THREE RUSSIAN PAPERS ON NORTHWESTERN PACIFIC PLANKTON

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THREE RUSSIAN PAPERS ON NORTHWESTERN PACIFIC PLANKTON

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TRANSLATOR'S ABSTRACT

The copepod fauna of the northwestern Pacific increases in specific richness but decreases in overall mass with increasing depth. This fact is significant in comparing the faunas of the deep Pacific and adjacent shallow, semi-isolated basins.

The boreal waters of the northwest Pacific are cooled to a depth of 200 m. in winter and considerably warmed in a shallow surface layer in summer, so that a cold layer persists at intermediate depths through the year. South of them the warm Kuroshio water shows small seasonal temperature changes and lacks the cold intermediate layer. These differences of temperature and structure of the water masses are expressed in the specific composition and biomass of the zooplankton. The boreal waters are characterized by paucity of species and high biomass, the Kuroshio waters by low biomass and great specific diversity. The summer boundary between these two plankton faunas is the 18°C. surface isotherm.

The abundance of the boreal plankter Calanus cristatus is at its minimum in the cold intermediate layer in boreal waters and increases below a depth of 200 m. In Kuroshio water, where the cold intermediate layer is lacking, there is no such minimum at 100-200 m.

In the boreal waters the plankton biomass is greatest in the shallowly warmed surface layer; in the Kuroshio water it is poor at the surface and peaks at 50-100 m.

Such species as C. cristatus, C. tonsus, and Eucalanus bungii, in the boreal region, become about twice as abundant in spring (May-June) as they are in summer. This biological spring in the plankton fauna seems to coincide with the feeding migration of whales.

Analysis of plankton collections from sections extending southeast from the Kuriles across the northwestern part of the Kuroshio make possible the distinction of three zones characterized by their copepod faunas: the southern part of the North Pacific Temperate Region, where Calanus tonsus is abundant; a transitional or subtropical zone, marked by the abundance of C. pacificus; and a tropical zone characterized by great specific diversity and low overall abundance. Seasonal presence of neritic forms such as Labidocera japonica in the tropical zone makes it possible to trace the eastward movement of the Kuroshio water. --W.V.C.

On the Vertical Distribution of Copepods in the Northwestern Pacific Ocean*

By

K. A. Brodskii

In the northwestern part of the Pacific Ocean southeast of Kamchatka the following plankton collections were made: one vertical haul from a depth of 4,000 meters, with a net having an opening 100 cm. in diameter, and seven horizontal hauls with a Juday net made of No. 38 bolting cloth.

The results of the analysis of the vertical haul samples are presented in another paper of ours in this same collection, and we will here explain the results obtained from the horizontal hauls.

As we pointed out in the paper referred to above, there was no information in the literature about the zooplankton of the northwestern Pacific Ocean, neither about its composition nor about its vertical distribution. Here we limit ourselves only to data on the vertical distribution of the copepods, not bringing in any materials on the specific analysis, which is adequately treated in the paper referred to above.

The horizontal plankton collections were made in the daytime with a Juday net, having an intake opening 37 cm. in diameter, at the following levels: 1,000-500, 500-200, 200-100, 100-50, 50-25, and 25-0 m. The processing of the samples was done by counting the number of organisms in a counting chamber under a binocular microscope and then converting the figures to correspond to 1 m.^{3}. When the quantity of specimens of a species was insignificant, the transformation to 1 m.^{3} was not made, and in table 1, given below, the number of specimens in the whole sample is given. For greater quantities the figures are given for 1 m.^{3} (underlined figures) on the basis of a calculation from a counting chamber. If two figures are given, the first is the result found in the general examination of the whole sample, and the second is the calculation from the counting chamber.

*From Investigations of the Far Eastern Seas of the USSR. III. Deep-water Fauna of the Northwestern Pacific Ocean, p. 88-94. Zoological Institute, Academy of Sciences of the USSR, 1952.

The material in the table makes it possible to divide the genera of Calanoida into groups in relation to their vertical distribution, that is, to separate out those which are not represented by a single species at depths less than 1,000 meters and which are encountered only below that level. To this group belong the following genera:

Bathycalanus	Valdiviella	Temorites
Drepanopsis	Xanthocalanus	Augaptilus
Aetideopsis	Mixtocalanus	Euaugaptilus
Chiridiella	Cornucalanus	Neoaugaptilus
Batheuchaeta	Lophothrix	Bathypontia
Pseudochirella	Amallothrix	

It is necessary to emphasize that the vertical distribution varies depending on the area. Many genera which appear only as deep-water forms in the area under consideration are in other regions, for example in the Arctic Ocean (Temorites and Augaptilus), represented by species which are encountered at slight depths or even in the surface waters. This phenomenon is related to temperature conditions and confirms the general rule of the ascent into the surface layers in the Arctic region of the abyssal species and genera of the temperate and tropical parts of the World Ocean.

To the other group we assign those genera, species of which are encountered above as well as below the 1,000-m. level (table 2).

According to the data in the table, the genera Pareuchaeta, Scaphocalanus, and particularly Lucicutia should be regarded as primarily abyssal genera, inasmuch as fewer species of these genera are encountered above 1,000 m. than in the deeper layers.

Certainly it is very difficult to give a general characterization of a genus, including, in the whole, species with differing ecological peculiarities, and it is probably more expedient to distinguish within the limits of the genus individual ecological groups which are differentiated in terms of their vertical distribution. For example, in the genus Metridia, along with three typically abyssal species, there are two which should be assigned to the bathypelagic group (M. pacifica and M. okhotensis), while in the genus Pareuchaeta only two species can be counted in this group (P. japonica and, probably, P. birostrata). The genus Lucicutia is undoubtedly typically abyssal, for of seven species only one appears as shallow as the 200-500-m. level, while with Pareuchaeta japonica the young stages are encountered in significant quantities up to the shallowest level sampled (0-25 m.).

Table 1.--Results of qualitative and quantitative analyses of the horizontal hauls with the Juday net

Species	Stage	Levels (in m.) 25-0	50-25	100-50	200-100	500-200	1000-500
Calanus pacificus Brodsky	V		20		1	1	
Calanus tonsus Brady f. *plumchrus* Marukawa	♀ VI					10	8
	♂ VI						4
	V	16					4
	IV	10				4	2; 1
	III			1			
	II	160				3	
	I	80			5		
Calanus cristatus Kröyer	♀ VI					1	
	♂ VI						2
	V		4	12	10	2	2
	IV		5	5	1	2	
	III	5		14	4	2; 3	
	II	1	20	23; 20	8		
	I		40	22	2; 5		
Nauplii, *Calanus*		120				3	1
Eucalanus bungii Gsbr.	♀ VI	2		1	1	20	25
	♂ VI				1		
	V				1		
	IV	120			5		4
	III	160	20	10	10		
	II	40					
	I						
Nauplii, *Eucalanus*		80					
Pseudocalanus elongatus (Boeck) (large form)	♀ VI	40		4	5	2	1
	♂ VI			3	1		
Pseudocalanus elongatus (Boeck)	♀ VI	120	10	40			
	♂ VI			20			
	V	80					
	IV	160					
	III	-	-	-	-	-	-
	II	80					
	I	160	60	30			
Microcalanus pygmaeus Sars	♀ VI						4
	V		20	70	15	12	9
	IV				25		5
	III			80	10		1
	II					3	
	I		40	50			
Spinocalanus spinipes Brodsky ♂ VI							1
S. stellatus Brodsky ♀ VI						3	3
S. similis Brodsky ♀ VI							1
Aetideus pacificus Brodsky	♀ VI						1
	V					4	1
Gaidius tenuispinus? Sars V						1	2
G. variabilis Brodsky	♀ VI					4	2
	♂ VI						1
	V					1	2
Gaetanus simplex Brodsky	♀ VI					6	7
	♂ V						2
	♀ V					1	2
	IV						1
Pseudochirella polyspina Brodsky	♀ VI						1

Table 1.--Results of qualitative and quantitative analyses of the horizontal hauls with the Juday net (cont'd)

Species		Levels (in m.) 25-0	50-25	100-50	200-100	500-200	1000-500
Pareuchaeta japonica Marukawa	V						1
P. birostrata Brodsky	♀ VI					2	1
	V						2
Pareuchaeta sp.	IV					4	
Onchocalanus magnus (Wolf.)	V						1
	IV					1	
Scaphocalanus magnus T. Scott	♀ VI						1
	♂ VI						1
	V					1	2
Scolecithricella ovata Farran	♀ VI					2	2
	V						1
	IV						1
S. minor Brady	♀ VI					5	
	♂ VI						3
	V				3	1	1
Racovitzanus antarcticus Gsbr.	♀ VI			1	2	3	3
	V					7	4
Metridia pacifica Brodsky	♀ VI			1	1	32; 3	40; 3
	♂ VI					6	12; 2
	V	-	-	-	-	-	-
	IV	40		20	20	3	
	III	40		50	25	6	
	II	200	60	130	35	6	4
	I	160	280	480	40	3	2
M. okhotensis Brodsky	♀ VI					1	
M. curticauda Gsbr.	♀ VI						1
	♂ VI					1	
	V						2
Pleuromamma scutullata Brodsky	♀ VI					13	7
	♂ VI					3	
Lucicutia ovaliformis Brodsky	♀ VI					2	2
	♂ VI					2	
Heterorhabdus robustoides Brodsky	♀ VI					1	
Heterorhabdus compactus Sars	♂ VI						1
H. tanneri (Gsbr.)	♂ VI					1	3
	IV					1	
	III						1
	II						1
Heterostylites major Dahl	♀ VI						1
	juv.						1
Haloptilus pseudooxycephalus Brodsky	♀ VI					1	1
	V						2
Pachyptilus pacificus Johnson	♀ VI					1	
	V						1
Candacia columbiae Campbell	♂ VI					1	
Nauplii, Calanoida		4600	400	1000	95	24	12
Calanoida l. st.							14
Exuvium, Calanoida				10	20	12	5
Ova, Calanoida				20	15		
Oithona plumifera Baird	♀ VI				1	1	3
O. Similis Claus	♀ VI			600	165	36	21
	♂ VI	13520	7600	100		3	1
	juv.			3300	35	27	7

Table 2.--Calanid genera represented above and below 1,000 m.

