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ORIGINAL RESEARCH PAPER

CTENOPHORES *Mnemiopsis leidyi* A. AGASSIZ, 1865 (TENTACULATA, LOBATA) AND *Beroe ovata* MAYER, 1912 (ATENTACULATA, BEROIDA) BIOLUMINESCENCE SEASONAL DYNAMICS AT THE BLACK SEA

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SYNOPSIS

The executed investigations have revealed the considerable seasonal variations of *Mnemiopsis leidyi* and *Beroe ovata* bioluminescence intensity. At spring intensity of the ctenophore luminescence is of the lowest indices, and minimum *M. leidyi* luminescence occurs in March and makes $9.21 \pm 0.46 \cdot 10^8$ $quant \cdot s^{-1} \cdot cm^{-2}$. *B. ovata* bioluminescence amplitude is minimal in May – less than $35.96 \pm 1.79 \cdot 10^8$ $quant \cdot s^{-1} \cdot cm^{-2}$.

M. leidyi maximal luminescence is observed in August – up to $841.97 \pm 42.09 \cdot 10^8$ $quant \cdot s^{-1} \cdot cm^{-2}$. Two peaks of bioluminescence were registered in *B. ovata*: in July up to $1382.25 \pm 69.11 \cdot 10^8$ $quant \cdot s^{-1} \cdot cm^{-2}$ and in September $852.56 \pm 42.62 \cdot 10^8$ $quant \cdot s^{-1} \cdot cm^{-2}$.

Just as energetic parameters of the ctenophore bioluminescence so duration of their luminescence varies considerably depending on season; in this connection the shortest signals are observed in February – March (0.79 – 1.32 s), and more long – in August – September (2.77 – 3.46 s with $p < 0.05$).

Seasonal changeability of the ctenophore bioluminescence can be explained by peculiarities of the seasonal dynamics of their chemical composition, related with the level of their food provision, and seasonal changes in temperature of the Black Sea water.

INTRODUCTION

Bioluminescence - the vital activity that reveals itself in a form of electromagnetic radiation in the visible part of spectrum – is the most important marine environment ecological factor (Tokarev, 2006). It has been assumed till recently, that microplankton (bacteria and dinoflagellates) contributes mainly into the bioluminescence field formation in the Black Sea as well as in other regions of the World Ocean (Gitelzon et al., 1992; Tokarev et al., 2003). But ctenophore *Mnemiopsis leidyi A. Agassiz* (order Lobata) and *Beroe ovata* Mayer (order Beroida), which had appeared in the Black Sea recently, are luminescent organisms as well and their bioluminescence intensity increased luminescence of the micro plankton representatives in hundreds thousand times (Shukshina et al., 2000; Vostokov et al., 2001; Shiganova et al., 2001; Vereshchaka, 2002).

Successful invasion to the Black Sea of *B. ovata*, which affected positively at recreation of this region pelagic ecosystem and preservation of its prey *M. leidyi* population is to a great extent conditioned by species diurnal migrations and their seasonal dynamics as well.

Considering this and the fact, that bioluminescence is an expressive index of the organisms physiological state, the aim of our investigations was the determination of seasonal variability in light emission characteristics of *M. leidyi* and *B. ovata* ctenophores under different stimulation types.

MATERIAL AND METHODS

Experimental investigations for *M. leidyi* were conducted in the department of the biophysical ecology of Institute of Biology of the Southern Seas of the National Academy of Sciences of Ukraine. Ctenophores were collected by Judy net in the coastal zone of Sevastopol in the layer of 0 – 50 m. The uniform-sized samples group (40 millimeters) was collected for the experiments. Ctenophores were kept in the temperature-controlled aquariums (50 l) with the filtered (diameter of filter membrane pores was 35 micrometers) marine water, being adapted during 6 – 8 hours to the temperature close to such in the sea in the given period.

Experiments on the ctenophores light signals registration were carried out using the instrumental complex “Svet” (Tokarev, 2006). The instrumental complex consists of high-voltage power pack (HV-22), luminescope that includes light receptor (FEU-71) and dark camera for the object and registration device – digital interface. Specially made cuvette (50 cm^3) for ctenophores mechanical and chemical stimulation was placed into the luminescope dark camera. Cuvettes for experimental and control organisms were made of transparent plexiglas.

