The distribution of plankton bioluminescence and fluorescence caused by physicochemical properties of aqueous medium in the water area of the Peruvian upwelling

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In a period of El Niño the intensity of plankton luminescence and physicochemical water parameters in the water area of the Peruvian upwelling were measured. It is shown that the correlation (R^2 = 0.81–0.95) exists between the location of bioluminescence extremes, the salinity gradient, and the oxygen concentration. The distribution of chlorophyll fluorescence maximum coincided with the location of pycnocline (R^2 = 0.85). The spatial distribution of intensities of bioluminescence and fluorescence in the region of research was different. It is assumed that this is due to the properties of the plankton forming the light fields in the ocean.

Introduction

A characteristic feature of the vertical distribution of bioluminescence in water of the World Ocean is its inhomogeneity. The depth of occurrence the bioluminescence maximum correlates (0.80–0.91) with the thickness of an isothermal layer.[1] Actually the highest intensity of bioluminescence occurs at the upper boundary of thermocline.[2] The correlation was found at the level of 0.18–0.65 (Ref. 1) between the physicochemical indices of aqueous medium and the intensity of plankton bioluminescence. In this case the highest correlation coefficient was observed between the bioluminescence and the oxygen concentration.

The vertical distribution of bioluminescence in the upwelling water areas has a clearly defined single-maximum profile.[1] The change of hydrophysical parameters in frontal areas not always produces an appropriate reaction of the bioluminescence characteristics. At the uniform temperature of the background, sharp changes were observed of the level of plankton bioluminescence, and, on the contrary, in the region of temperature fronts the intensity of bioluminescence remained invariable.[2]

The position of the phytoplankton fluorescence maximum is determined by the thickness of a quasi-homogeneous layer and the depth of occurrence of extremes of gradients of hydrophysical characteristics.[3] If the mixed layer is less than 70 m, the maximum fluorescence is found to be several meters under the extremes of gradients of the temperature, salinity, and density. At the thickness of a quasi-homogeneous layer of more than 70 meters the position of the above parameters varied, and the break will be several tens of metres.[3]

However, there exist some exceptions from this relationship. It is shown that in the subtropical water the peak of chlorophyll fluorescence is found at the depth of 80 m, and its position is determined by the maximum density stratification, which coincides with the seasonal thermocline.[4] In the Mediterranean Sea the peak of fluorescence coincided with the lower boundary of euphotic layer, and in the frontal zone it was localized between water layers where the light intensity was 1% and 3.5% of the light intensity incident on the surface.[5]

In the areas of frontal zones a definite regularity is not found between the intensity of chlorophyll fluorescence and hydrophysical parameters of seawaters. Thus, in the subantarctic front the profiles of phytoplankton fluorescence varied in the shape and intensity at adjacent water areas without reference to the surface temperature.[6] In the Baltic Sea the extremes of horizontal distribution of fluorescence were found outside the front, and no correlation between the fields of temperature and chlorophyll luminescence was observed.[7] However, in the Atlantic Ocean the areas of increased chlorophyll fluorescence in the northern and southern boundaries of subtropical front were connected with high horizontal gradients of salinity and temperature.[8]

From the above said, it may be seen that temperature is the general factor, affecting the distribution of fluorescence and bioluminescence. However, the general and characteristic features in the structure of luminescent fields have not been so far found at simultaneous measurements of the fluorescence, bioluminescence, temperature, as well as other physicochemical parameters of aqueous medium. The most convenient testing ground for performing such investigations is the highly efficient upwelling near the Peru shores, which functions the year round.[9,10] A supplementary argument in favor of selecting this area was the presence in the east Pacific area of the layer of deep-water oxygen minimum, which rises at the shores from 80 to 100 m.[11] In this case the origin of oxygen minimum is caused by hydrodynamics of ocean water.[12]

The goal of this research was to study and to determine the regularities of the distribution of

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bioluminescence and plankton fluorescence due to aqueous medium at simultaneous measurement of physical, chemical, and biological parameters of ecological system in the area of the Peru upwelling.

Equipment and investigation techniques

In the investigations a multichannel Romashka-3 sonde was used. The vertical profiles of bioluminescence, temperature, and underwater irradiance were measured using this sonde.[1] A bathyphotometer is provided with rotor dimmers to decrease the sunlight by a factor of 10^{10}–10^{12}. This makes it possible to measure the intensity of bioluminescence at any time. This sonde consists of 6 bathometers for water sampling at characteristic points of distribution of the parameters being studied.

Besides, to measure the chlorophyll fluorescence and physicochemical parameters of seawater a 150-liter bathometer was used. Using this bathometer, samples were taken simultaneously from 14–16 horizons of the upper 200 m layer. The horizons were selected using the results of vertical sounding of hydrophysical and hydrooptical characteristics for the purpose of determining the gradient zones.