Genera	Number of species below 1,000 m.	Number of species above 1,000 m.
Spinocalanus	3	3
Chiridius	1	1
Gaidius	1	2
Gaetanus	1	1
Pareuchaeta	6	3
Scaphocalanus	5	1
Metridia	3	2
Lucicutia	7	1
Heterorhabdus	1	3
Haloptilus	1	1
Candacia	1	1

The species of the genus Spinocalanus also do not rise above 200-500 m. and are not encountered in the surface layers, and therefore this genus, too, should be characterized as abyssal, a characterization which is confirmed by material from other regions of the Pacific Ocean and, particularly, from the Antarctic, Okhotsk and Bering seas, Arctic Ocean, etc., where species of the genus Spinocalanus are adapted to great depths. As can be seen from the data in table 1, out of the total number of species (93) found at the station, only six are encountered in the upper layers, to wit, Microcalanus pygmaeus Sars, Calanus tonsus Brady, Metridia pacific Brodsky, Calanus cristatus Kröyer, Metridia okhotensis Brodsky, and Eucalanus bungii Gsbr. /Translator's note: The apparent discrepancy between this statement and the data in table 1 is unexplained./ Finally we must point out the group of surface species, to which in the present case we must assign only Pseudocalanus elongatus (Boeck) and Calanus pacificus Brodsky.

The ecological differentiation of genera and species according to their vertical distribution appears to be very material to an understanding of the range of occurrence of Calanoida, in particular, in such sea basins as are isolated from the deeps of the World Ocean by narrow straits, such as the Sea of Japan, which is closed off from the deeps of the Pacific, and the Arctic Ocean, which, although it has a connection with the Atlantic, is almost isolated from the Pacific. Only that group of species which is distributed vertically to the surface layers of the water can penetrate into these basins by way of the surface fauna, and in the present case these are the six species indicated above. For clarification of the peculiarities of the vertical distribution of calanids both for basins the depths of which are directly linked with the great depths of the World Ocean and for basins which are partially isolated, we have compared the numbers of species and the numbers of specimens per 1 $m.^3$ at various levels in the northwestern part of the Pacific Ocean, the Sea of Japan (Brodskii 1941), the central part of the Arctic Ocean (Bogorov 1946), and the Greenland Sea (Jespersen 1934) (table 3).

In this table we have included, besides all Calanoida, one species of Cyclopoida, Oithona similis, as being of massive occurrence in the surface waters.

Let us consider some of the peculiarities of the material which is presented in table 3 as an attempt to compare the numbers of species of copepods vertically in various places of the World Ocean.

The increase in the number of individuals in the upper layers depends on the mass development of a few surface species of copepods which feed mainly on phytoplankton. It is characteristic that such an increase in the number of specimens is related to the small number of species inhabiting the upper levels of the water. This phenomenon can serve as a demonstration of the well-known rule of the mass development of a few species which have adapted themselves to unfavorable conditions1/, which in the upper layers consist of an abundance of phytoplankton, as well as relatively sharp changes in temperature conditions linked with seasonal changes.

The richness in species of the deep parts of the World Ocean is probably related to the variety of conditions to be observed in the immense thickness of the water mass (3-4 km.) and in an important degree also to the prolonged period of time during which these deeps have been in existence.

The material presented in table 3 shows plainly the sharp increase with depth in the number of species both in the northwestern Pacific Ocean and off the west coast of Greenland, which is dependent on the broad connections of these regions with the other parts of the World Ocean. The small number of species in the Sea of Japan increases only insignificantly

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1/ In recent times a large number of facts have accumulated indicating the harmful influence of mass concentrations of phytoplankton on a number of species of calanids.

Table 3. --Numbers of species and specimens of calanids per 1 $m.^3$ at various levels in various parts of the World Ocean

Northwestern Pacific Ocean			Northwestern Japan Sea			Arctic Ocean						West coast of Greenland	
						North of Novosibirsk Is.			North of Franz Josef Land				
Level (in m.)	Species	Specimens	Level (in m.)	Species	Specimens	Level (in m.)	Species	Specimens	Level (in m.)	Species	Specimens	Level (in m.)	Species
0-25	7	15 240	0-25	5	46 224	-	-	-	0-10	3	499	0-100	3
25-50	7	8 160	25-50	6	61 612	25-50	3	36	10-200	8	496	100-250	5
50-100	9	5 040	50-100	7	29 794	100-200	9	194	200-750	11	1581	-	-
100-200	10	320	100-200	8	3 401	200-300	8	31	-	-	-	500-1000	58
200-500	28	84	200-500	11	2 734	300-400	8	64	-	-	-	-	-
500-1000	30	65	500-1000	11	1 154	400-500	8	63	-	-	-	1500-2500	74
1000-4000	87	?	1000-2000	7	303								

down to the 200-500-m. level and again decreases at 1,000 m.: it is in general small, a fact which corresponds to the isolation of that sea both in the present epoch (shallow straits) and in past times (complete lack of connections). In the central part of the Arctic Ocean the number of species is not great and there is a small increase with depth which is related to the thickness of the Atlantic stratum penetrating the Arctic Ocean. Finally, for the northwestern Pacific and the Japan Sea, lying in the temperate zone, we can observe a definite regularity consisting of a sharp drop in the number of specimens with depth.

The vertical distribution of copepods in the northwestern Pacific Ocean, that is, the sharp increase in the number of species with depth, and the presence of a large percentage of new species and of three new genera in that region, naturally indicate the great significance which a free interchange of water and fauna with the whole World Ocean has for the deep-water calanoid fauna. Significant in this connection is the impoverishment of the fauna of the depths of such isolated basins as the Sea of Japan and the central part of the Arctic Ocean.

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Some Essential Features of Zooplankton Distribution in the Northwestern Pacific Ocean*

By

V. G. Bogorov and M. E. Vinogradov

The northwestern region of the Pacific Ocean is a place of accumulation of a large quantity of pelagic, plankton-feeding fishes and a feeding ground for whales, the distribution of which is closely tied to the distribution and concentration of forage zooplankton in different sections. However, the character of the distribution and the faunistic composition of the plankton of the northwestern part of the Pacific Ocean until very lately have remained little studied. Just in the last few years Soviet and foreign expeditions have begun to investigate this region intensively. In 1949, 1953, and 1954 an oceanographic expedition of the Institute of Oceanology worked there on the research vessel Vitiaz'; in 1951, 1953, and 1954 investigations were carried out by expeditions of the Institute of Oceanology of the USSR Academy of Sciences, for the study of cetaceans, and also by the American Transpac Expedition (1953) and a number of Japanese ships. The results of working up the collections of the Transpac Expedition have not yet been published. In Japanese works, taking in the region of the Komandorsky Is., the region to the east of the Tsugaru Strait, and the region of the Bonin Is. (Anraku 1954a, b), only the faunistic composition of the Copepoda is considered, and nothing is said about the quantitative distribution of the plankton.

The materials gathered by the Soviet Expeditions give a picture, not only of the faunistic composition but also of the quantitative distribution of the plankton. The results of the working up of the collections made by the expeditions of the Cetacean Laboratory of the Institute of Oceanology in 1951 and 1953 have been published in the works of K. A. Lubny-Gertsyk (1955) and K. A. Brodsky (1955). In the present paper we consider the distribution of the zooplankton in the area from the Kurile chain to 171°E. longitude and from the Komandorsky Is. to 27°-30°N. latitude.

The characteristics of the zooplankton are given on the basis of the collections made aboard the expedition vessel Vitiaz' in August-

*From Trudy Instituta Okeanologii, Academy of Sciences of the USSR, Vol. 18, p. 113-123. 1955.

October 1954. For collecting the plankton Juday nets of No. 38 gauze with an entrance area of 0.1 $m.^2$ and of No. 140 gauze, 0.5 $m.^2$ were used. With these nets stratified hauls were made at the 0-10, 10-25, 25-50, 50-100, 100-200, and 200-500 meter levels. Samples were weighed, examined under a binocular microscope, and counts were made of the larger species such as Euphausiacea, Calanus tonsus, Calanus cristatus, Parathemisto japonica, et cetera.

Distribution of the Plankton Complexes

The general distribution of the plankton in the northwestern part of the Pacific Ocean depends to a great extent on the character of the water mass and on seasonal phenomena in the area of observations.

The region of the Pacific Ocean investigated by us can be divided into two zones. The first is a zone of boreal waters occupying the whole region from the Komandorsky and Aleutian islands to 40°N. latitude. The southern boundary of this region does not run in a straight line but meanders in response to the extensions of the northern front of the warm waters of the Kuroshio. It is characterized by significant changes in the temperature regime of the waters in the course of the year. Thus, the investigations of the Vitiaz' in Kurile waters in May-July 1953 showed that the temperature of the surface layer of the water varied from 1° to 5°C. In the same area in August-September 1954 the temperature rose to 9°-15°C.

Because of the comparatively great winter cooling of the waters, taking in, thanks to convective mixing, the layers of water to a depth of 200 m., and the summer warming of only a comparatively thin layer of the surface waters, in a considerable part of the aquatorium of the boreal region, and particularly in the areas adjacent to the Kurile Is. and Kamchatka, throughout the year a cold intermediate layer is maintained with temperatures below 1°-1.5°C. The presence of a layer of cold "winter" waters materially influences the vertical distribution of the plankton (Vinogradov 1954, 1955).

