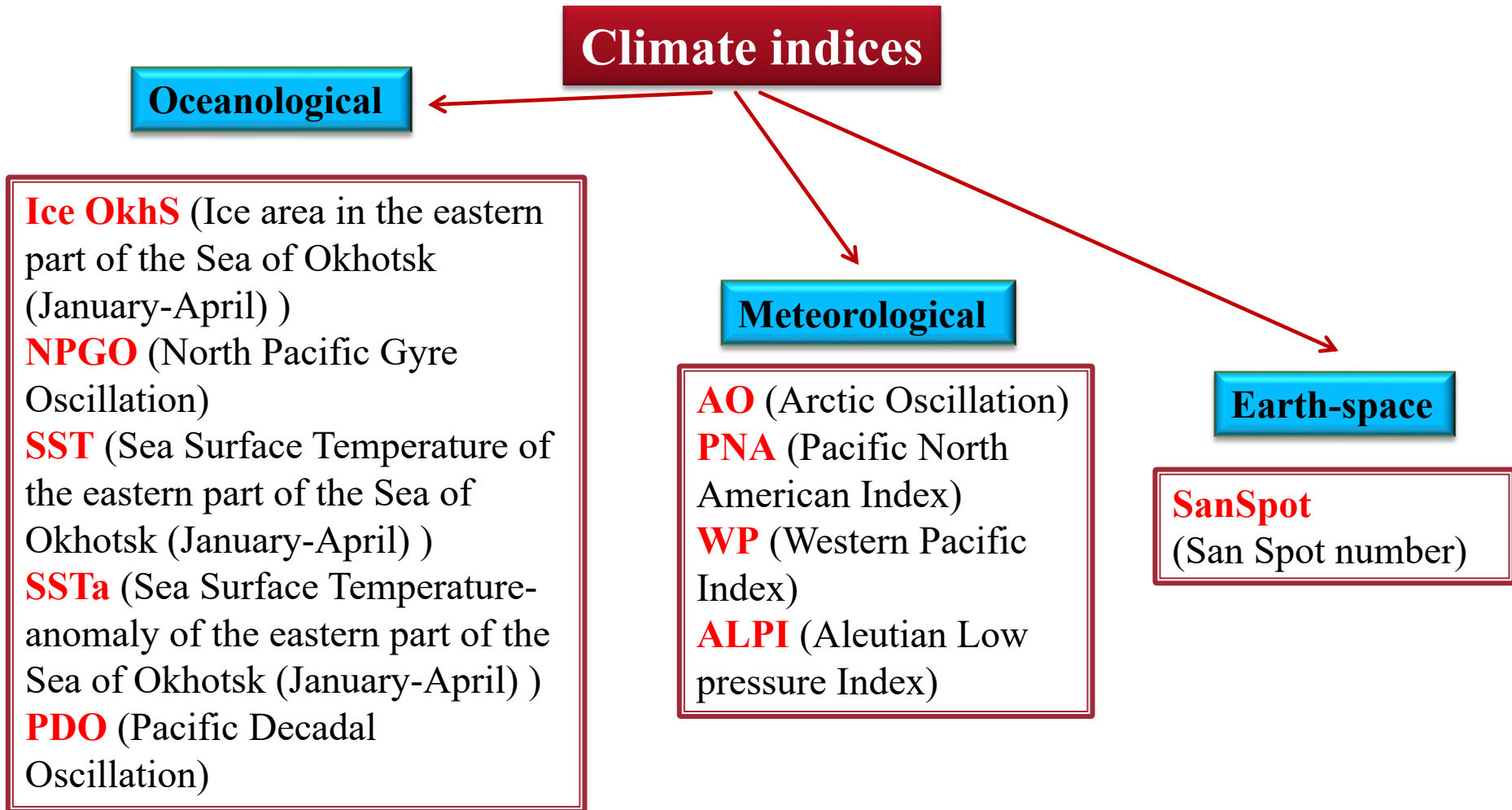
For evaluation of simple (one-dimensional)  
relations between the variables  
(«fish stock–fish stock»  
or «index–fish stock»)

Pearson correlation  
coefficient ( $r$ ) (“STATISTICA”)

To identify the degree of influence of  
the complex of climatic factors on  
the number of fish

Stepwise multidimensional  
regressive analysis  
(“STATISTICA”)

