Responses of relative abundance of dominants in fish communities to the Sea of Okhotsk climate variability

Vladimir Kulik

Pacific Fisheries Research Centre (TINRO-Centre), Vladivostok, Russia. E-mail: vladicon82@gmail.com

Summary

The dynamics of the relative abundance of dominant species and the dynamics of the factor scores of all the rest of the species of nekton in the upper and entire epipelagic layers is studied by years, according to the data of the summer and autumnal comprehensive ecosystem studies of the Sea of Okhotsk (1984–2006). Time-spatial differences in the discovered agreements of the fluctuations of relative abundance of species, abstractly have been the factors of multivariate analysis, with the dynamics of the number of sun spots. Climate Indices of the Northern Pacific, hydro- and atmospheric principal components and EOFs of the Sea of Okhotsk are discussed. Perceptible deviation of biotic factor scores noted in 1990, 1991 and 1997, 1998. Strong ($|R| \geq 0.8$) and statistically significant ($p < 0.05$) correlations between changes of relative abundance of species and abiotic factors of environment with a time-lag up to 6 years are extremely rare and most of them appeared as a result of analyzing data samples with a big proportion of common null values. A great role of casual variations is assumed. Attempts to use moving average and autocorrelation functions during time series analysis in most cases fail because there are a lot of gaps in the short time series (less than 25 years) we have. Even the successful one is useless yet because of a big confidence interval which is greater than the observed variability.

Introduction

Shuntov (1986) made a successful forecast for the long-term fluctuation in abundance of the main species in the Far Eastern Seas. Shuntov and his adherents considered that environmental changes were influenced by cosmic and climatic cyclicity. Some TINRO-Centre scientists believe that, in general, the higher trophic levels have sufficient resources for the consumers in the Sea of Okhotsk (Shuntov *et al.*, 1990; Temnykh *et al* 2003), despite the fact that in some regions during certain years there was a high demand for the resources (Kuznetsova, 2005; Chuchukalo, 2006). The study of Far Eastern Seas ecosystems has been based on independent data from commercial fishery scientific surveys, conducted in the late 1970s. Scientists from the Laboratory of Applied Biocenology, TINRO-Centre, processed millions of these records to filter out and normalize the most valuable data to build a new Geo Informatic System and Biological DataBase (BioDB) with datasets of acceptable quality for year-to-year comparisons, independent of the instruments and methods used. The first results of BioDB data processing and analysis, with a 5-year smoothing of selected datasets, were presented in the series of atlases and collection of tables edited by Shuntov and Bocharov (2003a, b). The Laboratory of Applied Biocenology is also trying to determine how the interannual variability of values in our BioDB can be used to forecast short time series. This work describes the use of the correlation method for time series analyses.

Biological patterns

Because of the lack of data for some years, we had to combine some time series from 7 biostatistical regions of the Sea of Okhotsk (Fig. 1); some data were also excluded. The number of sampling stations grouped by region from 1984 to 2006 is shown in Table 1.

The next task was to choose an abstraction method for presenting more then 300 registered marine species. It is almost impossible to describe all selected data records; therefore a principal components analysis (PCA) was used to extract the main factors in biomass fluctuation of communities. Main fish species were not associated with any such factor. Therefore, dominant fish communities were analyzed separately. All biological data sets were normalized by a logarithmic function ($\lg(m + 1)$, where m is kg km^2).