Waters coming from the Okhotsk and Bering seas have a great significance in the formation of the water masses of this region. Through the interaction of the waters of the ocean with the waters of the Okhotsk and Bering seas in the area of sea lying over the Kurile-Kamchatka Trench there is formed an area of mixing of waters, where, thanks to the strong vertical circulation, we can observe a phenomenon analogous to the "polar front".

Compared with the Kurile waters, the warm waters of the Kuroshio are characterized by small seasonal fluctuations in temperature. The cold intermediate layer is absent. Warm waters with temperatures above 10°C. occupy the whole mass to a depth of 400-500 m. The differences in origin, temperature regime, and the character of the stratification of the water masses of the boreal region and the waters of the Kuroshio are reflected above all in the composition of the plankton.

The moderately cold waters of the northern regions with surface temperatures of 9°-15°C. (August-October) are inhabited by a rather homogeneous plankton complex, common to the waters of the Okhotsk and Bering seas. Most characteristic of this complex are such species as Calanus tonsus, C. cristatus, Eucalanus bungii, Sagitta elegans (and below 100 m. also Eukrohnia hamata), Parathemisto japonica, and Euphausia pacifica.

All of these species can form concentrations of a very high biomass, as much as 2 g./$m.^3$. In the areas adjacent to the Kuriles and Hokkaido they are joined by Metridia okhotensis, and in the region of the continental shelf a notable role may be played by Pseudocalanus elongatus and larvae of bottom animals.

Besides these species found in great masses, the plankton complex of the moderately cold waters is characterized by the presence of a series of less numerous but constantly encountered forms such as, for example: copepods--Metridia pacifica, Candacia columbiae, Pleuromamma scutulata, Pareuchaeta japonica; amphipods--Cyphocaris challengeri and Hyperia galba; the medusa Aglantha digitale; and a number of other species.

Directly in the zone of contact of the cold waters of the moderate region with the warm waters of the Kuroshio the aspect of the zooplankton swiftly and sharply changes. In the surface layers, with a rise in temperature to 17°C. the species characteristic of the more northern areas disappear and go down below 100 m. or even 200 m. As a consequence of the disappearance from the surface zone of the most abundant species of cold-water plankton, the significance of Calanus pacificus and a number of small copepods in this zone increases; a considerable quantity of species, absent in the more northern areas, appears, Penilia avirostris and Pleuromamma sp., in particular, playing a substantial role in the warm-water plankton.

In waters with temperatures above 18°C. the plankton no longer has anything in common with the plankton of colder waters, either in its species composition or in the relationships and significance of the different taxonomic groups. The diversity of species increases sharply. Especially noticeable is the appearance of various Pteropoda (Euclio, Peraclis, Cavolinia, and others), Heteropoda (Pterotrachea, Carinaria, Atlanta), hypereid Curvicornia (Lycaeidae, Brachyselidae, Oxycerhalidae, Rhabdosomidae, and others), Sergestidae (Lucifer), the genera Sapphirina, Copilia, and Corycaeus among the copepods, salps (Salpa, Cyclosalpa, Doliolum), siphonophores, Halobates bugs, and other groups characteristic of tropical plankton.

The plankton of these areas is quantitatively very poor despite the great diversity of species.

With further movement to the south and a raising of the temperature to 20°-26°C. a number of new species appear, but the general aspect of the plankton remains almost unchanged.

The sharp change in the specific composition of the plankton, accompanied by a decrease in its biomass, observed in crossing from the moderately cold waters of the northern part of the Pacific Ocean to the warm waters of the Kuroshio permits us to consider the zone of contact of these waters as the boundary between different zoogeographical regions. An analogous conclusion was reached by K. A. Brodskii (1955).

Judging by our data, in August-September this boundary is at 40°-42°N. latitude, and only towards Japan, under the influence of the cold current running along the Kurile chain, does it drop farther south. Its location changes depending on the changes in the northern limit of the waters of the Kuroshio.

The material collected by M. M. Sleptsov in August 1954 and worked up by us shows that separate tongues of Kuroshio water, inhabited by warm-water plankton, penetrate to 43°-44°N. latitude.

In all of the areas investigated, excepting those directly adjacent to Japan and under the action of the current issuing through the Tsugaru Strait from the Japan Sea, this boundary coincides with the 18°C. surface isotherm (fig. 1). In 1951-52 (Anraku 1954) the zone of sharp change in the fauna was at approximately the same latitude (38°-42°N.).

Besides their faunistic composition, the boreal waters also strongly differ from the Kuroshio waters in the total biomass of their zooplankton. The boreal surface waters are everywhere abundantly populated by plankton. The biomass of plankton in the upper 100-meter layer varies from 200 to 1,000 mg./m.^{3}, while in the same layer of the Kuroshio waters it is usually 10-20 times less.

A comparison of the primary production of the plankton (by photosynthetic action using the "flask method") showed that the diurnal production of carbon in the warm waters of the Kuroshio is 10-20 times less than in the boreal region (Bogorov and Beklemishev 1955). Thus, in the waters of the Kuroshio the plankton is a great deal poorer than in the boreal waters. This impoverishment is expressed in the fact that there is very little forage plankton in the surface layer of the warm waters--the great accumulations of calanids and other large copepods, euphausiids, and amphipods are absent. Therefore the feeding conditions for large concentrations of plankton-eating fishes and whales are unfavorable here.

Distribution of the Plankton Biomass

The boreal waters in the area of investigation can be subdivided into several zones according to the distribution of the biomass of the plankton. The first zone includes the waters in the immediate vicinity of the Kurile Islands, the second the waters over the Kurile-Kamchatka Trench; the third occupies the southern part of the area of the boreal waters. The waters lying 20-30 miles from Hokkaido must be set off separately.

The waters in the immediate vicinity of the Kurile Islands are somewhat impoverished. In May-June 1953 the plankton biomass1/ in the 0-100 m. layer near the Kuriles did not exceed 500 mg./m.^{3}; in August-September 1954 it varied from 250 to 500 mg./m.^{3} in this region. The breadth of this "belt" is relatively small, from several to 50 miles from the coast (figs. 2 and 3).

1/ Data on the biomass of plankton in May-June are cited on the basis of the report of L. A. Ponomareva, who was in charge of plankton collecting in 1953 aboard the research ship Vitiaz.

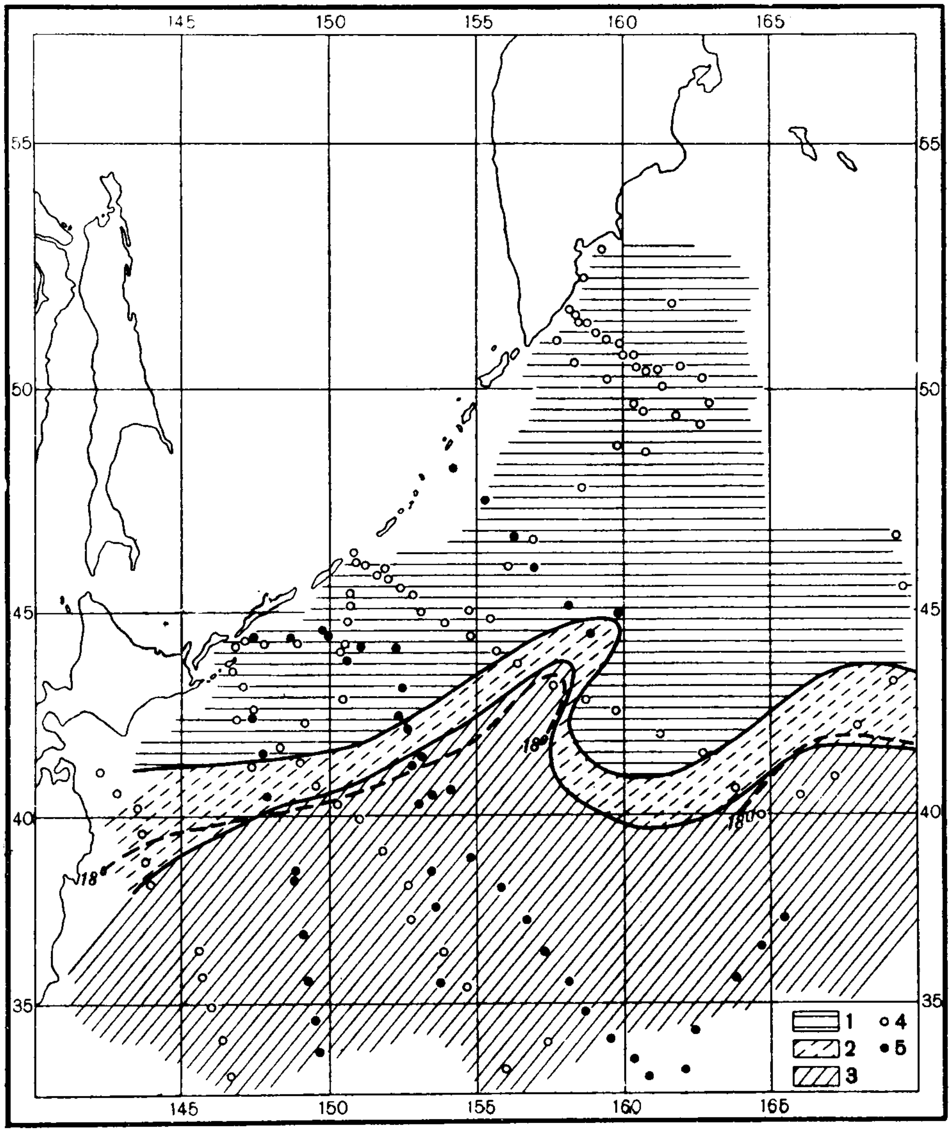

Figure 1.--Distribution of the basic plankton complexes. 1 - boreal region; 2 - transition zone; 3 - tropical region; 4 - stations of the research ship Vitiaz' in August-October 1954; 5 - stations of the expedition of the Cetacean Laboratory in August-September 1954.