Ctenophores bioluminescence was studied using mechanical and chemical stimulation in complete darkness (Tokarev, 2006). Mechanical stimulation of ctenophores was used in the experiment for creating the illustrative situation, adequate to the natural stimuli (Borodin, 2002). The water stream in the reservoir with bioluminescent was created by the pumping electromechanical device. Hydrophysical characteristics changes, arising because of the water transfer, lead to the ctenophores cell membrane deformation, which in turn induce action potential and, as a consequence, the light emission. In situ the bioluminescence flash is forced by the mechanical stimulus – the liquid shear stress. At that, the luminescence intensity rises sharply when liquid run changes from laminar to turbulent.

Chemical stimulation method was used in the experiment for obtaining the information about approach to the maximal bioluminescent potential. We have chosen the chemical reagent (96% ethanol), necessary for the maximal ctenophores luminescence under individual stimulation. Thus 3 cm^3 of 96% ethanol was inserted into cuvette using the injector (Tokarev, 2006).

RESULTS AND DISCUSSION

SEASONAL DYNAMICS OF THE *MNEMIOPSIS LEIDYI* BIOLUMINESCENCE

The studies conducted had revealed in *M. leidyi* bioluminescence intensity considerable seasonal fluctuations as for its amplitude characteristic as well as for temporal one (fig. 1).

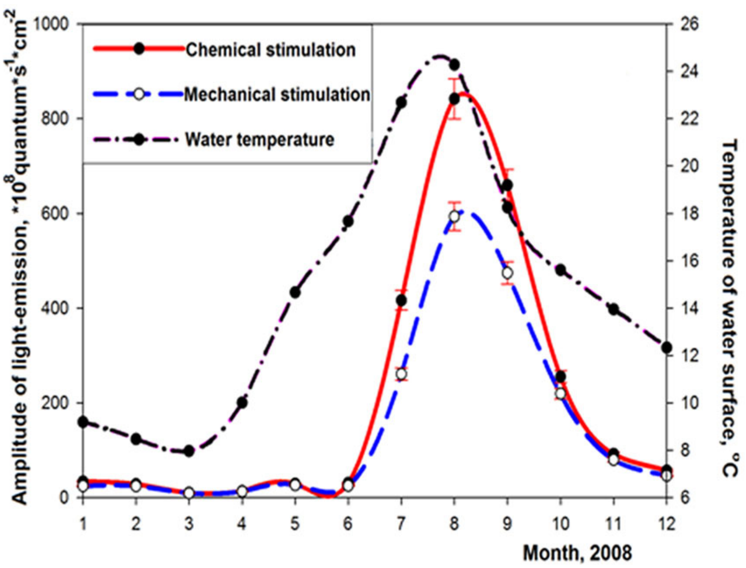

Figure 1: *Mnemiopsis leidyi* light emission amplitude seasonal dynamics under different stimulation types.

Thus, the first and not very intensive flash with the most amplitude (70.0 ± $3.4 \cdot 10^8$ quant·s^{-1}·cm^{-2}) followed by several much more weak signals is observed for the luminous ctenophores in the winter period. The light emission lasts about 2.0 s. The ctenophore luminescence intensity under both stimulation methods has the lowest indices in the spring period, minimal luminescence falls on March and makes 9.93 ± $0.49 \cdot 10^8$ quant·s^{-1}·cm^{-2} and 9.21 ± $0.46 \cdot 10^8$ quant·s^{-1}·cm^{-2} under the chemical and mechanical stimulation correspondingly.

The luminescence intensity rise (from 260.94 ± 13.04·10^8 quant·s^{-1}·cm^{-2} to 841.97 ± 42.09·10^8 quant·s^{-1}·cm^{-2}) is registered in the regular period of ctenophores reproduction beginning in July with its peak in August. At that, ctenophores luminescence intensity under the chemical stimulation is 2 – 2.5 times greater ($p < 0.05$), than under the mechanical one.

The ctenophore light emission intensity reduces during the following period of the year and it decreases almost 11 times in the middle of November, if comparing with the summer period, making 92.17 ± 4.6·10^8 quant·s^{-1}·cm^{-2} under the chemical stimulation and 79.60 ± 3.98·10^8 quant·s^{-1}·cm^{-2} under the mechanical one.

Seasonal changes of bioluminescence energy indices reveal themselves analogically (fig. 2).