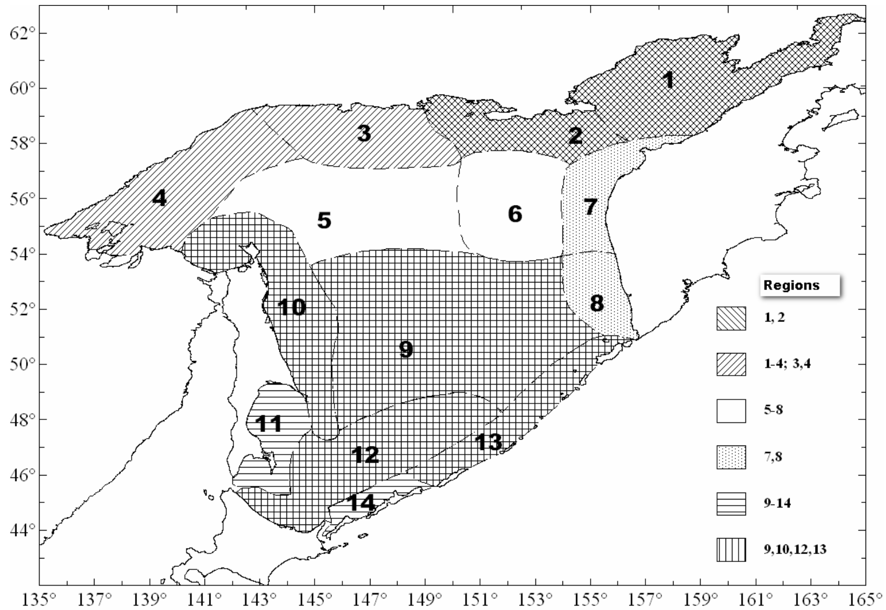

Fig. 1 Grouping of biostatistical regions in the Sea of Okhotsk.

Table 1 Number of samples (the number of stations) in each of seven observational series.

Year	Summer				Fall		
	Upper pelagic layer			Pelagic layer	Upper pelagic layer	Pelagic layer	
	Regions* 1–2	Regions 5–8	Regions 9–14	Regions 3–4	Regions 9, 10, 12, 13	Regions 1–4	Regions 7–8
1984	–**	–	–	–	3	28	10
1985	–	–	–	–	17	42	21
1986	4	15	20	24	–	–	–
1987	–	–	–	–	5	35	–
1988	18	22	26	9	–	–	–
1989	–	–	–	–	–	–	–
1990	–	–	–	–	–	9	14
1991	–	33	79	–	23	–	6
1992	4	64	50	–	–	–	–
1993	–	–	147	–	–	22	–
1994	13	54	86	–	19	11	–
1995	26	36	207	–	19	–	–
1996	–	45	84	–	–	–	–
1997	12	35	27	8	–	–	–
1998	–	–	24	20	36	26	21
1999	–	–	30	14	38	19	14
2000	–	–	32	19	44	23	22
2001	–	–	41	21	47	36	14
2002	–	–	37	10	27	13	–
2003	–	–	–	–	–	–	–
2004	–	–	–	–	44	35	–
2005	–	–	–	–	–	–	–
2006	–	–	–	–	46	13	–

* Scheme of combining biostatistical regions used here is taken from Figure 1.
** No data available, or the number of stations is less then 3.

Regime shifts in total abundance of nekton in the Sea of Okhotsk

It is known that there were some significant regime shifts of the Principal Component (2) SST index in the North Pacific region in 1990 and 1998 (Rodionov *et al.*, 2006). Figure 2 shows that even those species that migrate from mesopelagic depths to the upper pelagic layer also shifted their abundance in 1990–1991 and 1997–1998.

Thus we were motivated to measure the power of correlation between changes in the world with known climatic indices of the Northern Pacific and relative biomass fluctuation of nekton species.

Correlations between abiotic and biotic factors in the Sea of Okhotsk

We first used AOI, NPI.CPC, PDOw, PDOs, PDOa, SI, WPw, WPsp, NPI climatic indices (http://www.beringclimate.noaa.gov) for canonical analysis and relative species abundance. Results showed only one strong and significant (*Canonical R = 0.82585, Chi(70) = 104.22, p* << 0.01) correlation between changes in the WPw index and fluctuation of relative abundance of jelly fish and juvenile chum salmon in the upper pelagic layer during autumn, with a 5-year time lag, which was biologically unrealistic. Other significant correlations were not as strong between the WPw and pink salmon and rock trout juveniles in summer in the upper pelagic layer after a 4- and 6-year time lag (*Canonical R = 0.62690, Chi(54) = 121.58, p << 0.01*) and between the PDOw, SI and walleye pollock and herring juveniles in the epipelagic layer after a 1-year time lag (*Canonical R = 0.55328, Chi(48) = 84.184, p << 0.01*). Only one pair (PDOw, SI and walleye pollock) looks close to normal (Fig. 3) and could be explained, but it is not our main goal. All other 3D graphs showed very bad surface interpolations with negative abundance values in possible integers, and deviations from surfaces were also too big.

We found that the Siberian Index had the most frequent significant correlations with species. Also referred to as the Siberian Center, it reflects the strength of the Siberian High, and thus, the advection of cold Siberian air into the Sea of Okhotsk.

We next checked the strength of statistical correlations of changes in relative abundance of species with different local types of atmospheric and hydrospheric circulations, and compared them with sun spot activity. We chose the types of atmospheric processes over the Sea of Okhotsk classified by Glebova (2002, 2009) and empirical orthogonal functions (EOFs) of Sea of Okhotsk hydrodynamics extracted by Luchin (Luchin and Zhigalov, 2006; Luchin, 2008). Relative species abundance was presented as the principal components obtained from the groups with the longest time series. We had to use a rank type (Spearman) correlation analysis because the dimensions of different variables were not comparable.