Beyond the coastal waters, with their low zooplankton biomass, is spread a zone of high biomass. This zone extends along the Kurile Islands in a belt of varying width, usually not wider than 30-50 miles. In May-June 1953 the plankton biomass in this zone at 0-100 m. constantly exceeded 1,000 mg./m.^{3}. In August-September 1954 it was somewhat lower, and varied from 500 to 1,000 mg./m.^{3}. Thus the quantity of zooplankton declined, but the location of the zone of highest biomass did not change. Approximately the same area was also richest at the end of July 1951 (Lubny-Gertsyk 1955). South of the Kurile-Kamchatka Trench the plankton biomass in the upper 100-meter layer in May-June 1953 decreased to 500-1,000 mg./m.^{3}, but in August-September 1954 to 250-500 mg./m.^{3}, i.e. approximately to one-half. Still farther south, approaching the boundary of the boreal region, it quickly falls to 100-250 mg./m.^{3} in August-September.

In the region lying east of Tsugaru Strait the quantity of plankton is relatively great: from 250 to 500 mg./m.^{3}. But in its composition it differs from the plankton of the zone of the Kurile-Kamchatka Trench in that along with the species of the boreal region there appear

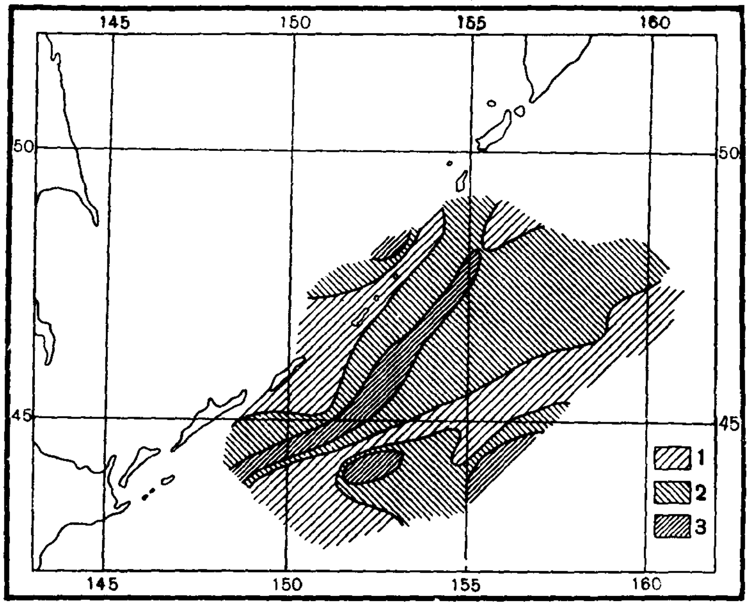

Figure 2. --Distribution of the biomass of the seston in the 0-100 m. layer in May-June 1953 (composed by L. A. Ponomareva). 1 - less than 500 mg. /m.^{3}; 2 - 500 to 1,000 mg. /m.^{3}; 3 - more than 1,000 mg. /m.^{3}.

many representatives of warm-water neritic plankton. The latter makes possible the rich development of life in the warm waters lying from 38°N. latitude to the Lesser Kuriles chain.

The transition from the boreal region to the warm waters of the Kuroshio is characterized by a sharp drop in the plankton biomass. In the waters of the Kuroshio it is everywhere less than 100 (and usually 50) mg. /m.^{3}.

With the comparatively small nets (0.1 and 0.5 m.^{2}) adopted by us for the collection of plankton it was not possible to capture adequately the rapidly moving forms of the macroplankton (large amphipods, euphausiids); therefore we cannot adduce reliable quantitative data on their distribution. We point out only the predominance in the boreal zone of, among the euphausiids, Euphausia pacifica, which forms, according to a communication from M.M. Sleptsov (1955), colossal aggregations (at the very surface of the water), Thisanoessa inermis, T. longipes, and in the coastal area T. rashii; among the amphipods Parathemisto japonica and, in the deeper layers, Cyphocaris challengeri. In the Kurile Islands and at the southern tip of Kamchatka, in the zones of exit of the cold waters, large Parathemisto libellula are encountered. The distribution of the large Copepoda which compose the overwhelming mass of the plankton in the waters of the boreal zone actually forms the same picture of the distribution of the plankton biomass that we looked at above. The greatest quantity of large Copepoda is spread in a broad band running along the Kurile Islands at a distance from the coast of 40-50 miles or somewhat nearer. Farther out the quantity diminishes, but in some sections which are under the action of waters from the Bering Sea it may again increase.

As an example let us look at the distribution of one of the leading species of the boreal plankton, Calanus cristatus. In waters with a cold intermediate layer, so characteristic of the Okhotsk and Bering seas and the waters of the Kurile-Kamchatka Trench, C. cristatus is present in the greatest quantity in the 25-50 m. layer, and is scarcer at 50-100 m. In the cold intermediate layer the quantity of the crustacean diminishes sharply, and often it is entirely absent. From a depth of 200 m. the quantity of C. cristatus again increases.

South of the moderate region, where there is no cold intermediate layer and the water temperature decreases evenly with depth, the vertical distribution of C. cristatus has a different character: this organism is completely absent in the warmed surface waters to a depth of 25-50 m., but below 50 m., and especially below 100 m., it inhabits the whole layer of water, and its biomass is never minimal in the 100-200 m. layer.

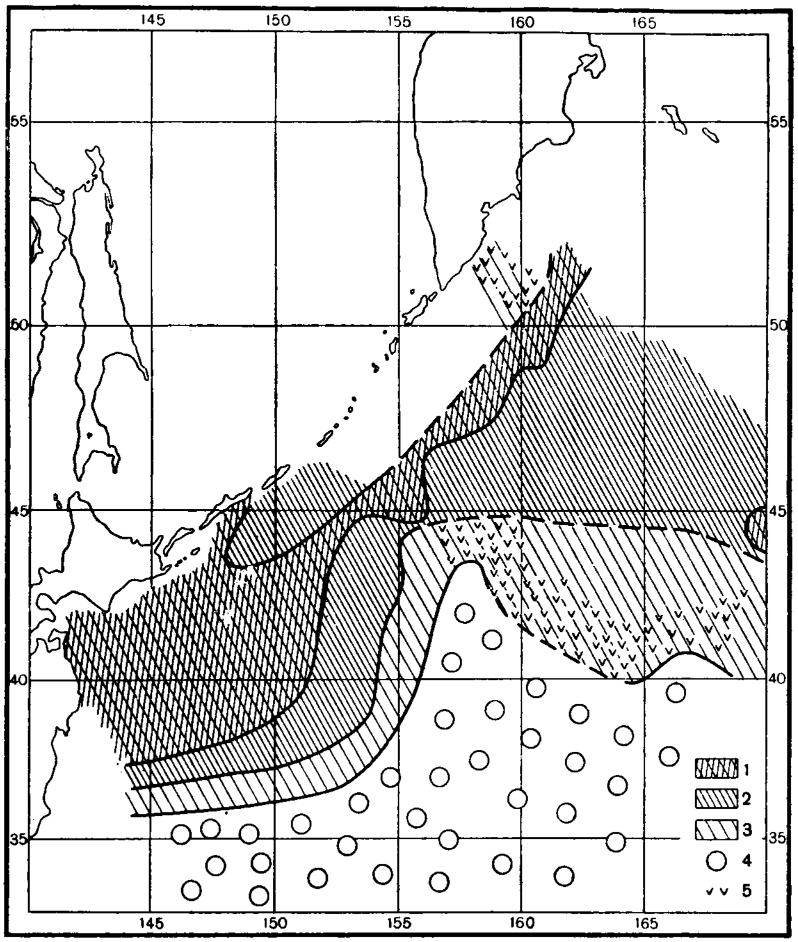

Figure 3.--Distribution of the plankton in the 0-100 meter layer in August-October 1954. 1 - above 500 mg./m.^{3}; 2 - 250-500 mg./m.^{3}; 3 - 100-250 mg./m.^{3}; 4 - less than 100 mg./m.^{3}; 5 - areas of "blooming".

The geographical distribution of C. cristatus in the 0-200 m. layer (fig. 4) shows its strict adaptation to the waters of the boreal region, the boundary of which coincides well with the southern boundary of its distribution in the surface layers. At depths greater than 200-500 m. it penetrates considerably farther south and was discovered by us in the 500-1,000 m. layer at 30°52'N.

The vertical distribution of the plankton biomass is not the same in the various parts of the area investigated. In the moderately cold waters of the boreal region, in the area adjacent to the Kurile Islands, under the influence of waters from the Okhotsk and Bering seas and characterized by the stratification found in them, in the presence of a cold intermediate layer, the relatively slightly warmed (to 10°-12°C.) surface waters are richest in plankton. In the 0-25 m. layer the biomass may sometimes reach 2 g./m.^{3}, and it fluctuates on the average from 200 to 1,000 mg./m.^{3}, increasing in the spring and decreasing in the autumn. The 25-50 m. layer is almost as rich, and in it is sometimes observed just as high a plankton biomass. In the 50-100 m. layer the biomass diminishes, but it is especially low in the 100-200 m. layer, below which it again increases. Thus, the cold intermediate layer is the poorest.