# Data and methods



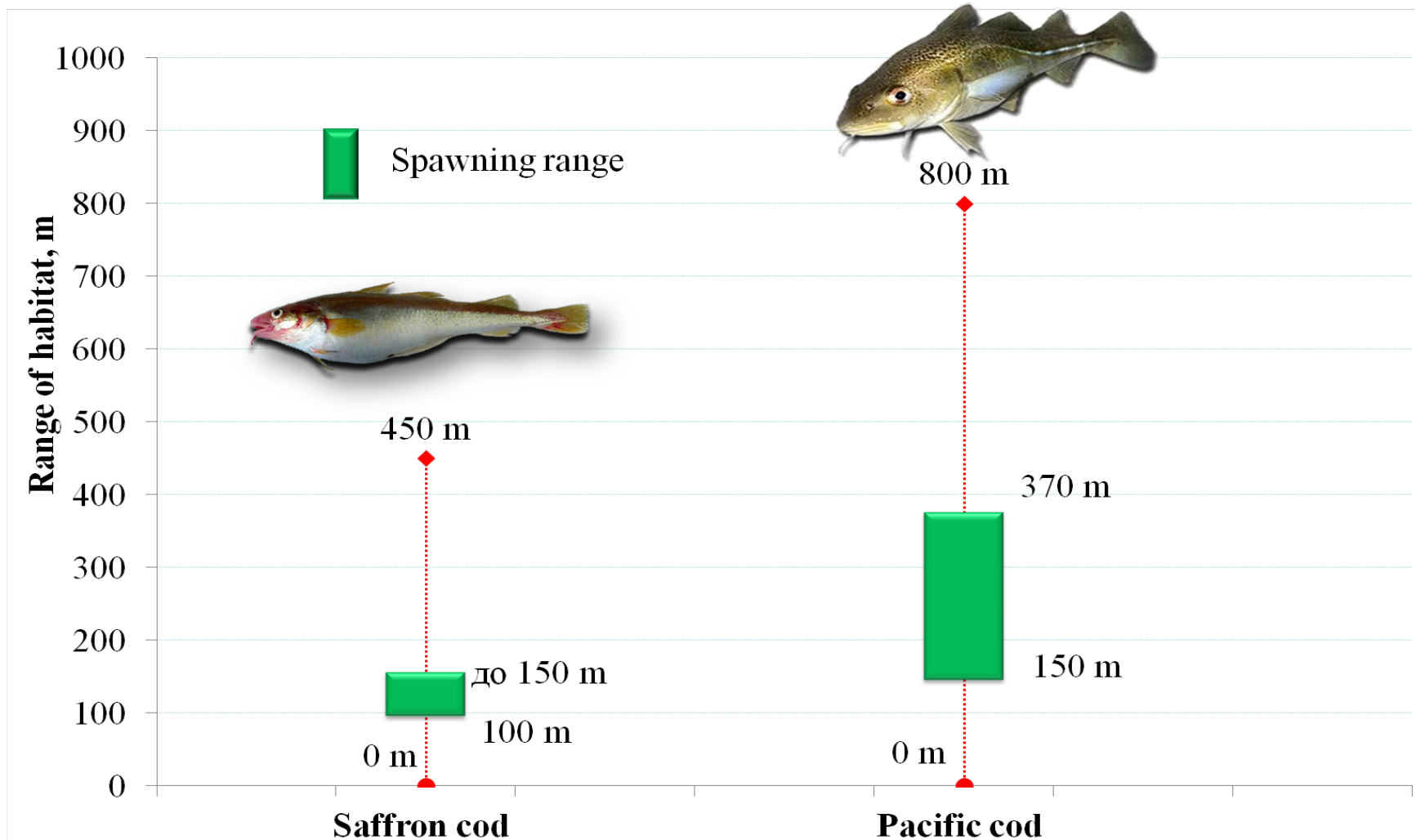
<https://www.esrl.noaa.gov/psd/data/climateindices/list/>

<http://www.pac.dfo-mpo.gc.ca> и

<http://www.03d.org/npgo/npgo.php>.

# Introduction

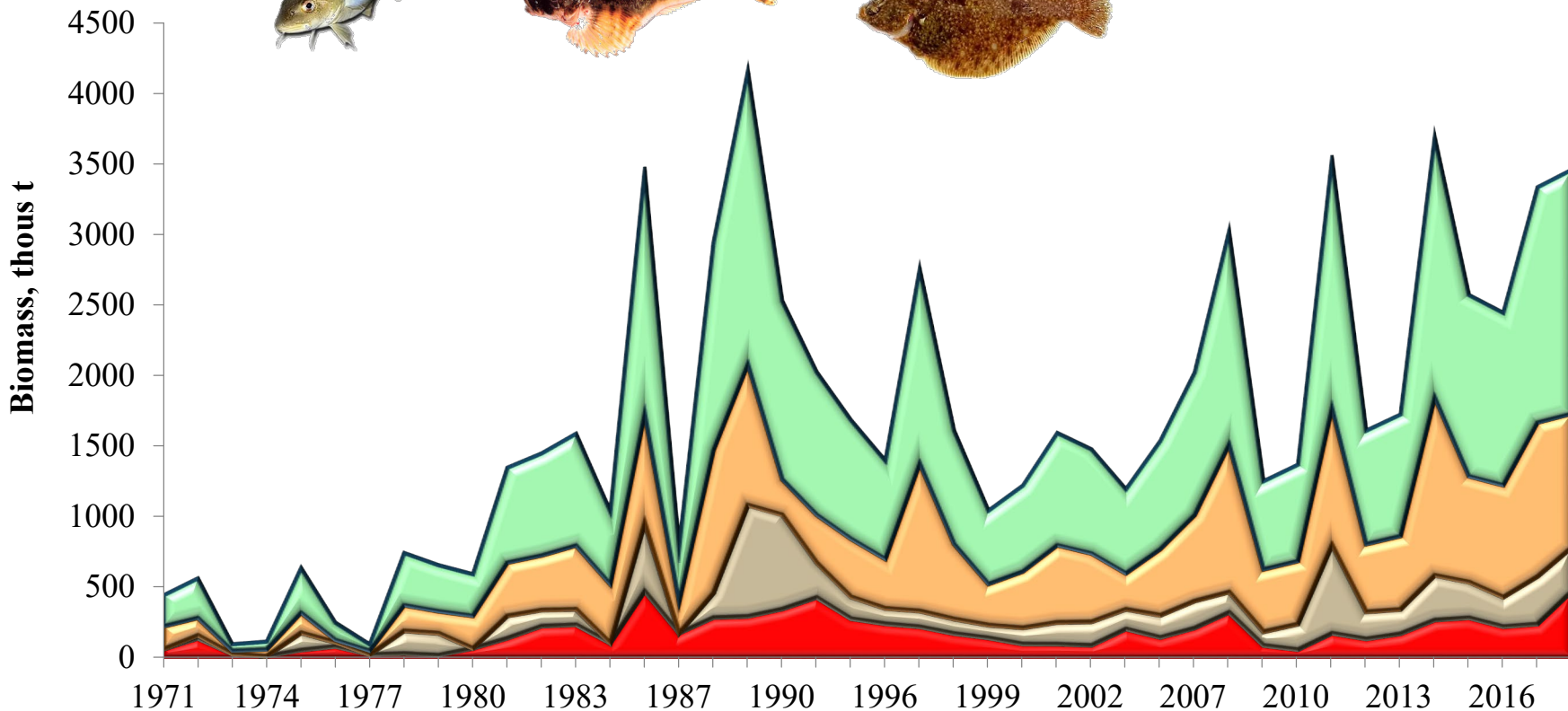
Depth range of the habitats and spawning grounds of saffron cod and Pacific cod (eastern part of the Sea of Okhotsk)