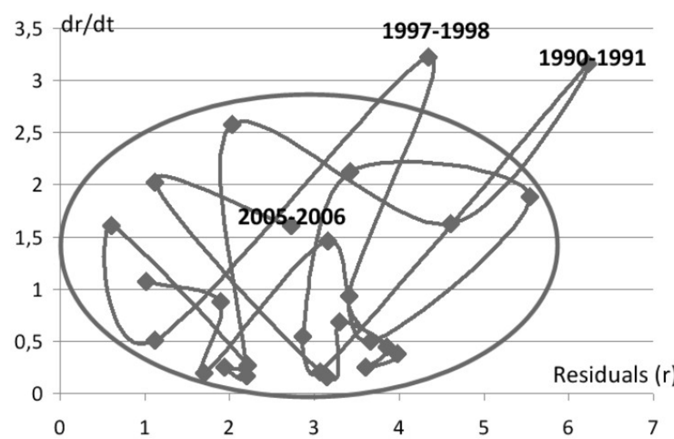

Fig. 2 The velocity of changes (dr/dt) vs residuals (r) of average subtraction from total normalized nekton biomass fluctuation in the Sea of Okhotsk.

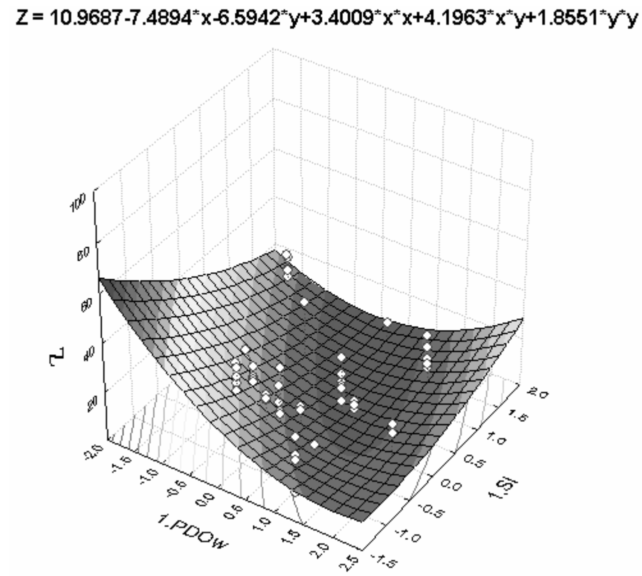

Fig. 3 Surface interpolation to the observed abundance of walleye pollock (Z), X and Y (horizontal) axes represent the values of climatic indices (PDOw and SI) with a 1-year time lag.

Before conducting further analysis, we wanted to know if there were any differences in the influential power on biological factors between sun spot activity, atmospheric and hydrospheric components. Therefore, nonparametric comparison analyses such as the Wald-Wolfowitz runs test, the Mann-Whitney U test, and the Kolmogorov-Smirnov two-sample test were chosen. The results were surprising because they were all different from each other. We obtained from non-significant differences to the next sequence: Hydro ->Atmo -> Sun or Hydro = Atmo > Sun due to the low frequency of strong and significant correlation occurrence. For example, only 6.5% of strong and significant correlation coefficients out of 1320 possible interactions in summer (Table 2) and 5.7% of 1122 possible interactions in autumn (Table 3) were found.

A little hope for stochastic modeling

Bernoulli first described the random walk in the 18th century. Later, Laplas, Brown, Einstein, and Viner advanced the techniques of analyzing stochastic processes (which are widely distributed in natural and technical events). However, population biologists often prefer to use deterministic models which require precise parameters that cannot be obtained experimentally in most cases. Why do they choose to estimate unknown parameters and make a lot of runs instead of using stochastic models so popular among physicists and economists?

The first problem to be solved is: How to fulfill the gaps in a time series where the quantity of real data values is sometimes less than the quantity of absent observations? The second question is: What should we do if the time period is not long enough to determine a model type?

Our answers do not pretend to be the best. At first, we did not use a time series with a big portion of zero values, and then we tried all possible types of moving average and autocorrelation models provided by the program “Statistica”. As a result, we could not find an adequate stochastic model. Instead, we got white noise over covering (even on the rows with determined interventions) after the first trend subtracted run. Unfortunately, we do not have a long uninterrupted time series; therefore, we had to interpolate values for some years from the adjacent points even on the longest time series. In all cases, the models did not have acceptable confidence intervals because all of them were as wide as the observed variability.