The standard stratification of the levels at which samples were collected somewhat obscures the poverty of the cold intermediate layer and at the same time diminishes the /apparent/ magnitude of the biomass maximum lying below it, for the 50-100 m. and 100-200 m. levels take in, in addition to the waters of the cold intermediate layer, waters rich in plankton which lie above and below this layer. A more differentiated selection of samples in the cold intermediate layer and in the layers adjacent to it

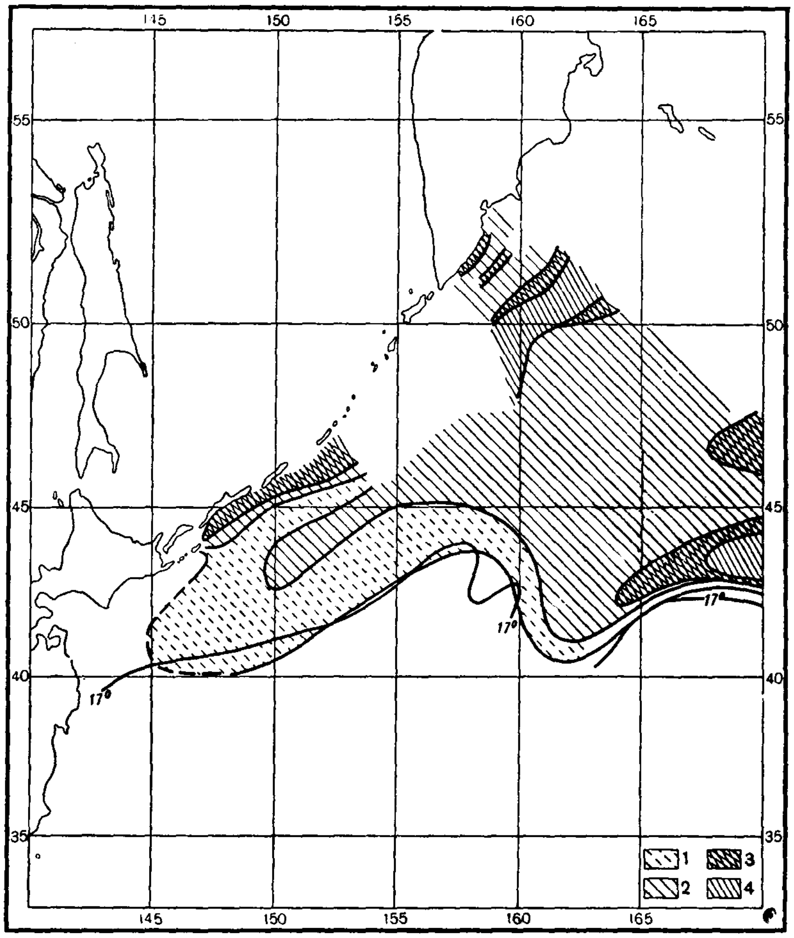

Figure 4.--Quantity of Calanus cristatus in the 0-200 m. layer in August-October 1954. 1 - 0-0.25 per m.^{3}; 2 - 0.25-0.5 per m.^{3}; 3 - 0.5-1.0 per m.^{3}; 4 - more than 1 per m.^{3}.

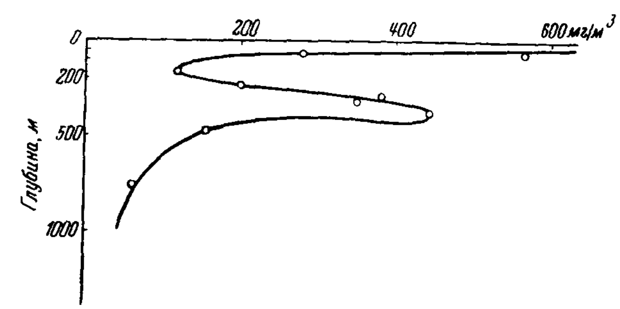

Figure 5.--Vertical distribution of the zooplankton biomass at one of the stations in the region of the Kurile-Kamchatka Trench.

shows the impoverishment of the levels corresponding to the cold intermediate layer and the abrupt enrichment of the 180-300 m. layer which lies below it (fig. 5).

The more strongly marked the cold intermediate layer is, the poorer it is in plankton. The correlation between the sharpness of the cold intermediate layer and the amount of plankton in it is well shown in a section from the island of Iturup (Etorofu) eastward (fig. 6). In that part where the section passes through the waters near the Kuriles, where there is a cold layer, the 100-200 m. level is shown to be somewhat impoverished in plankton. However, in the area 300-600 miles and more distant from the Kuriles the plankton biomass in the 100-200 m. layer is higher than in the area of the Kurile-Kamchatka Trench.

The impoverishment of this layer, in comparison with the layers lying above and below it, is very small or completely unnoticeable, and the plankton biomass decreases evenly with depth; in our opinion this is related to the disappearance in these regions of the cold intermediate layer.

The vertical distribution of the plankton has an altogether different character in the warm waters of the Kuroshio, the temperature of which drops slowly with depth and even at 400-500 m. does not go below 8°-10°C. In the uppermost surface waters, strongly illuminated by the sun, the biomass is negligible. Below 10-25 m. it increases insignificantly and, after reaching a maximum at 50-100 m., it again gradually decreases with depth. At night the quantity of organisms in the surface layers increases somewhat as a consequence of the ascent from the deeper layers of various bathypelagic crustaceans, squids, and fishes.

The small seasonal temperature changes in the waters of the Kuroshio do not bring about conditions permitting vertical circulation and mixing of the water. Therefore the surface layers are not enriched with biogenetic elements.

The absence of nutritive substances limits the development of the phyto-, and consequently, of the zooplankton. Such quantitative poverty of the plankton is also characteristic for other regions of the Pacific Ocean lying between 20°N. and 40°N. latitude, where the vertical circulation of the water is very weak. Only in the zone of the equatorial divergence does the plankton biomass again increase (Graham 1941).

Seasonal Changes in the Plankton

We can give an evaluation of the seasonal regime of the plankton only in the boreal waters.

In the spring months (May-June), in the surface zone, there accumulate for feeding an enormous quantity of zooplankton, consisting in the main of Calanus tonsus, Calanus cristatus, and Eucalanus bungii.

In summer the crustaceans, having transformed into the V copepodite stage and having stored up fat, begin to descend deeper. Judging by the data which we have on the plankton of the Bering Sea, this downward movement proceeds most intensively in the autumn, before the onset of the winter homothermy. As a result of the downward movement of the plankton into the deeper layers of the water, the quantity in the surface layers decreases appreciably. In addition, in these areas whales, saury and other plankton-eating fishes, and squid are feeding heavily. This also diminishes the concentration of plankton in the surface layers. Thus, in May-July 1953 Calanus cristatus was encountered over the greater part of the aquatorium in quantities greater than 5 per m.^{3} in the upper 100-m. layer, in August there were in all 1.6 per m.^{3}, and in September and October almost everywhere the quantity of this large crustacean became less than 1 per m.^{3}.

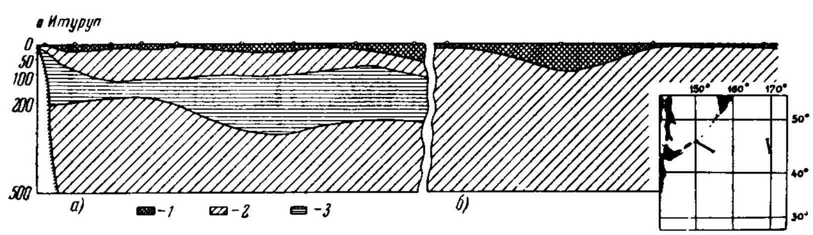

Figure 6.--Distribution of the plankton biomass on sections in the northwestern part of the Pacific Ocean. a - in a region with a cold intermediate layer; b - in a region without a cold intermediate layer. 1 - more than 500 mg./m.^{3}; 2 - 500-200 mg./m.^{3}; 3 - less than 200 mg./m.^{3}.

Changes in the Biomass of the Seston in the 0-100 m. Layer (mg. /m.^{3})

Months	Kurile coastal waters	Waters over the Kurile-Kamchatka Trench	Waters of the southern part of the boreal region
May-June 1953	500-1000	1000	500-1000
August-October 1954	250- 500	500-1000	250- 500

The changes in the plankton content in the upper 100-m. layer can be illustrated by the above table.

Thus, in spring the plankton biomass is usually about twice as great as in the summer.

We have analogous data for the Bering Sea (Vinogradov 1955). In spring (in May-June) the average zooplankton biomass in the central parts of that sea in the 0-100 m. layer was 747 mg. /m.^{3}, and at the end of summer (August-September) it was 326 mg. /m.^{3}.

At the end of May and the beginning of June we observed in waters with a surface temperature above 3°C. abundant "blooms" of various diatoms. In August-September massive accumulations of phytoplankton have almost nowhere been found in the waters of the boreal zone. Only small "patch" accumulations of phytoplankton are noted at that time close to the coast of Kamchatka.

A splendid development of phytoplankton (predominantly Thallasiothrix) was discovered between 155°E. and 170°E. longitude in the zone of impingement of the boreal waters on the waters of the Kuroshio. This is probably a constant blooming in response to the steady mixing in a zone of contact of different waters (fig. 3).

The available data testify that the months of May and June are the spring biological season in the plankton of the boreal waters of the northwestern part of the Pacific Ocean, and that August-October is the summer season.

In relation to the fact that the same biological season for plankton at different latitudes begins in different calendar months (Bogorov 1938), the different parts of the ocean simultaneously go through different biological seasons. Thus, the spring enrichment of the surface layer plankton in the southern part of the Japan Sea, under the influence of the warm Tsushima Current, occurs in March (Meshcheriakova 1954), in the northern half of the Japan Sea in May (Brodskii 1941, Kusmorskaia 1950), and in the cold Kurile waters at the end of May or beginning of June (according to L. A. Ponomareva's data). At about the same time (May-June) it occurs in the central areas of the Bering Sea and somewhat later (June-July) in the northern Bering Sea shallows and the Gulf of Anadyr (according to data of M. E. Vinogradov). On the other hand, the sharp autumn decline in the plankton begins earlier in the northern areas and thereafter extends southward. Thus, for example, the Anadyr Gulf area of the Bering Sea in October is in the stage of biological autumn, while in the Komandorsky Islands area at that time the plankton is in a summer condition.