# Introduction

The total biomass of demersal fish (cod and saffron cod) decreased significantly from the last half of the 1990s due to decrease of the cod stock

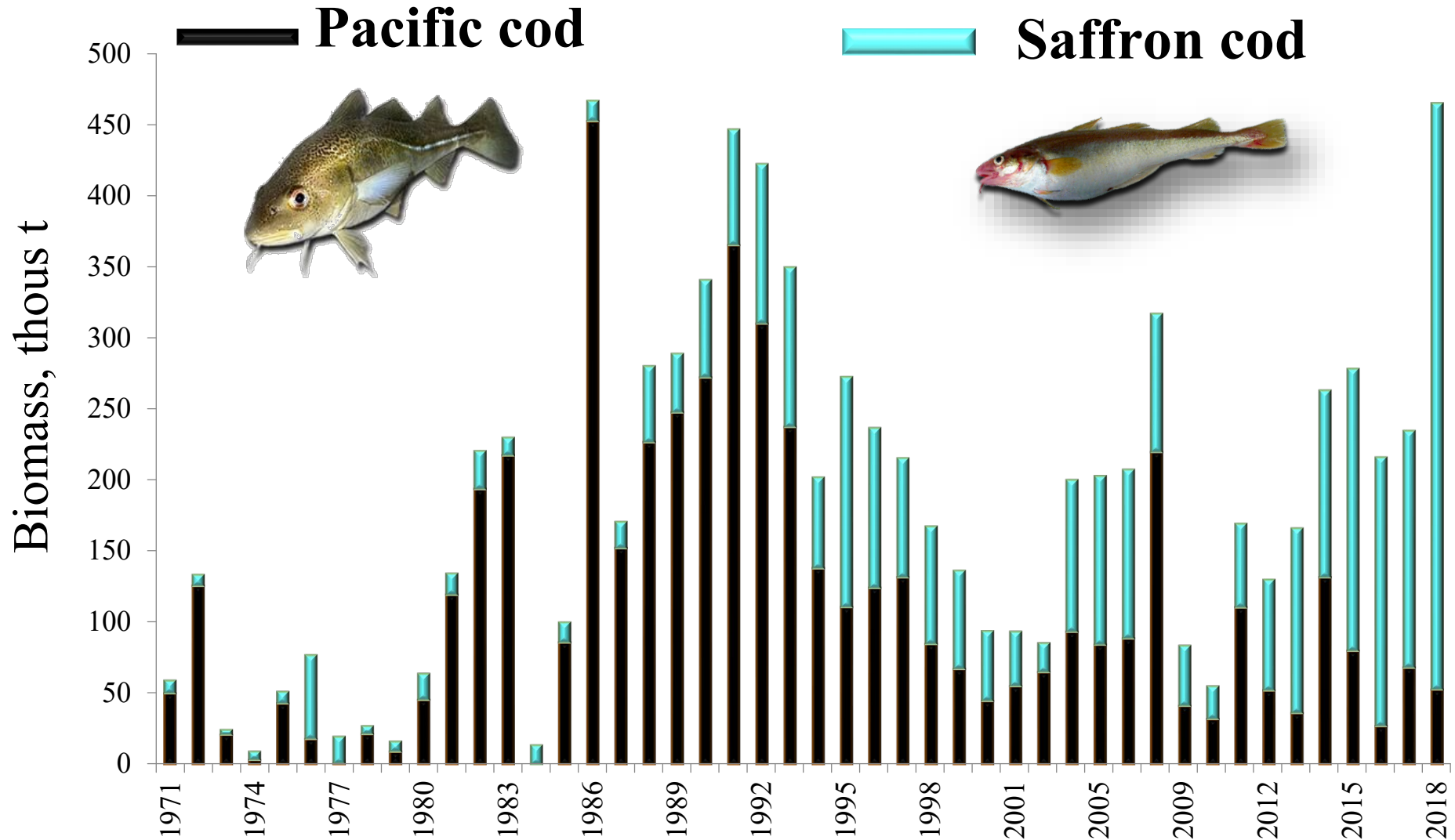
■ Gadidae   ■ Cottidae   ■ Pleuronectidae   ■ All major species





