Comparison of the Far Eastern seas and the North Pacific Ocean in terms of species diversity, its components, and other integral characteristics of net zooplankton in the epipelagial zone

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Abstract. - As a result of large-scale plankton surveys carried out by TINRO using the Juday net with a 0.1 m^2 opening in 1984-2013, comparisons can be made on the Chukchi and Bering seas, the Sea of Okhotsk, the Japan/East Sea and the adjacent Pacific Ocean in terms of species diversity *H* (binary digits/specimen), species richness *S* (number of species), species evenness by number of individuals *J* (unit share), total population density in abundance units *N* (thousand specimen/m^3) and biomass *M* (g/m^3), and average individual weight of animal *W* (mg/specimen). The Pacific waters are first in terms of *S*, but lag behind in terms of *N* and *J*. *W* is higher than in the ocean only in the Bering Sea. *H* is lower than in the ocean only in the Chukchi Sea, and *M* is lower only in the Japan/East Sea. The Chukchi Sea is first in terms of plankton *N* and *M*, second in terms of *J*, third in terms of *W*, and last in terms of *S* and *H*. The Bering Sea is first in terms of *W*, second in terms of *S*, *H* and *M*, third in terms of *N* and last in terms of *J*. The Sea of Okhotsk is second in terms of *W*, last in terms of *N* and third in terms of all other indicators. The Japan/East Sea is first in terms of *S*, *J*, and *H*, second in terms of *N*, but last in terms of *W* and, as a consequence, in terms of *M*. It seems that when going from south to north plankton density and size increase, while its diversity and its components decrease. However, this trend has many exceptions: the latitudinal trend is broken by the Japan/East Sea in terms of *N*, the Sea of Okhotsk in terms of *S* and *H*, and the Chukchi Sea in terms of *J* and *W*.

Key words. - comparison of water areas, Northern Pacific, East Arctic, zooplankton, abundance, species diversity, species richness, species evenness, size of animals

1 Introduction

The object of this report is *net zooplankton* – organisms fished using a standard sized Juday net made of kapron sieve No. 49 (0.168 mm mesh) with a 0.1 m^2 opening from a depth of 200 m to the surface, and where the depth is less than 200 meters from the bottom to the surface. These are animals weighing from hundreds to thousandths of a milligram – primarily the food resource of nekton and benthos, marine birds and mammals, as well as the larvae of invertebrates and fish. Hereinafter, for the sake of brevity, this is all referred to in the text as *zooplankton*.

The subject for comparison are 6 emergent integral properties of zooplankton, which characterize it as a whole: *species diversity* [1] *H* (bit/specimen), its 2 components – *species richness* *S* (number of species) and *evenness* [2] *J* (unit share), as well as the overall population density in number units *N* (specimen/m^3) and biomass *M* (g/m^3) and *the average individual weight of animal* *W* (mg/specimen).

Based on these characteristics of the pelagic and benthic trawl macrofauna almost all these waters have already been compared with each other [3-5]. After the creation of the new database of net zooplankton in the North Pacific and adjacent sector of the Arctic [6, 7] containing data from 21,952 measuring stations (Fig.) we can now supplement the previously made comparisons of waters in terms of macrofauna with the same comparisons but in terms of mesofauna.

2 Materials and Methods

Zooplankton was collected round the clock (day and night), if possible, all year round and every year by sampling station net, regularly covering the entire exclusive economic zone of Russia and sometimes the adjacent waters (see Fig.) from 1984 to 2013 inclusive. The samples were processed by the express method [8-10]. The surveyed water area includes primarily the subarctic Pacific waters, the north-western third of the Japan/East Sea, almost all of the Sea of Okhotsk, a large part of the Bering and Chukchi seas. Hereinafter, for the sake of brevity, they will be subsequently referred to in the text as *the ocean, the Japan/East Sea, the Sea of Okhotsk, the Bering Sea, and the Chukchi Sea.*