It is obvious that whales, in their feeding migrations, keep to the areas of greatest concentration of plankton in the surface layers and abandon these areas when the concentrations of food decline. The feeding link between whales and plankton arises either directly or through small schooling fishes and squid.

According to data of M. M. Sleptsov, the whales appear in the northern part of the Japan Sea and in the area of the southern Kurile Islands and Sakhalin in April and May, that is, in the period of the spring biological season of the plankton. In May and June the whales arrive at Kamchatka and the Komandorsky Islands. At this time the plankton of these areas is also characterized by the spring biological season. In July the whales pass through the Bering Strait into the Chukotsk (Chukchi) Sea, appearing there in the period of the spring biological season in the plankton. Since the summer biological season in the plankton of the polar seas is very short (Bogorov 1938), in September the whales have already begun their return migration through the Bering Strait. In September they appear in the area of the Komandorsky Islands, toward the end of the biological summer in the plankton, and in the Kurile Islands area they appear again in October, also before the end of the biological summer of the plankton. Such links between plankton abundance and the distribution of whales are hypothetical and require further investigations for the detailed clarification of the peculiarities of the indicated correlations. The solution of this problem will permit the working out of a system for forecasting the migrations of whales and the place and time of their aggregations.

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Plankton of the Northwestern Part of the Kuroshio and the Waters of the Pacific Ocean Adjacent to the Kurile Islands*

By

K. A. Brodskii

As a result of many years of work by planktologists, we have an outline of the zoogeographical divisions of the Far Eastern seas and the adjacent part of the Pacific Ocean, but the most important area--the area of contact of cold and warm waters in the northern part of the Pacific Ocean--has remained weakly illuminated. At the same time this area (the Pacific adjacent to the Kuriles and the Kuroshio) is of great interest, both theoretically and practically. Here can be observed a sharp change in conditions as a result of the rapprochement of the Kuroshio current and the cold waters to which are given the general name of "Oyashio". It might have been expected that through this very area would pass the boundary of the zoogeographical provinces and that there would occur here zones sharply differentiated by the composition and quantity of the plankton. Commercially the area is of substantial interest as a fishing ground for tuna, saury, and other valuable species. The Kurile waters, as is well known, are also a whaling area.

The plankton of the Kuroshio and of the part of the Pacific adjacent to the Kuriles has hardly been studied at all. A few expeditions have collected plankton at a small number of stations. Of published works we can mention only the papers of Wilson (1942, 1950), who worked on the collections of the Albatross (1900) and the Carnegie (1929). Some Japanese works concerned with the results of hydrological investigations in this area contain incidental information on the plankton (for example, the works of Uda), but they do not give any sort of general presentation of the composition and distribution of the plankton.

Soviet expeditions, especially those of the vessel Vitiaz', have made more or less detailed investigations of the plankton of the Kurile Islands and the region of the Kurile Trench (Vinogradov 1955, Zenkevich 1955), but the area of investigation of these and of some other expeditions (on the whaler Shkval, 1951) have been limited by 40°N. latitude and did not extend to the frontal zone of the Kuroshio, much less to the proper waters of this current in its northwestern part.

In 1953 the author of the present paper (from the Zoological Institute of the USSR Academy of Science) took part in expeditions of the Institute of Oceanology of the USSR Academy of Science and of the Pacific Research Institute for Fisheries and Oceanography (TINRO) and collected plankton in the waters of the Pacific adjacent to the Kuriles and in the northwestern part of the Kuroshio. Our basic task was to study the composition and horizontal distribution of the plankton in the surface layers of the water. The work attained the objectives of discovering the northern boundary of the Kuroshio, establishing the zonality of the distribution of the plankton, and clarifying the composition of the basic group of the zooplankton, the copepods.

The basic sampling tool was a fish-egg net of No. 15 bolting cloth with an opening 80 cm. in diameter. The hauls were made at the 0-50 m. level. The selection of the basic net and depth of hauls was determined by the following considerations. The fish-egg net is good for catching the adult stages of copepods and gives, perhaps better than the Juday net, a picture of the distribution of the larger forms of the calanids, which is important for answering practical questions about the feeding grounds of fishes and whales. The second consideration in favor of using the fish-egg net and the 0-50 m. stratum was the necessity of comparing the 1953 data with those obtained in the northwestern Pacific by the whaler Shkval in 1951.

The materials we had led us to assume that we would find the greatest biomass of the plankton in the 0-50 m. layer not only at night but also in the daytime. This assumption was supported by special investigations carried out by us in 1953.

As supplementary collecting gear we used a Juday net of No. 38 gauze for hauls at standard levels from 200 m. to the surface.

The arrangement of the sections was planned to take in the largest area possible with the smallest expenditure of time and to cut across the main streams of both cold and warm currents. Therefore the sections were perpendicular to the Kurile chain and extended from 400 to 750 miles in a south-southwest direction. In all, six such (long) sections were made, connected by shorter transverse ones. The

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*From Trudy Instituta Okeanologii, Academy of Sciences of the USSR, Vol. 18, p. 124-133, 1955.

distance between stations was 40 miles; besides the collection of plankton, at each station the water temperature was taken at levels down to 200 m. For studying the seasonal dynamics of the distribution and composition of the plankton the sections were run twice: from July 9 to August 12, and from September 7 to 23.

The plankton collections were made from a medium fishing trawler (SRT 662), on the deck of which was installed a winch of the "Ocean" type with an electric motor, footbrake, meter, and automatic level-wind. The hauls were made with a galvanized steel cable 3.1 mm. in diameter.

The collection of plankton from a medium fishing trawler, i.e. a relatively small (displacement about 300 tons, with a 280 H.P. engine) and extremely unstable vessel, which rolls heavily in even a small sea, has some special features. Under such conditions the plankton net, in the water, at times experiences very heavy dynamic loads even in a moderate swell. This can easily lead to breaking of the cable or damaging of the net. The net and the cable are subjected to especially heavy loads on the open sea with a constant monsoon of a force of 5-6, which makes for the appearance of large wind swells. In working on small vessels it is essential to use an accumulator. The "Ocean" type winch, with a 3.5 KW electric motor, in itself appeared to be an excellent accumulator. When there were heavy jerks while the net was being hauled up, the motor would cease to pull the net, and the cable would even pay out slightly. Thanks to this, not a single net was lost or torn during the whole operation.

In all, 139 stations were occupied from July 9 to September 23, 1953, 470 plankton samples were taken, and 653 water temperature determinations were made. A total of more than 10,500 miles was run, most of it on the open ocean. The investigations took in a significant area of the northwestern Pacific Ocean, from the Kurile chain south to 34°N. latitude. The southwestern boundary of the area runs approximately along the meridian of the northern tip of the island of Shikotan, and the northeastern one along the meridian of Cape Lopatka in Kamchatka.

Results of the Analysis of the Plankton

Composition of the Plankton. The systematic composition of the plankton of the area investigated, in view of the variety of the conditions encountered there, is extremely heterogeneous; the warm-water plankton is especially rich in groups and species. Most abundantly represented in it are the copepods, of which not only are the calanoids numerous (more than 100 species) but also the cyclopoids, among which abound extraordinarily beautiful, transparent Copilia, Corycaeus, and Sapphirina. Cladocerans are represented abundantly in a small number of species. There are many species of siphonophores, salps, pteropod mollusks, hyperiids, radiolarians (mostly of the family Acanthometridae), chaetognath worms, and crustacean larvae, among them the leaf-like Phyllosoma, the elongated Lucifer, and others.

Comparing the overall catalogue of copepods, hyperiids, radiolarians, and other groups from the area investigated in 1953 with the species catalogued for the Japan Sea (excluding its southwestern part) and the Bering and Okhotsk seas, it is possible to convince oneself that in species composition the plankton of the area investigated by us is considerably richer than that of all three of these seas taken together. This refers especially to the surface layers of the water.

The zoogeographical composition of the plankton is also varied, but there predominate, particularly among the copepods and cladocerans, three basic groups, which are extremely unequal in terms of the number of species, as follows:

1) Species of the North Pacific Temperate Region--the common species of the Far Eastern seas (Calanus tonsus, Eucalanus bungii, Metridia pacifica, and others). This is the poorest group in terms of species;

2) Subtropical species of the Indo-Pacific Subregion of the Tropical Circumequatorial Region. This group is relatively richer in species and includes many species of copepods (genera Labidocera, Acartia, Paracalanus, and others) and cladocerans;

3) Tropical species of the same region and subregion. This is the group that is richest in species (of the genera Eucalanus, Nannocalanus, Canthocalanus, Neocalanus, Undinula, Candacia, Paracalanus, Acrocalanus, Mecyanocera, and others).

The distribution of some of the species of the second group is limited to the waters adjacent to the Pacific coast of Japan. These species are related to the Japanese Subtropical

Province of the Tropical Circumequatorial Region.

The similar zoogeographical composition of the copepods and the cladocerans of the area studied indicates the presence in the area of at least two different zoogeographical regions. Actually, the northern boundary of the northwestern part of the Kuroshio is at the same time the zoogeographical boundary of two regions: the North Pacific Temperate and the Tropical Circumequatorial's Indo-Pacific Subregion.

Distribution of species. Let us look at the distribution of individual species, mostly of copepods. In view of the large number of species, we will separate them into groups and show the distribution only of some representatives of each group. The species fall into three natural groups according to their distribution and their relation to the water temperatures in the area investigated:

1) Relatively cold-water species (Calanus cristatus, C. tonsus, and Eucalanus bungii);

2) Relatively warm-water species (Calanus pacificus);

3) Subtropical and tropical species Nannocalanus minor, Labidocera japonica, Corycaeus spp., Sapphirina spp., Copilia spp., Penilia avirostris, Evadne tergetina, and salps).