The chlorophyll fluorescence was recorded using a FL-304 device of KSU by the above-mentioned procedure.[13,14] Physicochemical parameters of seawater were determined by use of conventional techniques.[15]

The investigations were performed in February 1987 during the 38th voyage of the research vessel *Dmitrii Mendeleev* in the upwelling water area of 137 miles in length, which beginning was at the station with the coordinates 7°39′S, 79°31′W and the end was at the station with the coordinates 8°11′S, 81°40′W.

Results of the investigation and discussion

The hydrological situation during the investigation of the distribution of plankton luminescence was as follows. The most part of the region was subjected to the transgression of high salt, warm waters with the temperature of the upper water layer being about 25°C (Ref. 16). The positive temperature anomaly reached 3°C (Ref. 17). In this connection the upwelling decreased. The isotherm of 20°C, which was followed up to 6–7°S in the period of research was not elevated to the north of 25°S.[16,18] The upwelling was found only in the 30-mile coastal line.[16] The character of oceanological conditions, corresponding to El Niño, was sharply manifested in the spatial temperature distribution (Fig. 1). The thermocline was found at the surface in a narrow 10-mile coastal strip. The warm waters rose to the surface at the temperature more than 21°C from a thin subsurface layer of 25–30 m in thickness at low concentration of the biogenic elements. A typical for this region deepening of the isotherms started from the isotherm of 20°C and not from 15°C as it is observed at normally developed upwelling.[19,20] In February 1987 a very strong deepening was found in the direction toward the coast of the isotherm 15°C (Fig. 1). Such deepening is due to warm waters from the open water area of the ocean.[16]

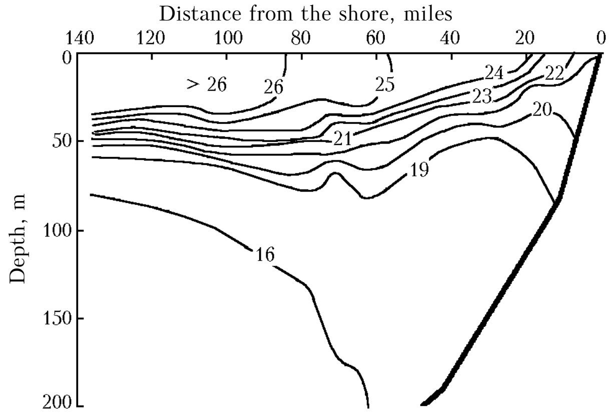

Fig. 1. The temperature distribution (°C) in the Peruvian profile.

The oxygen distribution also differed from that observed usually. At the marked upwelling, isooxygens 1–5 ml/l rise to the surface from the west to the east.[12] In 1987 this trend could be found only relative to isooxygens 3–4 ml/l (Ref. 11). The isolines, representing the oxygen concentrations of 0.2 and 0.5 ml/l tend to the deepening as they approach the coastal zone. At the developed upwelling these isolines are described by a complex curve.[12] In the observation period the isooxygens 1.5 and 2.0 ml/l were characterized by many extremes.[11]

Using measurement data on temperature and salinity, the gradients of these parameters were calculated. The calculations have shown that at the cross section the horizontal profiles of thermocline and halocline differ. On the whole they are similar to some typical isolines. The maximum of the temperature gradient is similar to 21–22°C isotherms (Fig. 1). The halocline was similar to the 35‰ isoline located in the upper fifty meters layer (Fig. 2). Over the length of 137 miles of the Peru profile the upper limit of the gradient of conditional density (pycnocline) did not go below 50 meters (Fig. 2).

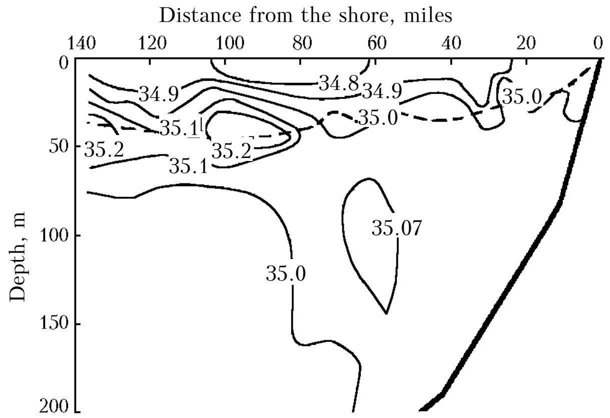

Fig. 2. The salinity distribution (‰) in the Peru profile. The position of the upper limit of conditional density of pycnocline is shown by dashed curve.