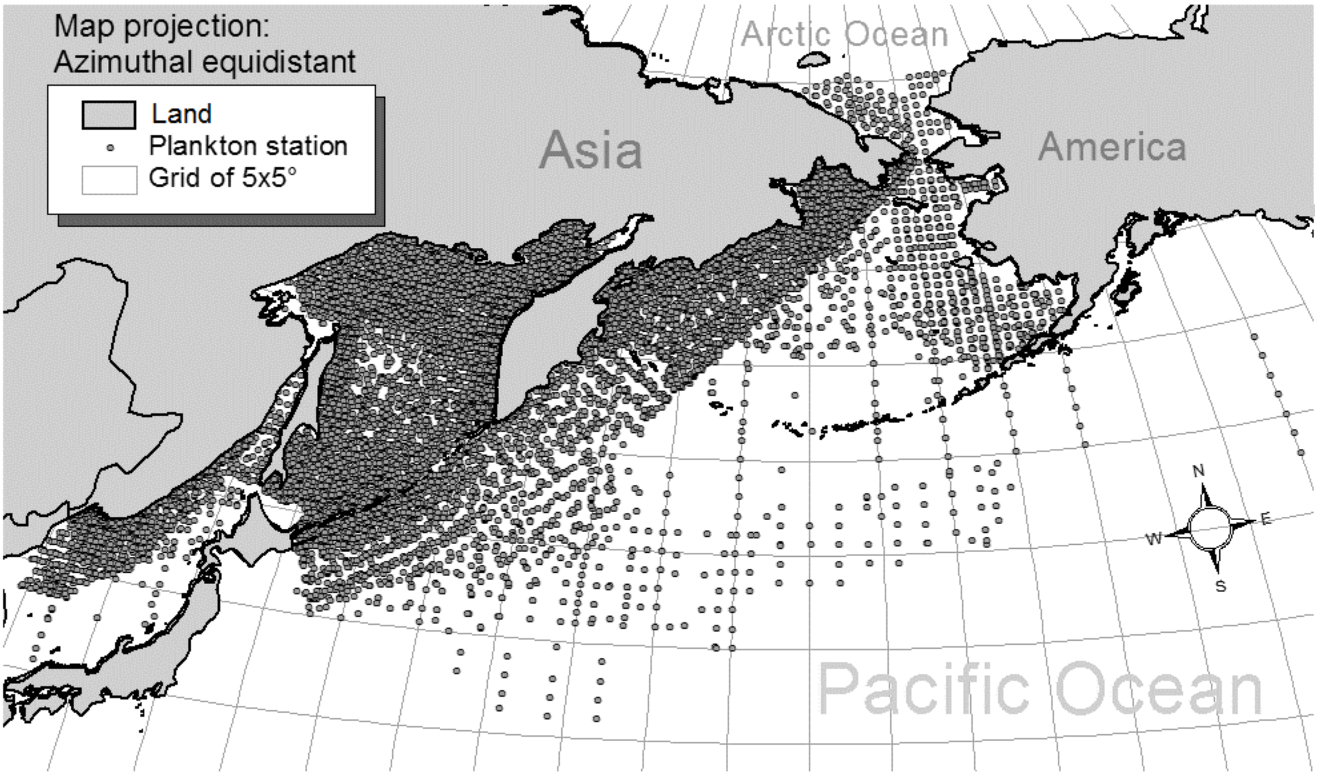

Figure. Spatial distribution across the surveyed waters of plankton stations, information from which is used for the calculation of integral characteristics

The same source data from 25,512 plankton stations were previously used to make five tabular reference books [11-15] summarizing information on the species composition, occurrence, abundance and biomass of zooplankton in the pelagic zone of the surveyed region. In those directories methods are detailed for estimating the number and biomass of zooplankton – *N* and *M*. *W* is obtained by dividing *M* by *N*. The formulas for calculating the *H* and *J* have long been known [1, 2].

3 Results and Discussion

Based on the results (table 1) we can give the following brief characteristics of the surveyed waters.

The Pacific waters are first in terms of *S*, but lag behind in terms of *N* and *J*. *W* is higher than in the ocean only in the Bering Sea. *H* is lower than in the ocean only in the Chukchi Sea, and *M* is lower only in the Japan/East Sea.