The distributions of the three species named for the first group are very similar; we shall therefore limit ourselves to the character of the distribution of the species which is present in the greatest mass in the area studied, Calanus tonsus. This species is broadly distributed in all three of the Far Eastern seas (the Sea of Japan, the Okhotsk, and the Bering), and extends as far as the southern part of the Chukotsk /Chukchi/ Sea. In the area investigated it occupies a narrow expanse in the form of a band along the Kurile chain. The southern boundary of this band runs at a distance of 240 miles off the southern Kuriles and more than 400 miles from the northern islands of the chain, corresponding approximately to the 12°-13°C. isotherms of the surface waters in July-August.

The distribution of the two remaining species (Calanus cristatus and Eucalanus bungii) is similar to that of Calanus tonsus, but it has some specific peculiarities. In particular Calanus cristatus, which is distributed like Calanus tonsus in an elongated band parallel to the Kurile chain, forms accumulations in places of upwelling of cold waters to the surface layers.

Among the species of the second group, the most typical distribution is that of Calanus pacificus, which, like the two species pointed out in the first group, is distributed in a band along the Kurile chain, with, however, this difference, that this band (or zone) occupied by Calanus pacificus is displaced somewhat to the south-southeast. The band-like or zonal distribution of this species is especially noticeable in September.

The third group is heterogeneous. Both subtropical and tropical species enter into it, but they naturally differ in the degree of their stenobiontism. As an example let us take a species less stenobiontic than the rest, the cladoceran Penilia avirostris. The northern boundary of the distribution of this crustacean coincides with the northern boundary of the distribution in general of all of the subtropical fauna in the area investigated. As an example of a more stenobiontic species we can take the copepod Nannocalanus minor, the northern boundary of which is in good agreement with the northern boundary of the tropical fauna in the area.

The region of distribution of Penilia avirostris in the waters of the Pacific Ocean off the Kuriles occupies a more southern position than the regions of distribution of the species of the first and second groups, that is, the moderately cold-water group and the moderately warm-water group. The northern boundary of Penilia avirostris, where the species is represented by only a small number of specimens (from 1 to 4 per $m.^3$), does not come any closer to the Kurile Islands than 300 miles in the southern part and 400 miles in the middle of the chain. The greatest quantity of individuals of this species is distributed considerably farther south than the region of distribution of the moderately cold-water and moderately warm-water species and lies at a distance of 400-500 miles to the southeast from the chain, which position corresponds to the 17°C. surface isotherm in July. In September the aggregations of this crustacean are displaced somewhat closer to the chain and are even distributed slightly north of the 40° parallel.

The distribution of Nannocalanus minor resembles that of Penilia avirostris with the difference that in 1953 the greatest quantity of individuals of this species was encountered in

July no closer than 600 miles to the Kurile chain (on the western section) and only in September were they found at a distance of 300 miles to the south-southeast from the chain. An abundance of Nannocalanus minor was discovered when the temperature of the surface layer rose to 22°C. (in July) and 25°C. (in September).

The cited examples of the distributions of representatives of the three indicated groups compel us to assume the presence of a well-defined zonality (or banding) in the shifts of the plankton in the area investigated. For clarification of this problem let us look at the changes in the plankton from the Kurile chain to the south-southeast (roughly speaking, to the south).

Changes in the plankton from north to south. In the immediate vicinity of the Kurile chain the plankton in July and August, 1953, was characterized by an abundance of microscopic algae, which occupied a relatively narrow band along the whole chain; the southern boundary of this band was 40-50 miles distant from the chain. In September this band was greatly narrowed and in places was interrupted. From investigations of the plankton along the Kurile chain in past years it was known that as a consequence of strong mixing and low water temperatures (about 2°-5°C.) the area of the Kurile Islands is characterized by a prolonged and intense plankton bloom. Seasonal changes in the course of the spring, summer, and autumn do, of course, show up in the decrease in quantity and change in species of the algae, but the bloom, although limited in extent, does not disappear even in the summer. That was the case, at least, in 1953. Analogous observations were made by us in 1950, too; the same thing appears from the data of E. Fedorova for 1952.

The zooplankton in the zone of blooming is poor in species, and in its composition it differs little from the zooplankton of the areas slightly farther south; it may be only that its biomass is somewhat smaller.

Directly adjoining the zone of abundant phytoplankton, there extends to the south a broad strip, also parallel to the Kurile chain, which is characterized by an abundance of a few species (found in great quantities) of calanids typical of the North Pacific Temperate Region, which serve as forage for pelagic plankton-eating fishes and baleen whales (fig. 1). The width of this zone is determined by the southern limit of the distribution of Calanus tonsus, which was discussed earlier. There are present here, in all, 5 or 6 species of calanids, 3 of which (Calanus tonsus, C. cristatus, and Eucalanus bungii) are encountered in mass quantities. Of the most abundant species--Calanus tonsus, represented mostly by the fifth copepodite stage--there were in July about 200-800 individuals per $m.^3$, or 240-960 $mg./m.^3$.

The zone rich in large species of calanoids, which constitute food for fishes and whales, extends along the whole Kurile chain from Shikotan Island to Cape Lopatka. In the area of the northern islands of the Kurile chain the zone of abundance of Calanus tonsus is considerably broader than at the southern islands. The phytoplankton in this zone was very poor, and no tropical species of zooplankton were discovered there in 1953. The temperature of the water here is still relatively low; at the various stations in July and August, 1953, it varied from 5° to 15°C. at the surface.

Judging by the volume of settled plankton and the quantity of specimens of large copepods, the zone with Calanus tonsus represents the southernmost extent of the rich forage plankton of the Far Eastern seas, that is, the southern boundary of the plankton which is characterized by high biomass. In September 1953 the biomass became considerably less than in July (fig. 2). The reasons for the decrease in the biomass are not yet exactly known. It can only be postulated that it reflects the migration of the calanoids and the devouring by consumers; it is hard to say now which of these causes has the greater significance.

South of the indicated zone, the quantity of individuals of Calanus tonsus decreases, but the quantity of Calanus pacificus increases noticeably. The latter, especially in September, forms a continuous band lying approximately between the 15°C. and 18°C. surface isotherms in July.

The transition from the zone of Calanus tonsus to the zone of Calanus pacificus is gradual in some places, but in others the composition of the plankton changes sharply. This is connected mainly with low and high water temperature gradients. Together with Calanus pacificus in the plankton appear Eucalanus hyalinus, Evadne spinifera, and other warm-water species. Judging by the specific composition, the zone of Calanus pacificus evidently represents a transitional region between the faunas of the temperate and subtropical zones. The boundary between these zones lies between

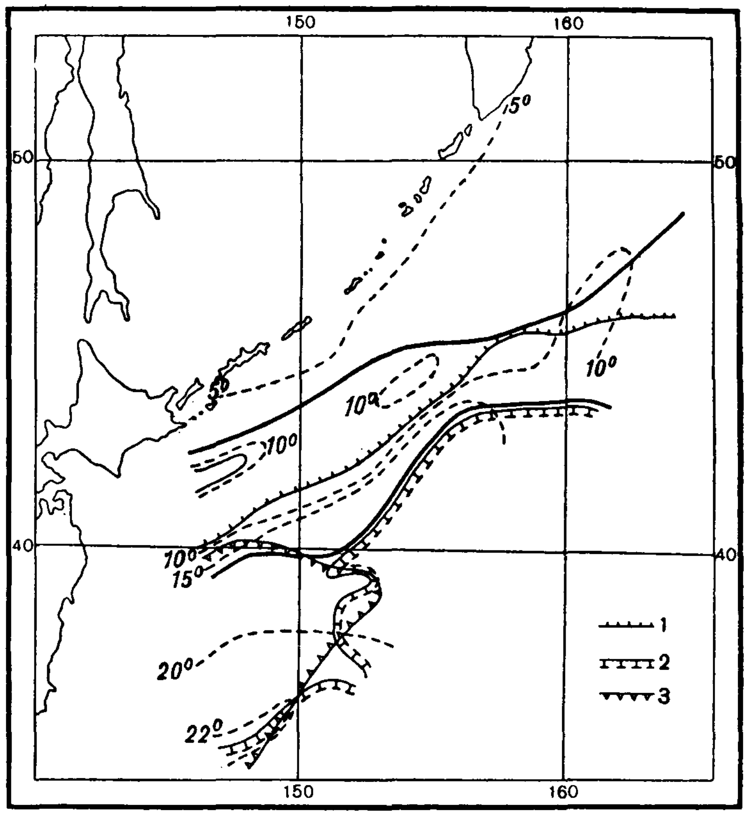

Figure 1.--Distribution of the plankton at the time of the first survey (July 9-August 12). 1 - southern boundary of the North Pacific Temperate Region (the zone of Calanus tonsus); 2 - northern boundary of the Tropical Circumequatorial Region (tropical zone); 3 - boundary of the subtropical fauna. The solid lines without marks indicate the boundary of the transitional zone with Calanus pacificus; the broken lines show the surface isotherms for July 9 to August 12, 1953.

the 15°C. and 18°C. surface water isotherms in July. These isotherms also outline very well the northern frontal zone of the Kuroshio.

South of this transitional zone lies a narrow band of the subtropical fauna. In July this fauna is found mainly in the western part of the area of investigations, that is, approximately in line with the islands of Shikotan, Iturup, and Kunashir, but in September it spreads to the east, almost to the line of Cape Lopatka in Kamchatka.

The transition between the zone of Calanus pacificus and the belt of subtropical fauna is relatively abrupt: the differences in the composition, in the color of the plankton sediment, and in its volume are clearly noticeable, even between adjacent stations 40 miles apart. This boundary is also revealed by the appearance of such organisms as Physalia, and also by numerous salps, Pyrosoma, flying fish, blue sharks, sunfish, and turtles.

