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KOMPLEKSNIYE ISSLEDOVANIYA SVECHENIYA MORYA V NAUCHNOY EKSPEDITSII

(Comprehensive investigations of luminescence in the sea during
scientific expeditions)

by

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BJUL. OKEANOGRAFICHESKOY KOMMISSII AN SSSR

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ABSTRACT

The level and scope of investigation of marine luminescence in the Soviet Union and the United States is compared. The great interest of American oceanographers in the phenomenon and their achievements are underscored. In order to elucidate the complex nature of bioluminescence, the authors urge to intensify investigations and construct charts of the distribution of luminescent organisms in vertical and horizontal directions, of intensity of bioluminescence, its variations in various taxonomic groups at various depth levels, and hydrological seasons, etc.

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Bioluminescence is widely distributed in nature. Especially intense and diverse is the phenomenon of bioluminescence in the sea. The so-called luminescence of the sea occurs as a result of a sufficient frequency of luminescence in a given place at the same time; this phenomenon is very significant from a practical and theoretical viewpoint: it is observed in surface and bottom layers, notable in the discontinuity layer, (Boden, Kampa, 1958) in high and low latitudes.

The luminescence of the sea which is perceived at night or in deep layers represents an increase in the brilliance of sea water which results from an accumulation of luminescences emanating from luminescent organisms as a result of mechanical, thermal, chemical or biological stimuli. The mechanical and biological stimuli are most common as regards the luminescent marine organisms.

It need be stated that bacterial luminescence is not created nor intensified by mechanical or any biological stimuli (Voytov et al., 1960).

As is known, the luminescence of the sea is an important factor in reconnoitering and catching commercial marine organisms; besides, the phenomenon shows the behavior of fishes; the luminescence affects also navigation, by masking submarine obstacles or by disclosing local intensifications of currents and wave motions, and oceanographic investigations, pointing out refined and different local characteristics of dynamical pattern of the sea, in surface and deep layers as well.

Theoretically, the luminescence of marine organisms presents a unique possibility of disclosing the physical-dynamic mechanism of bioluminescence in connection with a number of general problems of bioenergetics.

Many species of almost any group, beginning with bacteria, mushrooms, /76 and the simplest forms and ending with fishes are capable of luminescence. The biological significance of luminescence is clear in higher groups of animals. However, we have not yet found the significance of biological luminescence in bacteria mushrooms, the simplest organisms and coelenterata. Such a common occurrence of bioluminescence makes one assume that general reactions accompanied by energy exchange in a quantum form take place in the energetic exchange. The intensification of reactions in the process of evolution has led to external de-excitation of organisms, notably marine inhabitants, which are most diverse as to their ecology and taxonomy.

Hence, an interesting concept on bioenergetics may ensue--namely, that the quantum form of energy is evidently typical of metabolism of a live organism not less that of metabolism of green plants, but that

it differs by opposite transition sign: photosynthesis brings about the fixation of radiant energy in the form of chemical reaction, but a reverse process is observed in animals. Such a concept is to a large measure confirmed by investigations of energy migrations.

Thus, the problem of bioluminescence transcends the bounds of a specific phenomenon--the luminescence of individual, if diverse, forms. Its close relationship with the actual problem of modern biophysics and biology in general is manifest, i.e. with the problem on physico-chemical mechanism, which secures an organized energy exchange in live cells and the possibility of its existence.

Hence, the belonging of a given problem to "physico-chemical and structural bases of life phenomena" is evident, which was assumed to be one of the basic aspects in the plans of AS USSR.

Together with this, luminescence represents a typical feature in the biology of marine organisms--a feature which undoubtedly plays an important part in the luminescent organisms and in species which feed on them or are otherwise associated with them. Without knowing the factor or without taking it into consideration, the concepts of ecology of marine organisms, notably the pelagic ones, will not be satisfactory.

Thus, the problem of bioluminescence appears to be significant with respect to theoretical, general biological as well as with respect to practical aspects, taking into consideration the numerous phases of utilizing the sea.

When examining the voluminous existing literature on bioluminescence, one can note that the greater portion of studies describe the phenomenon itself, lending to it a qualitative and, at times, a semiquantitative character. Much has also been done in order to decipher the main pattern of the biological process that accompanies the liberation of energy spent on luminescence. The fermentative character of the reaction has been accurately determined; its dependence on the presence of a number of vitamin forms, notably B₁₂, has been established. American and Japanese biochemists (Johnson, 1955; Johnson, Haneda, Sie, 1960) have been successful in this direction as well as in finding luciferin and luciferase in some species of various taxonomic groups and in determining the possibilities of luminescence as a result of interaction among the elements obtained from representatives of various groups (fishes, ostracods). A number of studies dealing with the luminescence of the sea have been conducted in the last years by hydrobiologists and hydroopticians on instructions by the U. S. Navy in various areas of the World Ocean, as for example, off California coast, in Caribbean /77

Sea, in western and eastern sections of Mediterranean Sea (Boden, Kam'a, 1957, 1958; Clarke and Hubbard, 1959; Clarke and Breslau, 1959, 1960).