What was the effect of the frontal zones on the spatial distribution of plankton? First of all, using the investigations carried out at the station located in the middle of the profile, we consider vertical profiles of bioluminescence in the daytime and nighttime and explain the origin of the luminescence maxima (Fig. 3). It has been found experimentally that in the daytime the net intensity of luminescence in the entire water column is about 10 times lower than in the nighttime. This is connected with photoinhibition of bioluminescence by sunlight. At 8:00 local time at water transparency $S = 9$ m the bioluminescence appeared from the depth more than $2S$, and at 20:00 local time, when it is dark, the luminescence began to appear from the upper water layers. The daytime vertical profile of bioluminescence was characterized by three maxima, and the nighttime vertical profile was characterized by four maxima. At these vertical profiles two lower maxima coincided in location in space and were determined by zooplankton accumulation.[18] Two upper maxima of bioluminescence at the night vertical profile coincided with the fluorescence distribution.

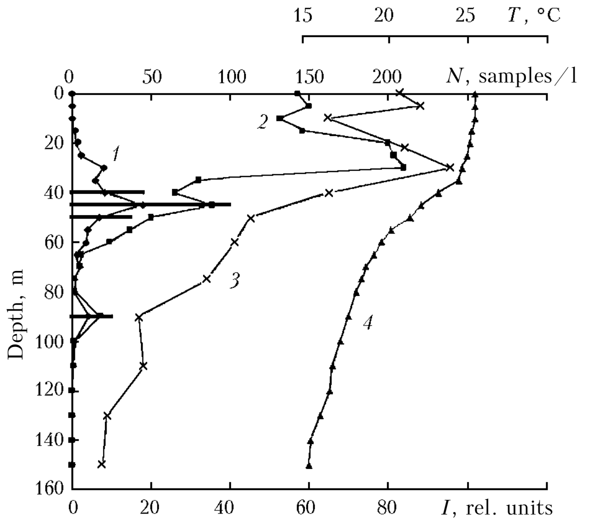

Fig. 3. Vertical distribution of hydrobiological parameters and temperature at the station (07°58′09″S, 80°45′07″W): intensity of bioluminescence in the daytime (8:00) (*1*) and at night (20:00) (*2*); fluorescence of chlorophyll (*3*); temperature (*4*). Horizontal lines show the quantity of zooplankton.

In the daytime these extremes of bioluminescence degenerated in one weak peak, whose spatial position corresponded to the depth at which maximum chlorophyll fluorescence was observed. Thus, the daytime profile of bioluminescence reflected inadequately the phytoplankton structure. On the contrary, the relation between zooplankton distribution and bioluminescence was more evident and did not depend on the irradiance.

Bioluminescence distribution at the Peru upwelling is given in Fig. 4. Maximum intensity of the bioluminescence well correlated, almost at all stations of the profile, with the position of halocline (see in Fig. 2 isoline 35‰ located closer to the surface), with the only exception for the station far removed from the shore where the irradiance peak was found at the depth of 65 m, and halocline was found at 20 m. Bioluminescence was centered in a narrow water layer (60–80 m) as compared with all other stations. In the vertical profile of luminescence separate peaks stood out that was typical for luminous zooplankton. It is probable that the invasion of salt water (35.2‰) and warm water (>26°C) from the open ocean affected such plankton distribution (Figs. 1 and 2). Along the whole length of the Peruvian upwelling the correlation coefficient between the position of the salinity isoline 35‰ (halocline) and the depth of maximum intensity of bioluminescence was 0.52. If excluding from consideration the last ocean station the correlation coefficient was 0.81.

The lower limit of bioluminescence at the upwelling was limited to isooxygens 0.5 and 1.5 ml/l (Fig. 4). In this case the oxygen limitation changed in the frontal zone, formed by the interaction of above shelf and ocean waters. This zone was located at the distance of 55 to 70 miles from the shore.[18] In the frontal zone area at the depth of 130 to 150 m a relatively small water lens at the oxygen concentration below 1.5 ml/l was found. It affected the position of lower limit of bioluminescence (Fig. 4). The correlation coefficient between the lower limit of bioluminescence and the oxygen concentration from 0.5 to 1.5 ml/l was 0.92–0.95.

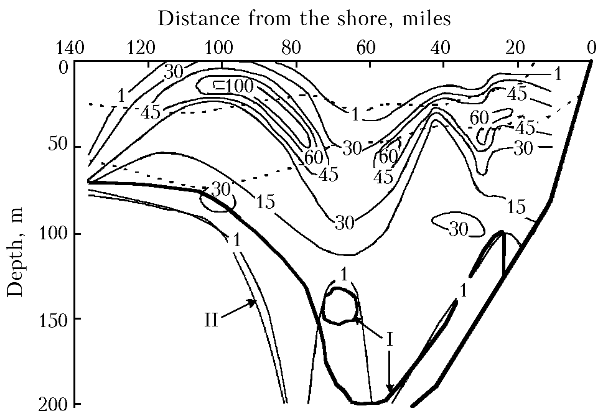

Fig. 4. The distribution of bioluminescence intensity in the Peru profile. The position of upper and lower limits of thermocline is shown by dashed curves. The distribution of isooxygen is shown by bold solid lines: the oxygen concentration 1.5 (I) and 0.5 ml/l (II).