# Introduction

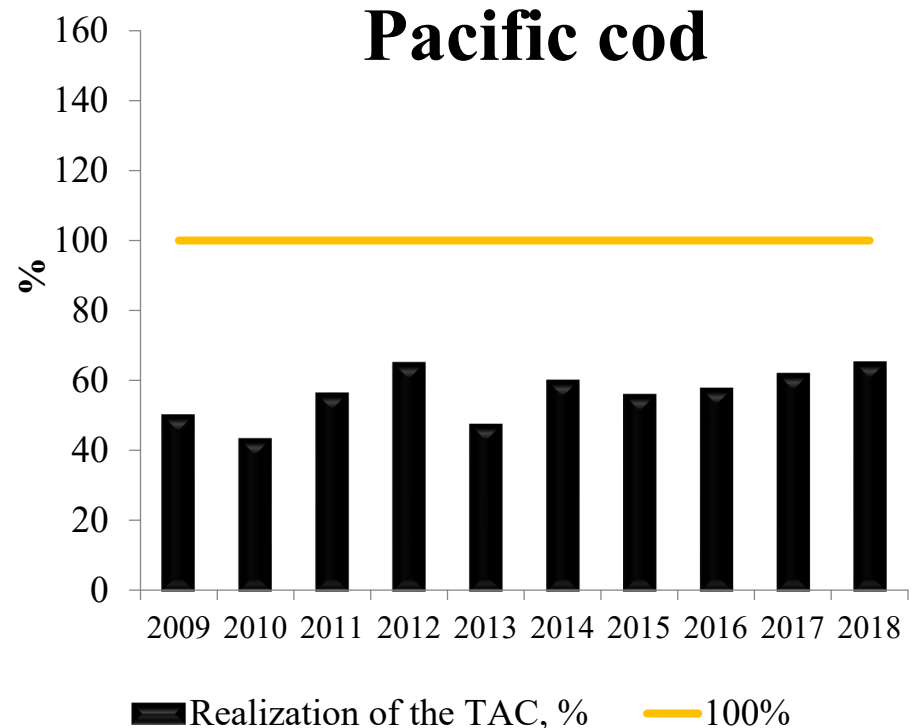
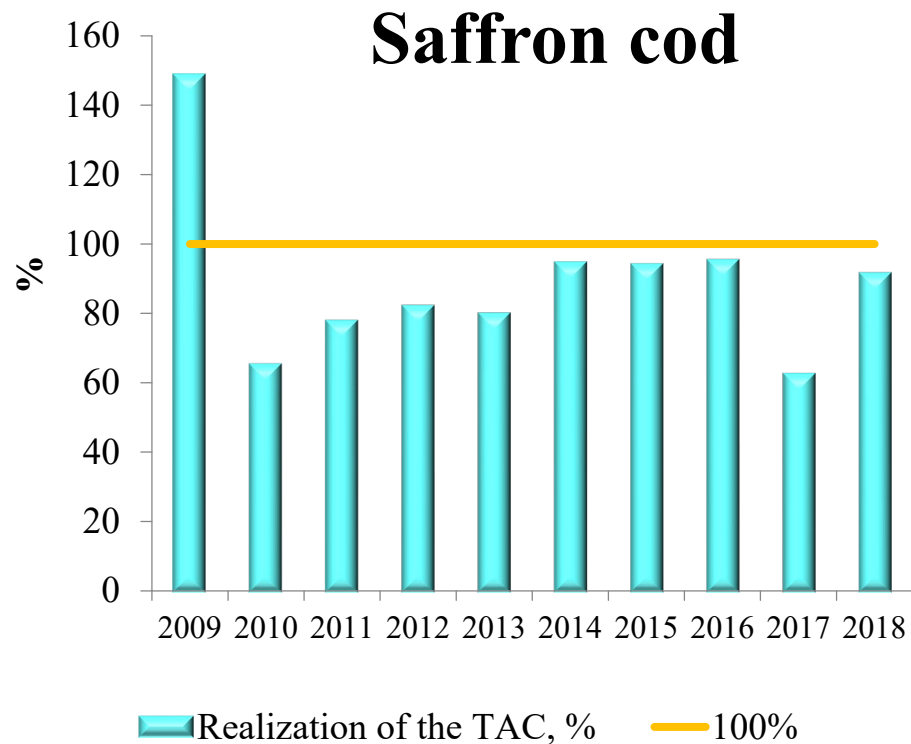
Consequent decrease of the Pacific cod stock abundance to a low level and a quick increase of the biomass of saffron cod