Table 2 Significant Spearman correlation coefficients of species group factor scores in the Sea of Okhotsk in summer with types of atmospheric and hydrospheric processes and sun spot activity.

Types of circulation and sun spot activity	Upper epipelagic layer													Epipelagic layer						
	Regions 1–2			Regions 5–8							Regions 9–14			Regions 3–4						
	Bio factors			Bio factors							Bio factors			Bio factors						
	1	2	3	1	2	3	4	5	6	7	1	2	3	1	2	3	4	5	6	7
I-0*	–**	–	–	–	–	–	–	–	–	–	0.7	0.8	–	–	–	0.9	–	–	–	–
I-1	–	–0.8	–	–	–	–	–	–	–	–	–	0.6	–	–	–	–	–	–	–	–
I-2	–	–	–	–	–	–	–	0.8	–	–	–	–	–	–	–	–	–	–	–	–
I-3	–	–	–	–	–	0.8	–	–	–	–	–	–	–	–0.8	–	–	–	–	–	–
I-4	–1	–	–	–	–	–	–	0.7	–0.7	–	–	–	–	–	–	–	–	–	–	–
II-1	0.8	–	–	–	–	–0.8	–	–0.7	–	–	–	–	0.6	–	–	–	–	–	–	–
II-2	0.9	–	–	–	–	–0.8	–	–0.8	0.8	–	–	–	–	–	–	–	–	–	–	–
II-3	–	–	–	–	–	–0.9	–	–0.8	0.7	–	–	–	–	–	–	–	–	–	–	–
II-4	–	–	–	–	–	–0.7	–	–	–	–0.8	–	–	–	–	–	–	–	–	–	–
II-5	–	–	–	–	–	–	–	–	–	–	–	0.6	–	–	–	–	–	–	–	–
III-0	–	–	–	–	–	–	–	–	–	–	–	–0.8	–	–	–	–	–	–	–	–
III-1	–	–	–	–	–	–	–	–	–	–	–	–	–	0.9	–	–	–	–	–0.7	–
III-2	–	–	–0.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
III-3	–	–	–1	–	–	–0.7	–	–	–	–	–	–	–	–	–	–	–	–	–	–
III-5	–	–	1	–	–	–	–	–	–	–	–	–	–	–	0.9	–	–	–	–	0.7
IV-0	–	–	–0.9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
IV-1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.8	–	–
IV-2	–	–0.9	–	–	–	–	–	–	–	–	–	–	–	–	0.9	–	–	–	–	–
IV-3	–	–0.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
IV-4	–	–	0.9	–	–	–	–0.8	–	–	–	–	–	–	–	–	–	–	–	–0.8	–
IV-5	–	–	–	–	–	–	–	–	0.8	–	–	–	–	–0.9	–	–	–	–	–	–
V-3	–	–	–	–	–	–	–	–	0.8	–	–	–	–	–	–	–	–	–	–	–
VI-1	–	–	–	–	–	–	–	–	–	–	–	–0.7	–	–	–	–	–	–	–	–
VI-2	–	0.9	–	–	–	–	–	–	–	–	–	–	0.6	–	–	–	–	–	–	–
VI-3	–	–	–	–	–	–	–	–	–	–	–	–	0.6	–	–	–	–	–	–	–
VI-4	–	–	–0.8	–	–	–0.8	–	–	–	–	–	–	–	0.7	–	–	–	–	–	–
VI-5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.7	–	–

Table 2 Continued.