Thus, in the area of Peruvian upwelling under the effect of El Niño, the controlling factors in the distribution of bioluminescence were halocline and isooxygens (0.5–1.5 ml/l). Gradient zones of hydrophysical parameters, such as pycnocline, isothermal layer, and thermocline did not affect the spatial distribution of plankton bioluminescence.

The intensity distribution of chlorophyll fluorescence at the profile is shown in Fig. 5. At the ocean stations, located outside the frontal zone (55–70 miles), the maximum fluorescence was observed between the upper and lower limits of thermocline. In this region the highest concentrations of phytoplankton and chlorophyll were recorded.[21,22] In the 30-mile coastal zone the fluorescence intensity on the surface was the same as at the upper boundary of thermocline. This is connected with the peculiarities of the development of phytoplankton in the upwelling.[21] At a distance of 33 to 60 miles from the shore we observed the deepening of an isoline corresponding to 50 arbitrary units of fluorescence intensity. In this case the maximum of chlorophyll luminescence coincided with the upper boundary of thermocline. It should be noted that during the developed upwelling the deepening of the peak of fluorescence occurred at a distance of 115 miles from the shore.[23] For lower limit of phytoplankton fluorescence the correlation with the distribution of salinity, temperature, and oxygen was not found. It is obvious that its position was determined by the rate of sedimentation of plankton, containing chlorophyll, and by the dynamics of the depth waters.[16,21]

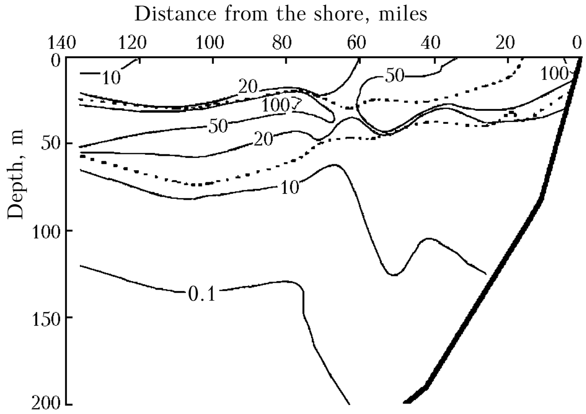

Fig. 5. The distribution of bioluminescence intensity in the Peruvian profile. The position of upper and lower limits of thermocline is shown by dashed curves.

For the Peruvian upwelling it is shown that the increased chlorophyll content is observed in pycnocline or above it.[22] Because the plankton fluorescence is determined precisely by this pigment, the relationship was evaluated between the horizons of detection of maximum intensity of chlorophyll fluorescence and the depths of upper limit of conditional water density (see the Table). The correlation coefficient was 0.85. A similar coefficient, calculated relative to the thickness of euphotic layer, was 0.61. Consequently, among the investigated water medium parameters, position of the upper limit of pycnocline is the decisive factor in the distribution of chlorophyll fluorescence in the area of the Peruvian upwelling.

In the distribution of bioluminescence and fluorescence in the water area of the Peruvian upwelling, no general regularities were revealed (Figs. 4 and 5). If in the position of peak of chlorophyll fluorescence a trend was observed to deepening along the direction from the west, the character of variation of the position of bioluminescence maximum was more complicated.

Table. Thickness of euphotic layer, the position of the upper limit of pycnocline, and the depth of detection of maximum chlorophyll fluorescence in the area of Peru upwelling

Distance from the shore, miles	Horizon of fluorescence maximum, m	Thickness of euphotic layer, m	Position of upper limit of pycnocline, m
3	5	18	6
11	12	48	19
26	16	40	27
42	22	38	36
56	27	35	31
63	25	38	37
71	32	36	31
78	28	37	40
101	35	46	46
136	40	55	37

Besides, in the frontal zone of mixing the shelf and ocean waters the deepening and decrease of the value of bioluminescence peak were observed (Fig. 4). The influence of this frontal zone on the phytoplankton fluorescence was less evident and was expressed only in decreasing the level of chlorophyll luminescence (Fig. 5). The maximum intensity values of bioluminescence and fluorescence, recorded at Peruvian upwelling, did not coincide in their spatial position. The distinctions in the structure of two types of luminescence are caused by the fact that the fluorescence shows the distribution of plankton containing chlorophyll, while the bioluminescence shows the distribution of plankton, which does not contain photosynthetic pigments.[1,3]

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