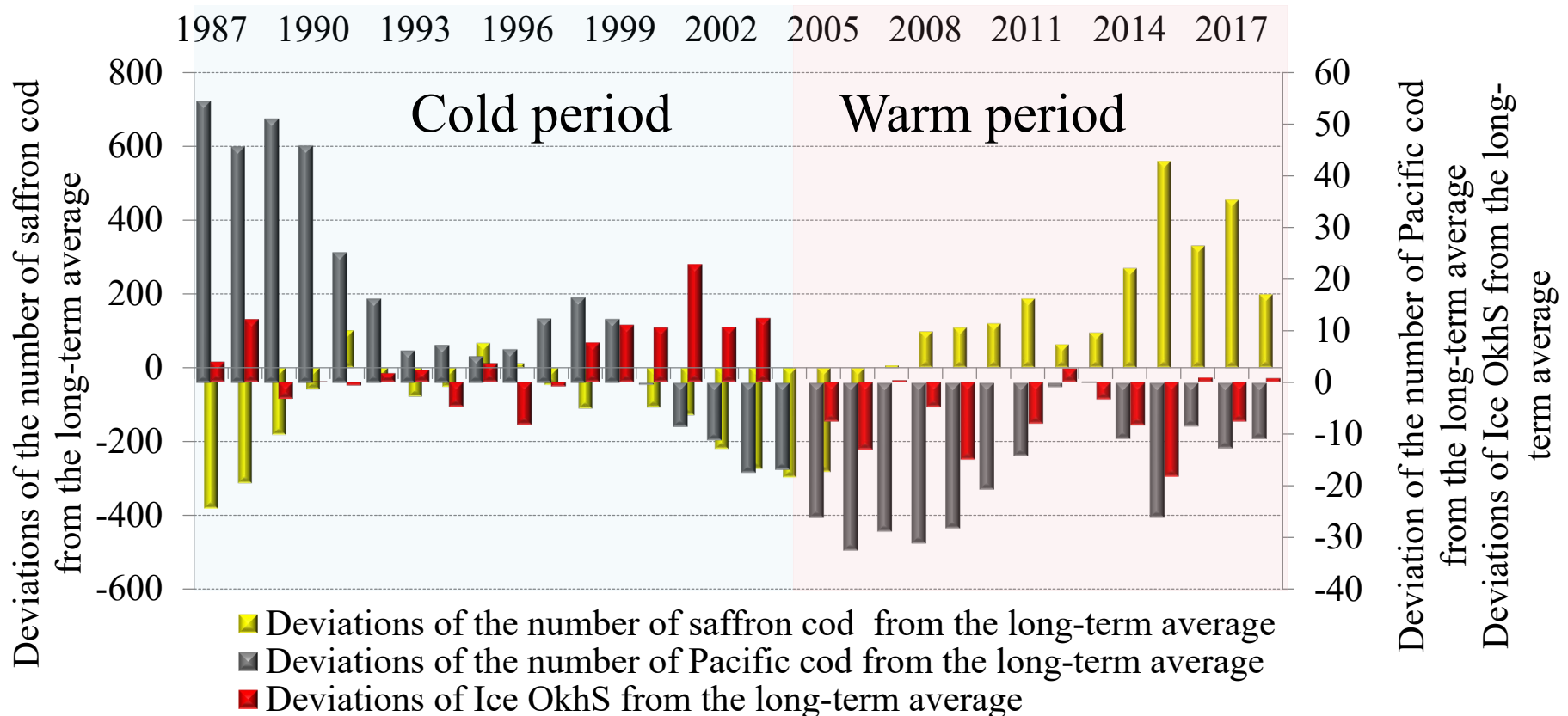
# Introduction

The ratio between the stock biomasses was observed at the background of underexploiting the resources of cod and almost 100% realization of the TAC for saffron cod



# Results

Correlation coefficients between saffron cod and Pacific cod stock abundance (eastern part of Okhotsk sea, 1987–2018)



The stock abundance of Pacific cod and saffron cod demonstrate changing in antiphase:  $R = -0.3811$ ,  $p = 0.031$

# Results

The values of the Pearson correlation coefficients ( $r$ ) and the confidence probability ( $p$ ), characterizing the correlation between the stock abundance of **saffron cod** and the climatic indices on the data for 1987–2018 (**the lag of 1 year**)

Climatic indices	Ice OkhS	NPGO	SST	SSTa	San Spot	PDO	AO	PNA	ALPI	WP
Stock abundance	-,0365	-,1719	,0297	<b>,5977</b>	,2388	,1324	,0280	-,2715	-,3515	-,1144
	p=,897	p=,540	p=,916	<b>p=,022</b>	p=,391	p=,638	p=,921	p=,328	p=,199	p=,685

*Saffron cod had highly abundant generations in case of increasing surface temperature of the Sea of Okhotsk near the coast of Kamchatka (SSTa) ( $r = 0,59$ ).*

## Results

The values of the Pearson correlation coefficients ( $r$ ) and the confidence probability ( $p$ ), characterizing the correlation between the stock abundance of **saffron cod** and the climatic indices on the data for 1987–2018 (**the lag of 3 years**)

Climatic indices	Ice OkhS	NPGO	SST	SSTa	San Spot	PDO	AO	PNA	ALPI	WP
Stock abundance	<b>-0,6651</b>	,1586	-,4370	,0880	-,2489	,4478	,0782	-,5027	,1354	-,3351
	<b>p=,024</b>	p=,684	p=,239	p=,822	p=,518	p=,227	p=,842	p=,168	p=,728	p=,378

*Highly authentic negative correlation was obtained between the abundance of generation reached mass maturation and ice condition of the sea (Ice OkhS) ( $r = -0.6651$ ).*

# Results

The values of the Pearson correlation coefficients ( $r$ ) and the confidence probability ( $p$ ), characterizing the correlation between the stock abundance of **Pacific cod** and the climatic indices on the data for 1971–2018 (**the lag of 1 year**)

Climatic indices	Ice OkhS	NPGO	SST	SSTa	San Spot	PDO	AO	PNA	ALPI	WP
Stock abundance	<b>0,841</b>	,1562	-,1879	,2102	-,0829	,3247	,1897	-,3334	,1289	-,5048
	<b>p=,000</b>	p=,578	p=,502	p=,452	p=,769	p=,238	p=,498	p=,225	p=,647	p=,055

*With the lag of 1 year Pacific cod demonstrated highly authentic correlation to the ice condition of the sea (Ice OkhS) ( $r = 0,84$ ).*

## Results

The values of the Pearson correlation coefficients ( $r$ ) and the confidence probability ( $p$ ), characterizing the correlation between the stock abundance **Pacific cod** and the climatic indices on the data for 1971–2018 (**the lag of 4 years**)

Climatic indices	Ice OkhS	NPGO	SST	SSTa	San Spot	PDO	AO	PNA	ALPI	WP
Stock abundance	,0192	-,0937	-,5825	-,1034	-,3573	<b>,6955</b>	,3394	,3353	,1617	,4986
	p=,961	p=,810	p=,100	p=,791	p=,345	<b>p=,038</b>	p=,372	p=,378	p=,678	p=,172

*With the lag of many years (4 years) the most strong correlation was obtained in case of the change of the Pacific Decade Oscillation (PDO) phase ( $r = 0,69$ ), calculated on the ocean water surface temperature anomalies.*

# Results

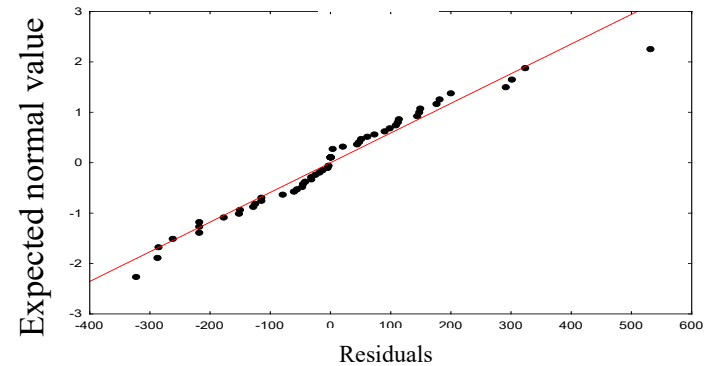
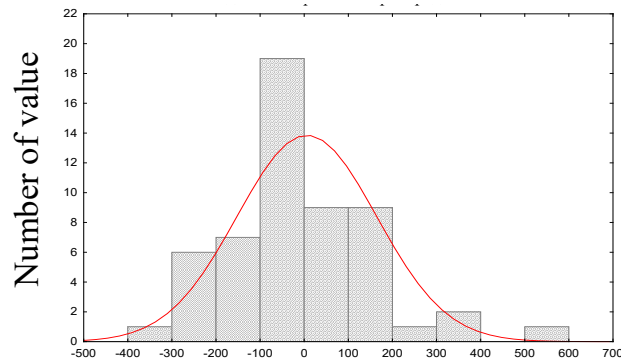
The results of the multidimensional regression modeling the correlations between the **saffron cod** stock abundance (mln.) and the climatic indices on the data for 1987–2018