It need be pointed out that in contrast to the study of oceanography abroad, where bioluminescence usually constitutes an integral part of the program of oceanographic expeditions, we pay little attention to the problem. This is confirmed by comparing even the quantity of literature on bioluminescence. While a number of monographs have been published abroad in addition to special collections and regular reports in newspapers and magazines and symposiums organized on the subject, we publish articles on bioluminescence only sporadically; only one comprehensive publication has appeared here (N. I. Tarasov, Luminescence of the Sea, 1956)* which summarizes the work done in the field and outlines the problems that must be elucidated in the future (see also Tarasov, 1957, 1959, 1961).

Meanwhile the successes of modern physics and the optical instrument production in the Soviet Union make it possible to raise markedly the standard of investigation of bioluminescence and to attempt to disclose its physical-chemical aspects in addition to the improving oceanographic and hydrobiological interpretation of the luminescence of the sea.

The essence of the oceanographic approach to the luminescence of the sea, as conceived by us, consists of elucidation of the distribution of luminescence by its character, concentration and brilliance in space and time depending upon hydrodynamic factors, i.e. upon the distribution of water masses, their stratification, banded structure of currents, convergence and divergence, internal waves and turbulence associated with upwelling and sinking, and upon wind waves, swell and even submarine earthquakes (Kalle, 1960). /78

The biological aspect, however, requires, first of all, the following elucidation: (a) taxonomic composition of luminescent organisms at various stations and depths, and (b) their quantitative relationship (Bogorov, 1947) in determining the degree of participation in or input into the composite phenomenon of luminescence.

An analysis of the compiled information must enable us to construct, for example, the charts of biomass distribution of luminescent plankton organisms and the frequency charts of luminescence characterized by various degrees of intensity at various depth levels and in various

* TRANSLATION NOTE: In 1960 the book was published by the AS of China. Translated by U. S. Naval Oceanographic office in 1960.
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water layers. Such an analysis will make it possible to characterize the dependence of perception of luminescence at sea surface upon hydrometeorological factors [visibility, wave motion which greatly increases the luminescent surface (Vladimirov, 1960) etc.] and the dependence of its degrees of brilliance recorded by instruments in surface and bottom layers upon dynamic and hydrobiological factors. These factors include, for example, subsurface currents, internal waves, peculiarities of discontinuity layer, composition of pleuston, plankton and nekton, as well as benthos in its relation to luminescent forms.

Of special interest may be morphological-physical and spectral--photometric information pertaining to concrete and, sometimes, taxonomically closely related luminescent organisms. For example, it would be very important to learn by means of quantitative microbiological observations in the sea whether the luminescent "free-living" bacteria are in actuality associated with tripton and dependent in their quantitative distribution upon its density.

Another aspect of the multilateral problem of luminescent sea organisms is as follows: is the ability to luminesce an independent phenomenon or is it dependent upon the presence of the corresponding and often very specialized organisms of symbiotic luminescent bacteria which are very specialized in morphological and optical relations? In the latter case the bacteria may even be found in cultures outside the organisms of the given species, i.e. being extremely specialized or being able to develop and luminesce in cultures of artificial media.

In line with the development of the oceanological and hydrobiological /79 approach, which was discussed above, the formulation of the following problems is advisable.

1. To obtain the spectra of luminescence of as many species of luminescent organisms of various taxonomic groups as possible. The measurements must be materialized with a high degree of monochromatization which is achieved by the modern recording spectrophotometers. It is necessary to investigate a wide spectral band (mainly the visible band and the contiguous infrared and ultraviolet bands) with a view to carrying out quantitative calculations of quantum results and elucidating the physical-chemical nature of reactions: of great interest is the physical mechanism with the aid of which the energy that is liberated as a result of the main biochemical reaction of luminescence is transformed in radiation having various frequencies.

2. To attempt to find and investigate the organs of luminescence beginning with various stages of specialization, i.e. where the

function is not yet the only function of an organism, where the organ has not yet become optically complex, i.e. being without reflector, lens, etc., and where the mechanism of luminescence is most primitive. In order to carry out this work, one must have a spectrophotometer with a highly sensitive recording instrument. For example, the apparatus used for recording spectra characterized by combined scattering can be utilized.

3. To record the spectra of reflections from pigments of external covers of animals (fishes, cephalopods, crustaceans) and to compare them with the spectra of radiation.

In order to carry out these tasks, one must have spectroanalytical instruments with automatic and photographic recording and a highly sensitive receiving apparatus for recording the spectra radiated by animals and spectra radiated by their coverings. The prospects of catching deepwater animals and their examination in a live state must be secured; also luminescent tissues in a living state and the preservation by freezing of investigational objects must be secured.

4. Cooperation of biophysicists with oceanographers, hydroopticians, planktonologists and ichthyologists and, sometimes, with benthologists is necessary.

The first stage of the work must be conducted by one of the ships of expedition during the cruise; the ships must be equipped for deepwater expeditions, as for example, the Vityaz'. Systematic investigations in expeditions and laboratories must supplement each other by maintaining liaisons between various investigations. In other words, all /80 the study of marine bioluminescence must be conducted jointly and synchronously.

Such an approach to the problem must secure the needed cooperation among scientists and the needed methodical level of investigation in physical as well as biological and oceanographical relations.

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