Types of circulation and sun spot activity	Upper epipelagic layer													Epipelagic layer						
	Regions 1–2			Regions 5–8							Regions 9–14			Regions 3–4						
	Bio factors			Bio factors							Bio factors			Bio factors						
	1	**2**	**3**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
VII-1	–	–	–	–	–	–	0.8	–	–	–	–	–	–	–	–	–	–	–	–	–
VII-2	–	–	–	–	–	–	–	–	–0.8	–	–	–	–	–	–	–	–	–	–	–
VII-3	–	–	–	–	–	0.7	–	0.9	–	–	–	–	–	0.7	–	–	–	–	–	–
VII-4	–	–	–	–	–	0.7	–	–	–	–	–	–	–	–	0.8	–	–	–	–	–
VII-5	–	–	–	–	–	–	–	–	–	0.7	–	–	–	–	–	–	–	–	–	–
SS -1	–	–	–	–	–	0.8	–	–	–	–	–	–	–0.7	–	0.8	–	–	–	–	–
SS -2	–	–	–	–	–	0.7	–	0.8	–0.8	–	–	–	–0.6	–	–	–	–	–	–	–
SS -3	–	–	–	–	–	0.7	–	0.8	–0.7	–	–	–	–	–	–	–	–	–	–	–
SS -4	–	–	–	–	–	–	–	–	–	–	–	–	–	–0.7	–	–	–	–	–	–
SS -5	0.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
v1-1	–	–	–	–	–	0.7	–	–	–	–	–	–	–	–	–0.7	–	–	–	–	–
v1-2	–	–	–	–	–	–	–	–	–	0.8	–	–	–	–	–	–	–	–	–	–
v1-3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–0.7	–
v1-5	–	–	–	–	–	–	–	–	–	0.8	–	–	–	–	–	–	–	–	–	–
v2-0	–	–	0.9	–	–	–	–	–	–	–	–	–0.5	–	–	–	–	–	–	–	–
v2-2	–	–	–	–	–	–	–	–	–	–	–	–0.5	–	–	–	–	–	–	–	–
v2-3	–	0.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
v2-5	–	–	–	–	0.7	–	–	0.7	–	–	–	–	–	–	–	–	–	–	–0.7	–
v3-0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–0.9	–	–
v3-2	–	–	–	–	–	–	–	–	–0.8	–	–	–	–	–	–	–	–	–	–	–
v3-5	–	–	–	–	–	–	–	–	–	–	–0.6	–0.7	–	–	–	–	–	–	–	–

* Roman numerals represent the type of atmospheric circulations described by Glebova (2002, 2009), SS – sun spot activity, v1, v2 and v3 – EOFs by Luchin and Zhnigalog (2006) and Luchin (2008). Arabic numbers after first signs present a time lag in years.

** Significance of correlation was low ($p > 0.05$).

Table 3 Significant Spearman correlation coefficients of species group factor scores in the Sea of Okhotsk in autumn with types of atmospheric and hydrospheric processes and sun spot activity.

Types of circulation and sun spot activity	Upper epipelagic layer					Epipelagic layer											
	Regions 9, 10, 12, 13					Regions 1–4						Regions 7–8					
	Bio factors					Bio factors						Bio factors					
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
I-0	–	–	–0.6	–	–0.6	–	–	–	–	–	–	–	–	–	–	–0.7	–
I-1	0.7	–	–0.7	–	–0.7	–	–	–	–	–	–	–	–	–	–	–	–
I-2	–	–	–0.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
I-4	0.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
II-0	–0.6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
II-1	–	–	–	–0.7	–	–	–	–	–	–	–	–	–	–	–	–	–
II-2	–	–	–	–0.6	–	–	–	–	–	–	–	–	–	–	–	–	–
II-4	–	–	–	–	–	–0.6	–	–	–	–	–	–	–	–	–	–	–
III-0	–	–	0.6	–	–	–	–	–	–	–	–	–	–	–	–	–	0.7
III-1	–	–	–	–	–	–	–	–	–	–	0.8	–	–	–	–	–	–
III-2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.7	–
III-4	–	–	0.6	–	–	0.7	–	–	–	–	–	0.7	–	–	–	0.7	–
IV-5	–	–	–	–	–	–	–	0.7	–	–	–0.7	–0.9	–	–	–	–	–
V-2	–	–	–	–0.6	–	–	–	–	–	–	–	–	–0.7	–	–	–	–
V-4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–0.8	–
V-5	–	–	–	–	–	–0.6	–	–	–	–	–	–	–	–	–	–0.8	–
VI-0	–	–	–	–	–	0.6	–	–	–	–	–	–	–	–	–	–	–
VI-1	–	–	–	–	–	–	–	0.6	–	–	–	–	–	–	–	–	–
VI-2	–	–	–	–	–	–	–	–	–	–	–	–	0.8	–	–	–	–
VI-4	–	–	–	–	–	–	–	–	–	–	–	0.7	–	–	–	–	–
VII-0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–0.8
VII-1	–0.6	–	–	–	–	–	–	–	–0.6	–	–	–	–	–	–	–	–
VII-2	–	–	–	0.8	–	–	–	–	–	–	–	–	–	–	–	–	–
VII-3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–0.7	–	–
VII-4	–	–	–	–	–	–	–	–	–	0.6	–	–	–	–	–	–	–
VII-5	–	–	–	–	–	0.6	–	–	–0.6	–	–	–	–	–	–	–	–

Table 3 Continued.