With the lag of 1 year

The results of the regression						General parameters of dependent variables						
R	R <sup>2</sup>	SE	F	df	p	Predictor	Beta	SE (Beta)	B	SE (B)	t	p
0,48	0,23	207,1	1,2	4,24	0,15	b <sub>1</sub> (ALPI)	-0,27	0,18	-24,5	16,4	-1,49	0,14
						b <sub>2</sub> (WP)	-0,20	0,18	-116,0	104,2	-1,11	0,27
						b <sub>3</sub> (PNA)	-0,26	0,18	-11,7	8,3	-1,39	0,17
						b <sub>4</sub> (PDO)	0,23	0,18	55,9	44,2	1,26	0,21



Expected normal distribution



*The level of the correlation was  $R = 0,48$  with the lag of 1 year. In this case all indices, determining the conjugacy of the multidimensional interaction, were unreliable.*



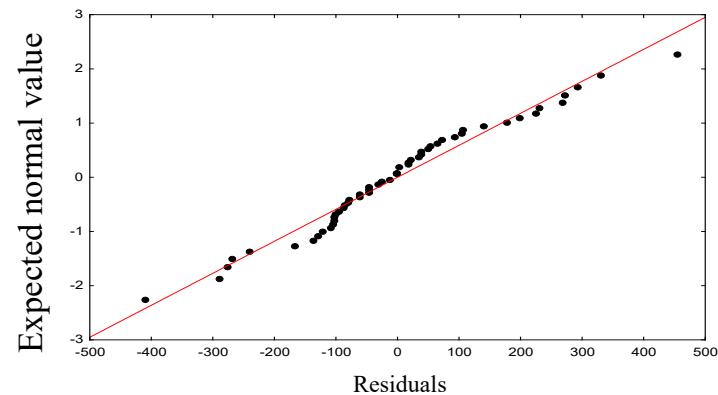
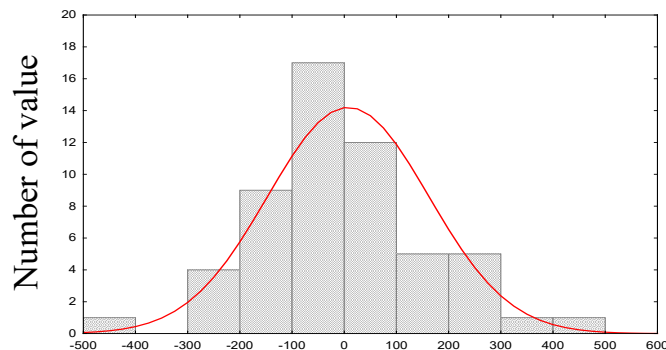
# Results

The results of the multidimensional regression modeling the correlations between the **saffron cod** stock abundance (mln.) and the climatic indices on the data for 1987–2018

With the lag of 3 years

The results of the regression						General parameters of dependent variables						
R	R <sup>2</sup>	SE	F	df	p	Predictor	Beta	SE (Beta)	B	SE (B)	t	p
0,58	0,34	194,2	2,7	4,22	<0,05	<b>b<sub>1</sub> (PNA)</b>	<b>-0,52</b>	<b>0,18</b>	<b>-23,6</b>	<b>8,4</b>	<b>-2,79</b>	<b>&lt;0,05</b>
						b <sub>2</sub> (WP)	-0,25	0,17	-146,2	99,5	-1,46	0,15
						b <sub>3</sub> (PDO)	0,37	0,21	87,9	49,1	1,79	0,08
						b <sub>4</sub> (NPGO)	0,24	0,20	52,3	43,4	1,20	0,24

Expected normal distribution



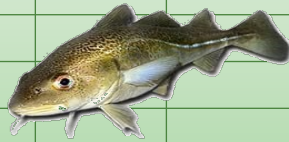
*The level was higher  $R = 0,58$  with the lag of many years (3 years). Nevertheless, the results of the multidimensional modeling demonstrated only one reliable index –  **$b_1$  (PNA) = -0,52**.*

# Results

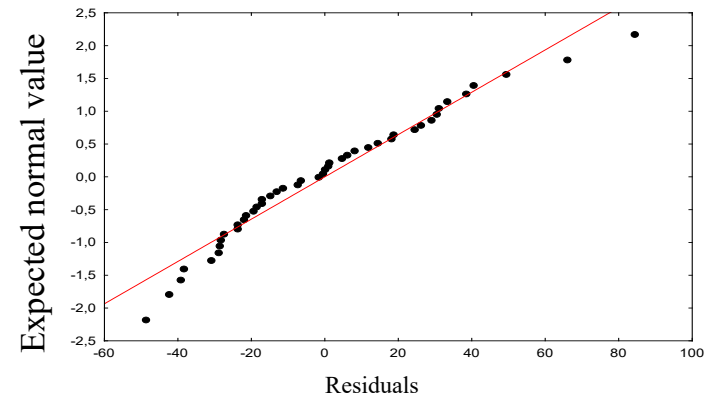
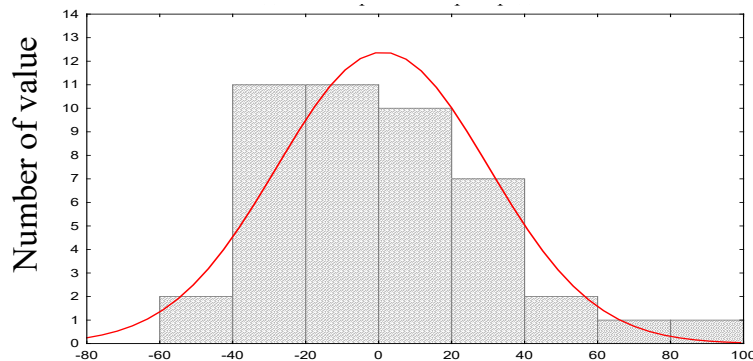
The results of the multidimensional regression modeling the correlations between the **Pacific cod** stock abundance (mln.) and the climatic indices on the data for 1971–2018