Table 1. Integral characteristics of net zooplankton and the Far Eastern seas of the North Pacific

Water area	*S*	*H*	*J*	*N*	*M*	*W*
Chukchi Sea	55	2,801	0,485	11,033	1,153	0,104
Bering Sea	95	2,943	0,448	4,386	1,079	0,246
Sea of Okhotsk	85	2,886	0,450	3,695	0,821	0,222
Japan/East Sea	130	3,417	0,487	6,842	0,626	0,092
Pacific Ocean	156	2,837	0,389	3,399	0,800	0,235
Whole water area	214	3,246	0,420	4,021	0,849	0,211

Note: Here and in the following table species richness is denoted by the letter *S*, diversity – *H*, evenness – *J*, number – *N*, biomass – *M*, and the average individual weight of animal – *W*.

Out of the seas (for ease of comparison the rankings are given in table 2), *the Chukchi Sea* is first in terms of plankton *N* and *M*, second in terms of *J*, third in terms of *W*, and last in terms of *S* and *H*. *The Bering Sea* is first in terms of *W*, second in terms of *S*, *H* and *M*, third in terms of *N* and last in terms of *J*. *The Sea of Okhotsk* is second in terms of *W*, last in terms of *N* and third in terms of all other indicators. *The Japan/East Sea* is first in terms of *S, J,* and *H*, second in terms of *N*, but last in terms of *W* and, as a consequence, in terms of *M*. *The entire water area as a whole* features (see table 1) the highest species richness, because it includes all the species found in each basin. The other characteristics are average (weighted average) for the multitude of water bodies included in the surveyed region.

Table 2. The ranking of the Far Eastern seas in descending order of integral characteristics of zooplankton

Sea	*S*	*J*	*H*	*M*	*N*	*W*
Chukchi	4	(2)	4	1	1	(3)
Bering	2	4	2	2	3	1
Okhotsk	(3)	3	(3)	3	4	2
Japan/East	1	1	1	4	(2)	4

Note: The number denotes the ranking of the water area in terms of the respective characteristic. The figures enclosed in brackets are those which go against the latitudinal trends. Explanations are provided in the text.

In summary, it should be noted that *going from south to north (with a decrease in temperature and increase in nutrient concentrations) plankton density and size increases, while diversity and its components decrease*. However, among all these variables in a large water area scale no statistically significant (at the 95% confidence level) correlations (either positive or negative) were found due to the small number of points and relatively large number of exceptions. The latitudinal trend is broken by the Japan/East Sea in terms of *N*, the Sea of Okhotsk in terms of *S* and *H*, and the Chukchi Sea in terms of *J* and *W*.

In conclusion, it should be emphasized that this paper gives only very generalized static comparative characterizations of water areas in which averaging is performed of data at the highest possible spatial and temporal scales – 30 years and almost 7 million km^2. In fact, the distribution of the integral characteristics within each of the areas is very uneven, and the time interval covers a period of major ecosystem transformations in the regional biota caused by global change of climate and oceanology and cosmogeophysical factors since the early 1990s (see, for example [16-21]).

Long-term, seasonal and daily changes in the abundance of zooplankton in the spatial scale of one-degree trapezoids were partly studied in the recently published paper [7], and for large standard regions, in which averaging is performed of information, they can be found in the five above-mentioned tabular directories [11-15]. Subsequent publications will be devoted to a more detailed analysis of the patterns of spatial and temporal variability of the integral characteristics of zooplankton.

References

[1] Shannon C.E., A mathematical theory of communication, *Bell Syst. Techn. J.,* Vol.27, 1948, pp. 379-423, 623-656.

[2] Pielou E. C., The measurement of diversity in different types of biological collections, *J. Theor. Biol.*, Vol.13, 1966, pp. 131-144.

[3] Volvenko I.V., The comparative statuses of Far Eastern Seas and the Northwestern Pacific based on the range of integral characteristics of pelagic macrofauna, *Russian Journal of Marine Biology*, Vol.35, No.7, 2009, pp. 515-520.

[4] Volvenko I.V., The comparative statuses of the Far Eastern seas and the northwestern Pacific Ocean based on the range of integral characteristics of pelagic and bottom trawl macrofauna, *Journal of Asia-Pacific Biodiversity*, Vol.8, 2015, pp. 31-37.

[5] Shuntov V.P., Volvenko I.V., Comparative analysis of the abundance of bentic and pelagic macrofauna in the Far East Seas and adjacent waters of the Pacific Ocean, *Problems of Fisheries*, Vol.17, No.2, 2016. pp. 133–147. (in Russian).