Types of circulation and sun spot activity	Upper epipelagic layer					Epipelagic layer											
	Regions 9, 10, 12, 13					Regions 1–4						Regions 7–8					
	Bio factors					Bio factors						Bio factors					
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
SS -0	–	–	–	–	–	–	–	–0.8	–	–	–	–	–	–	–	–	–
SS -1	–	–	–	–	–	–	–	–0.7	–	–	–	–	–	–	–	–	–
SS -3	–	–	–	–	–0.6	–	–	–	–	–	–	–0.9	–	–	–	–	–
SS -4	–	–	–	–	–	–	–	0.6	–	–	–	–	–	0.8	–	–	–
SS -5	–	–	–	–	–	–	–	0.8	0.6	–	–	–	–	–	–	–	–
v1-0	0.6	–	–0.7	–	–0.7	–	–	–	–	–	–0.8	–	–	–	–	–	–
v1-3	–	–	–	–	–	–	–0.6	–	0.6	–	–	–	–	–	–	–	–
v1-4	–	–	–	0.6	–	–	–	–	–	–	–	–	–	–	–	–	–
v1-5	–	–	–	–	0.6	–	–	–	–	–	–	0.9	–	–	–	–	–
v2-2	–	0.7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
v2-3	–	–	–	–	–	–	0.7	–	–	–	–	–	–	–	–	–	–
v2-5	–	–	–	–	–	–	–	–	–	–	0.6	0.9	–	–	–	–	–
v3-0	–	–	–	–	–	–	–	–	–	–0.8	–	–	–	–	–	–	–
v3-2	–	–	–	–	–	–	–	–	–	–	–	–	0.8	–	–	–	–
v3-4	–	–	–	–	–	0.7	–	–	–	–	–	–	–	–	–	–	–

* Roman numerals represent the type of atmospheric circulations by described by Glebova (2002, 2009), SS – sun spot activity, v1, v2 and v3 – EOFs by Luchin and Zhigalov (2006) and Luchin (2008). Arabic numbers after first signs present a time lag in years.

** Significance of correlation was low ($p > 0.05$).

Conclusions

In spite of the large number of indices and indicators used operationally all over the Northern Pacific to quantify the state of the climate and its variability, almost none of them can be used to predict interannual changes in biological parameters, or dominant nekton species of the epi- and upper epipelagic layer of the Sea of Okhotsk. With all the power of statistics, why are we still unable to make precise predictions on the state of species abundance of nekton in the Sea of Okhotsk ecosystem when we have access to fast and powerful computers, remote sensing, and other facilities?

This work shows the complexity of making even simple (at a first glance) correlations between nekton species of the epipelagic layer and their environment by the use of some sort of abstraction – factors of PCA. A detailed discussion would take a lot of space, and some parts have already been published (Kulik, 2007, 2008). In conclusion, we will not find uninterrupted time series of fish abundance surveys if we chose them only according to the biostatistical regions of the Sea of Okhotsk, studied layers of the water column, and survey season. This limitation forces us to fill the times series with some hypothetical data (interpolated data) for statistical analyses. Therefore, we get wide confidence intervals of approximations, which do not let us even know where the similarities and real differences are. On the other hand, insignificant changes in communities (at a first glance) may lead to unpredictable states in the future (the well known "butterfly effect").

If we want to get precise data, then we need to conduct ecosystem studies of the Sea of Okhotsk every year during the same time periods and in the same regions. Until then, statistical analysis of strong and significant multivariate, canonical and other analyses may lead to unacceptable biologically nonsensical results. Nevertheless, we can make some conclusions:

1. The interrelationship between groups of species are more complex in the southern part of the Sea of Okhotsk in summer, and in the northern part of the Sea in autumn;
2. The changes in abundance correlate both with the regional climate conditions and heliophysical factors (sun spots), but are very rare;
3. Most of the species do not have alternating variability of abundance, although it is usual for dominant species;
4. Perceptible deviation of biotic factor scores were noticed for the periods 1990–1991 and 1997–1998;
5. Strong ($|R| \geq 0.8$) and statistically significant ($p < 0.05$) correlations between changes of relative abundance of species and abiotic factors of the environment, with a time-lag up to 6 years, are extremely rare;
6. Attempts to use moving average and autocorrelation functions during time series analysis failed because there are a lot of gaps in a short time series (less than 25 years).

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