With the lag of 1 year

The results of the regression						General parameters of dependent variables						
R	R <sup>2</sup>	SE	F	df	p	Predictor	Beta	SE (Beta)	B	SE (B)	t	p
0,58	0,34	31,4	5,4	4,0	<0,01	<b>b<sub>1</sub> (PDO)</b>	<b>0,42</b>	<b>0,13</b>	<b>17,0</b>	<b>5,3</b>	<b>3,18</b>	<b>&lt;0,01</b>
						b <sub>2</sub> (SanSpot)	0,20	0,13	0,11	0,1	1,52	0,13
						b <sub>3</sub> (ALPI)	0,26	0,13	3,9	2,0	1,98	0,05
						b <sub>4</sub> (AO)	0,17	0,13	15,8	12,3	1,28	0,21
						b <sub>5</sub> (WP)	-0,16	0,13	-15,2	12,6	-1,20	0,24



Expected normal distribution



*In case of Pacific cod the most strong index was **b<sub>1</sub> (PDO) = 0,42** with the lag of 1 year. Multidimensional modeling provided the multiple regression coefficient **R = 0,58**.*

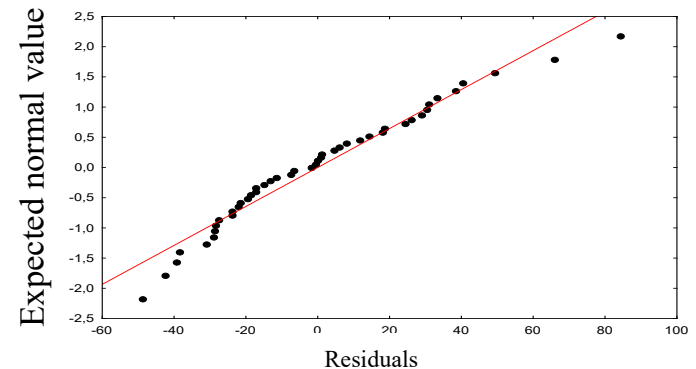
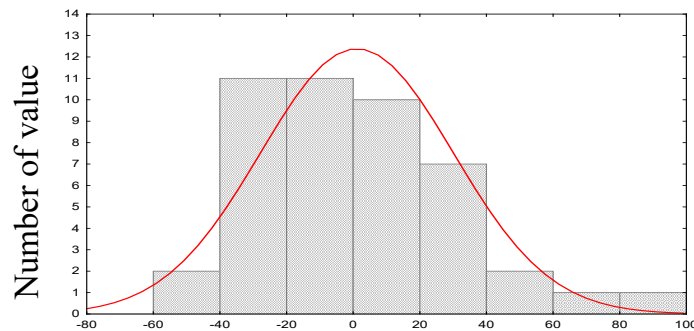
# Results

The results of the multidimensional regression modeling the correlations between the **Pacific cod** stock abundance (mln.) and the climatic indices on the data for 1971–2018

With the lag of 4 years

The results of the regression						General parameters of dependent variables						
R	R <sup>2</sup>	SE	F	df	p	Predictor	Beta	SE (Beta)	B	SE (B)	t	p
0,70	0,49	27,0	3,9	6,25	<0,01	b <sub>1</sub> (SanSpot)	0,28	0,18	0,1	0,1	1,55	0,13
						<b>b<sub>2</sub> (PDO)</b>	<b>0,40</b>	<b>0,15</b>	<b>15,0</b>	<b>5,5</b>	<b>2,73</b>	<b>&lt;0,05</b>
						b <sub>3</sub> (WP)	0,13	0,17	11,9	15,7	0,76	0,45
						b <sub>4</sub> (PNA)	-0,17	0,15	-1,3	1,2	-1,11	0,27
						b <sub>5</sub> (SST)	-0,27	0,18	-20,9	14,1	-1,48	0,15
						b <sub>6</sub> (AO)	0,22	0,19	17,3	14,9	1,16	0,25

Expected normal distribution



*The level of the correlation between the climatic indices and generation stock abundance, when more than 50% of individuals being mature (the lag of 4 years), was higher  $R = 0,70$ . The index  **$b_2$  (PDO) = 0,40** was also statistically significant.*

# Results

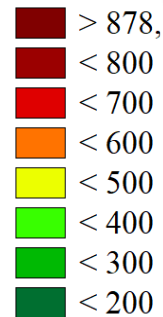
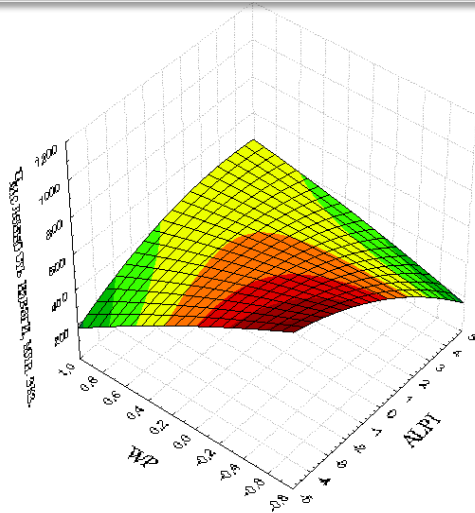
The correlation between the **saffron cod** stock abundance (mln.) and the most strong climatic indices on the data for 1987–2018