[6] Volvenko I.V., Volkov A.F., Dolganova N.T., Database "Net zooplankton of the North Pacific 1984-2013", *Copyright certificate No. 2016620026, Russia, 2016.* (in Russian).

[7] Volvenko I.V., First experience of using a new database on net zooplankton in the Far-Eastern Seas and adjacent Pacific waters, *Izvestiya TINRO,* Vol.187, 2016, pp. 19-47. (in Russian).

[8] Volkov A.F., *Recommendations on express processing of net plankton in the sea*, Vladivostok: TINRO, 1984. (in Russian).

[9] Volkov A.F., Concerning the Technique of Plankton Sampling, *Izvestiya TINRO*, Vol.119, 1996, pp. 306–311. (in Russian).

[10] Volkov A.F., Technique of collecting and processing the samples of plankton and the samples on nekton feeding (step-by-step instructions), *Izvestiya TINRO*, Vol.154, 2008, pp. 405-416. (in Russian).

[11] Dolganova N.T., Volvenko, I.V., *Net Zooplankton of the Northwestern Part of Japan (East) Sea: Occurrence, Abundance, and Biomass. 1985-2013*, Vladivostok: TINRO-Center, 2016. (in press). (in Russian).

[12] Dolganova N.T., Volvenko, I.V., *Net*

Zooplankton of Peter the Great Bay (Japan/East Sea): Occurrence, Abundance, and Biomass. 1988-2013, Vladivostok: TINRO-Center, 2016. (in press). (in Russian).

[13] Volkov A.F., Volvenko, I.V., *Net Zooplankton of the Western Part of the Bering Sea: Occurrence, Abundance, and Biomass. 1986-2013*, Vladivostok: TINRO-Center, 2016. (in press). (in Russian).

[14] Volkov A.F., Volvenko, I.V., *Net Zooplankton of the Okhotsk Sea: Occurrence, Abundance, and Biomass. 1984-2013*, Vladivostok: TINRO-Center, 2016. (in press). (in Russian).

[15] Volkov A.F., Volvenko, I.V., *Net Zooplankton of the Northwestern Pacific: Occurrence, Abundance, and Biomass. 1985-2013*, Vladivostok: TINRO-Center, 2016. (in press). (in Russian).

[16] Shuntov V.P., Dulepova E.P., Radchenko V. I., Temnykh O.S., On the beginning of large reformations in communities of plankton and nekton of the Far-Eastern Seas, *North. Pac. Mar. Sci. Org. (PICES), Second Annual Meeting: Abstracts*. Seattle, 1993, pp. 35.

[17] Shuntov V.P., New Data on Alterations in Pelagic Ecosystems of Far Eastern Seas, *Vestnik DVO RAN*, No.2, 1994, pp. 59–66. (in Russian).

[18] Shuntov V.P., Reorganizations in the Okhotsk sea pelagic ecosystems – real fact, *Rybnoye Khozaystvo (Fisheries)*, No.1, 1998, pp. 25-27. (in Russian).

[19] Shuntov V.P., Radchenko V.I., Dulepova E.P., Temnykh O.S., Biological Resources of Economic Zone: The Structure of Pelagic and Benthic Communities, Contemporary Status, and Trends of Long Dynamics, *Izvestiya TINRO*, Vol.122, 1997, pp. 3-15. (in Russian).

[20] Shuntov V.P., Dulepova E.P., Temnykh O.S., Volkov A.F., Naydenko S.V., Chuchukalo V.I., Volvenko I.V., State of Biological Resources in Connection with Dynamics of Macroecosystems in the Far Eastern Economic Zone of Russia, *Dynamics of Marine Ecosystems and Contemporary Issues in Conservation of Biological Potential of Russian Seas,* Vladivostok: Dalnauka, 2007, pp. 75-176. (in Russian).

[21] Shuntov V.P., Temnykh O.S., Modern restructuring in marine ecosystems in Association with climatic changes: the priority of global or regional factors?, *Bulletin N 6 implementation of "Concept of the Far Eastern basin program of Pacific salmon study"*, Vladivostok: TINRO-Center, 2011, pp. 49-64. (in Russian).