Beyond the narrow belt of subtropical fauna begins the true tropical fauna, abounding in various groups and numerous species. Among the copepods we encounter here Undinula darvinii, U. vulgaris, Nannocalanus minor, Neocalanus robustior, Canthocalanus pauper, a series of species of the genus Eucalanus (E. crassus, E. subcrassus, E. monarchus, E. attenuatus), Clausocalanus arcuicornis with its three varieties, Calocalanus pavo, Corycaeus, Copilia, Sapphirina, species of the genera Centropages, Candacia, et cetera. There are numerous siphonophores, salps, Lucifer, Pteropoda, and Carinaria and other genera of Gastropoda; one is struck by the abundance of Chaetognatha; and there are numerous radiolarians of the Acanthometridae. Here there are more than 100 species of calanoids alone, while in the zone of Calanus tonsus there were only 5 or 6. The plankton biomass here is significantly less than in the zone of abundance of Calanus tonsus.

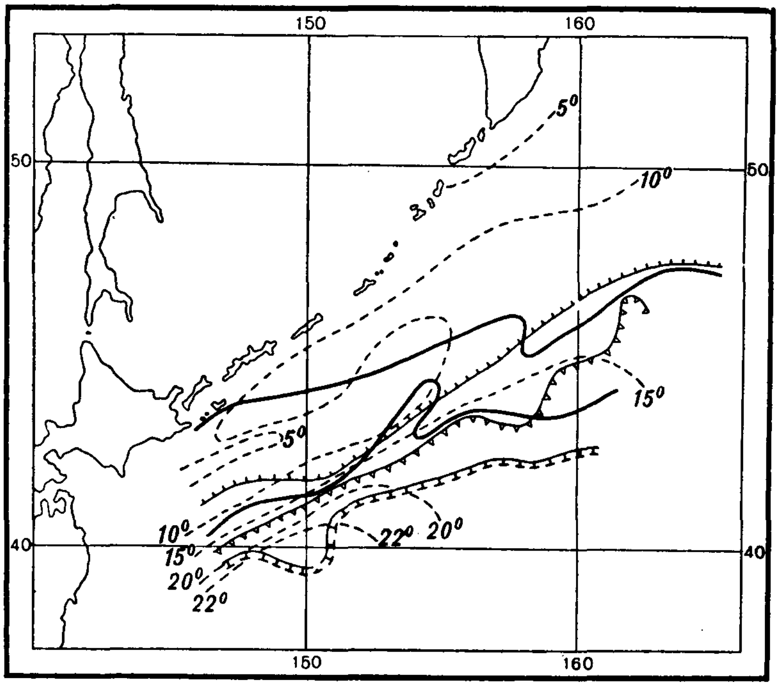

Figure 2.--Distribution of the plankton at the time of the second survey (September 7-23). Notations the same as for figure 1. (Isotherms are for the period September 7-23)

The northern temperature boundary of the subtropical fauna can be considered the 18°C. surface isotherm in July, and 22°C. for the tropical fauna.

Thus, judging by the changes in the composition of the plankton and the quantity of its separate components, and also by the size of the biomass, in the area investigated it is possible to distinguish the following zoogeographical zones or areas of the plankton.

I. Zone with Calanus tonsus.

This zone with the highest biomass is regarded by us as the southern boundary of the highly productive North Pacific region. Large volumes of plankton determined by settling are characteristic for this zone as well as its red color caused by the large number of individuals of Calanus tonsus which have a great deal of fatty substances containing red pigment.

II. The transitional zone with great quantities of Calanus pacificus.

This zone lies farther south than the first one and is characterized by the blue color of the plankton sediment caused by the presence in the samples of individuals of the above-named species. The content of fatty substance in these crustaceans is significantly less than in Calanus tonsus; the blue color of the sediment depends on general coloration of the body and appendages of the crustacean.

III. The tropical zone lying south of the transitional zone is characterized by small colorless plankton sediments consisting of a large number of small species of copepods with an abundance of siphonophores, salps, chaetognath worms, and so forth.

In enumerating the zones of the plankton it is not by chance that we pay attention to the color of the plankton sediments; it very obviously (at the time of collection of the plankton) shows the change from one type of plankton to another. If we were to present a picture of the changes in the plankton encountered as a vessel moves from the Kuriles to the open sea, i.e., roughly from north to south, we would get the following succession of changes in color of the sediments. At the Kurile Islands, very large (in volume) samples of a dark green color ("bloom"). After that, with the same volume, they would become red (Calanus tonsus), and with a decrease in the volume a beautiful blue color (Calanus pacificus), and finally with a sharp decrease in volume of the samples the sediment would become colorless (small subtropical and tropical species of copepods).

In 1953 on the southern stations of the meridional sections we encountered tropical plankton. Evidence that the vessel actually reached the area of the true tropical plankton fauna was the common occurrence of forms found by us and listed in the station catalogues of plankton forms from the tropics (Wilson 1942, Sewell 1932, 1947 and 1948, Vervoort 1949, and others). Thus, as common forms there appeared species of the genera Acrocalanus, Clausocalanus, Undinula, Candacia, Pleuromamma, Eucalanus, Canthocalanus, Neocalanus, Nannocalanus, Corycaeus, Copilia, Sapphirina, and many others. However, establishing the similarity of the plankton fauna studied in the 1953 collections with the tropical plankton from the open sea, it is possible to establish also the well-known specificity of the plankton of the area of the Kuroshio under study, i.e., the presence in this plankton of a significant mixture of neritic forms making up at times in terms of the number of individuals the predominant part (at some locations the first place in terms of quantity of specimens in the samples was occupied by Penilia avirostris).

Plankton of such a composition is typical of coastal areas in the tropical latitudes, particularly at the Great Barrier Reef (Farran 1936), on the west coast of India (George 1933, Chidambaram and Menon 1945, Jacob and Menon 1947, Chacko 1950 and others), on the Australian coast (at Sydney) (Dakin and Colefax 1933), and from other places in the tropics. In the works listed, particularly in the Indian ones, there are indications of the predominance of Penilia avirostris, species of the genera Acartia, Labidocera, Noctiluca, Acanthometridae among the Radiolaria and salps in the plankton.

The neritic character of the plankton in our samples varied with the time and place of collection. Thus, in July it showed up mostly in the southern part of the western sections, while in September such neritic species as Labidocera japonica and others extended all the way to the easternmost section. It is possible to postulate that the water of the Kuroshio passing along the coast of Japan is somewhat transformed and produces favorable conditions for occurrence of the Japanese neritic fauna at a great distance from Japan, almost to the area lying south from Cape Lopatka in Kamchatka, i.e., over a distance of almost 1,000 miles. However, the neritic character of the plankton did not extend to the southernmost stations of the 1953 sections. Thus, in July on the western section neritic species were not encountered south of 36°56'N. latitude or were represented by single individuals. South of this latitude the plankton took on the character of the oceanic tropical plankton. It is difficult to say how far the region occupied by this plankton extends, but judging by the character of the circulation of the water the fauna found at the southernmost stations of the 1953 sections probably extends over a greater area, perhaps all the way to the North Equatorial Current. In other words, in the northwestern part of the Pacific Ocean only the northern boundary of the tropical plankton is clearly pronounced, and to the south of it over a broad area there occurs a plankton of similar composition (Wilson 1942). We know little about the southern boundary of the tropical plankton in the Southern Hemisphere (Steuer 1933).

The zonality in the distribution of the plankton of which we have spoken earlier is most clearly pronounced on the sections running from the southern half of the Kurile chain and becomes unclear with the fading out of the boundaries of the zones in the easternmost part of the area investigated. This evidently is connected with changes in the position and most importantly the force and character of the Kuroshio as that current moves farther from the Japanese coast to the east (see Marine Atlas, Vol. 2).

Comparison of the distribution of the plankton with the circulation of water in the surface layer. By comparing our data on the plankton with Soviet and Japanese material on the circulation of the water we disclose a great deal of coincidence with our hydrological data. Thus, the general regionalization of the plankton made on the basis of the 1953 material reflects very well the scheme of the circulation of the water. The sharp change in the plankton (between the zone of Calanus tonsus and the tropical zone) clearly indicates the northern frontal zone of the Kuroshio. The distribution of certain species indicates the presence on the one hand of nuclei of cold water in the area near the Kuriles (distribution of Calanus cristatus) and on the other hand the existence of tongues of warm water extending through the straits of the Kurile chain into the Sea of Okhotsk (distribution of Calanus pacificus).

Not only can we follow very well through the changes in the composition and distribution of the plankton the distribution and origin of the water masses, but through the seasonal changes in the plankton we can even define the speed of transport of the water. Thus, a comparison of the charts of the distribution of the plankton for July and September can give material for judging this question. For example, at the time of the first plankton survey (July 10-15) Labidocera japonica was found at the southern stations on only the westernmost section (in line with Shikotan Island), but on the second survey (September 20) it was discovered also at the southern stations but now on all sections all the way to the easternmost (in line with Cape Lopatka in Kamchatka). The distance between the southern stations of these sections was about 900 miles. As there were 75 days between July 15 and September 20, the mean velocity of transport of the "Japanese" water of the Kuroshio consequently was about 12 miles per day. According to hydrological data the velocity of transport of the Kuroshio water (east of Japan) is somewhat less than 12 miles per day, i.e., close to the magnitude which can be defined by the seasonal change in the extension of plankton forms.

On the basis of this example and also of data on the speed of spread of other neritic species of the zooplankton it is possible to assume that the "Japanese" water extended to the east 900 miles in 2-1/2 months with the result that favorable conditions were produced for the survival and development of such species as Labidocera japonica, Penilia avirostris, Nannocalanus minor, Copilia spp., and a series of others which were carried away from the coast of Japan and also from the south.

In the present paper we have attempted to solve to some extent two problems: 1) to sketch the general scheme of regionalization of the plankton in the waters of the Pacific Ocean off the Kuriles and in the northwestern part of the Kuroshio, and 2) to determine the boundaries of the distribution of some species characteristic of different ecological and zoogeographical groups of the zooplankton, primarily copepods.

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