With the lag of 1 year

**Stock abundance saffron cod**

$$=548,524-(27,6877*ALPI)-(109,4662*WP)-$$

$$(3,8562*ALPI*ALPI)+(54,5675*ALPI*WP)-(28,3991*WP*WP)$$



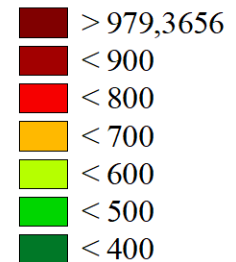
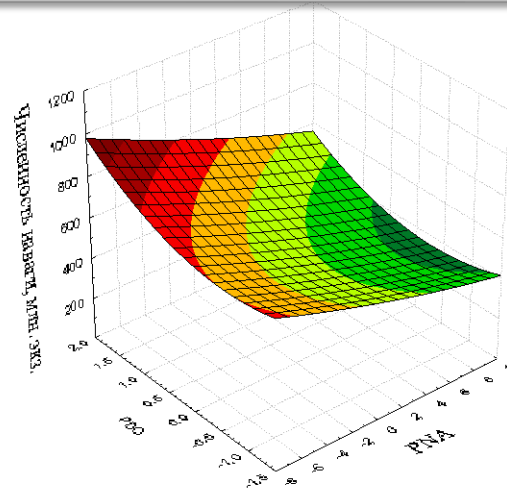
R	R <sup>2</sup>	p	Indices
0,38	0,14	0,13	ALPI, WP

With the lag of 3 years

**Stock abundance saffron cod**

$$=531,8941-(20,5329*PNA)+(36,553*PDO)+(0,2793*PNA*PNA)-$$

$$(1,6664*PNA*PDO)+(41,3915*PDO*PDO)$$



R	R <sup>2</sup>	p	Indices
0,49	0,24	<0,05	PNA, PDO

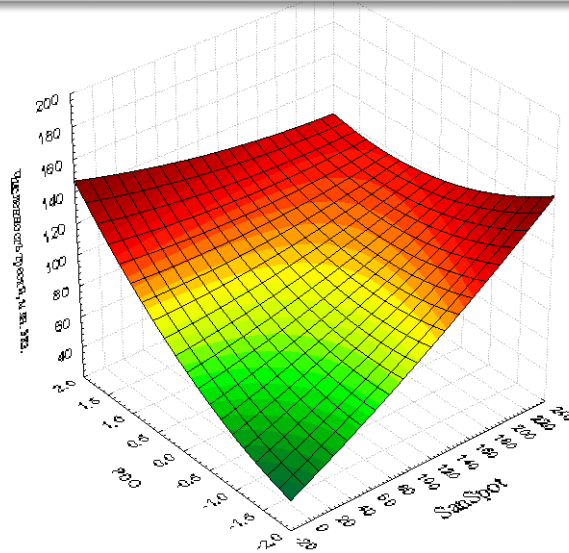
# Results

The correlation between the **Pacific cod** stock abundance (mln.) and the most strong climatic indices on the data for 1971–2018

**With the lag of 1 year**

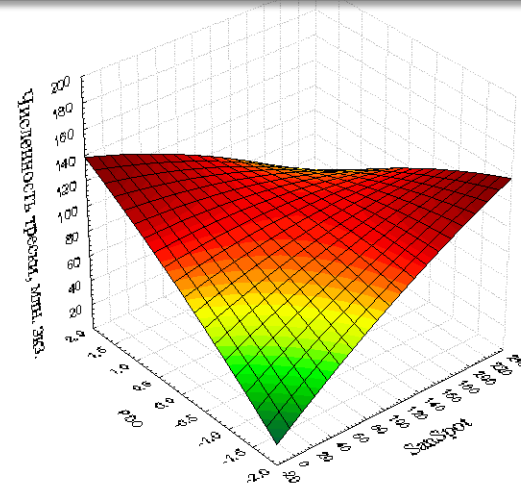
**Stock abundance Pacific cod**

$$=78,3453+(0,0981*\text{SanSpot})+(24,2011*\text{PDO})+(0,0003*\text{SanSpot}*\text{SanSpot})-(0,1324*\text{SanSpot}*\text{PDO})+(4,1401*\text{PDO}*\text{PDO})$$



**Stock abundance Pacific cod**

$$=87,9104+(0,1659*\text{SanSpot})+(26,3234*\text{PDO})-(0,0005*\text{SanSpot}*\text{SanSpot})-(0,2058*\text{SanSpot}*\text{PDO})-(1,7074*\text{PDO}*\text{PDO})$$



R	R <sup>2</sup>	p	Indices
0,31	0,15	<0,05	SanSpot, PDO

R	R <sup>2</sup>	p	Indices
0,50	0,24	<0,01	SanSpot, PDO

# Conclusion

- In **direct correlative** analysis the prolific generations of **saffron cod** appeared with increasing temperature anomalies of the surface of sea of Okhotsk near the Western coast of Kamchatka (SSTa) ( $r = 0,58$ ). Highly reliable negative correlation was obtained between the number of fish generation reached mass puberty and the ice coverage of the Okhotsk sea (Ice OkhS) ( $r = -0.66$ ).
- With a lag of 1 year **Pacific cod** was noted high reliable correlation with Ice OkhS ( $r = 0.84$ ). With a long-term lag (4 years), the strongest dependence was obtained with phase change Pacific decadal oscillation (PDO) ( $r = 0.69$ ).

# Conclusion

- Stepwise multivariate regression analysis has showed the greatest impact the indices **PNA** on **saffron cod**, and the indices **PDO** on **Pacific cod**. All the obtained results showed the presence of true relationships with the number of generations of fish in the second year of life and with the number of generations of fish that have reached more than 50% of maturation.
- On the basis of the obtained equations of multiple regression of the relationship between the numbers of fish with the selected most active climatic indices, three-dimensional regression models were constructed, satisfactorily describing the dynamics of the initial numbers of fish.