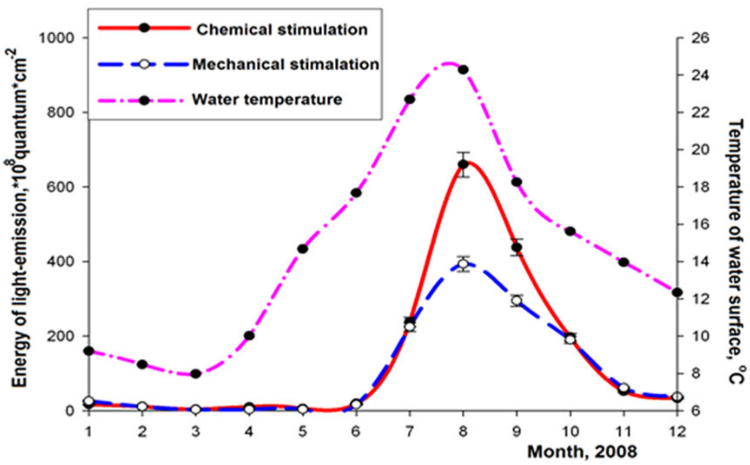

Figure 2: ***Mnemiopsis leidyi*** **light emission energy seasonal dynamics under different stimulation types.**

Thus, winter-spring period is characterized by the low energy indices of mnemiopsis light emission, achieving minimal values in February. But ctenophores luminescence energy achieves maximal values in August, making 659.97 ± 32.98·10^8 quant·cm^{-2} under the chemical stimulation and 393.39 ± 19.66·10^8 quant·cm^{-2} under the mechanical in the summer period, when their irruption is observed. The ctenophores light emission energy as well as intensity reduces during the following year period: it decreases under the chemical stimulation in 12 times (61.19 ± 3.05·10^8 quant·cm^{-2}) and under the mechanical one in 6 times (51.86 ± 2.3·10^8 quant·cm^{-2}) in the middle of November, if compare with the summer period.

Duration of the ctenophores luminescence varies considerably under both stimulation methods (fig. 3) together with their bioluminescence energy parameters seasonal change and the shortest signals are observed for the ctenophore in February – March – 0.79 – 1.32 and more prolonged ones – in August – September, - 2.77 – 3.46 s ($p < 0.05$).

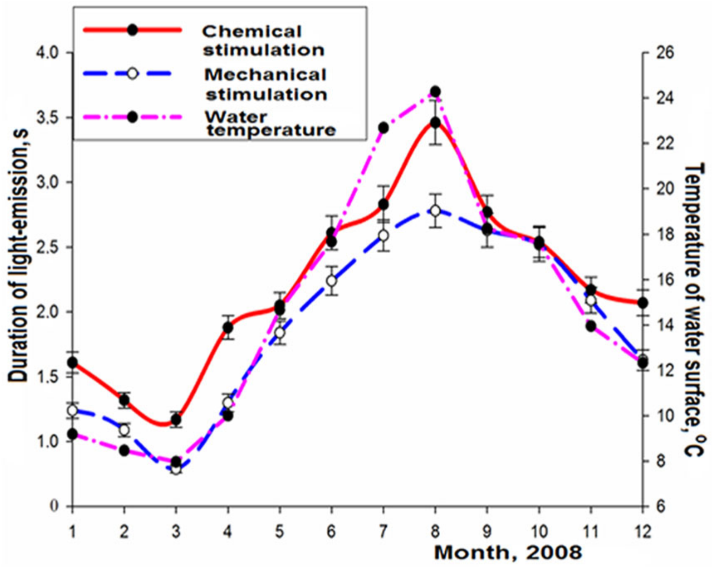

Figure 3: *Mnemiopsis leidyi* light emission duration seasonal dynamics under different stimulation types.

Ctenophores bioluminescence seasonal changeability can be explained, on our opinion, by the peculiarities of their chemical composition seasonal dynamics. Indeed, different food supply is the most probable reason of the changes of the given organisms biochemical composition. Thus, ctenophores state in the winter-spring periods may be estimated as depressed in connection with the food concentration considerable shortage (Lebedeva et al., 2003). And ctenophores luminescence amplitude and energy have the lowest indices in these periods as we had shown.

Nutritional conditions of *M. leidyi* are the most favorable in the summer period, considering reliable summer increase of glycogen and waxes concentrations in the organisms (Anninsky, 1995). The *M. leidyi* population concentration density increases in this period in connection with mesozooplankton concentration increase and achieves maximum in August. Other maximal bioluminescence intensity indices are observed in August as well.

The Black sea water temperature seasonal change may be the other reason, explaining ctenophore bioluminescence intensity seasonal dynamics. Thus, water temperature decrease (8 ± 2 ºC) is observed in the winter-spring periods. The given temperature is unfavorable for the mnemiopsis vital activity and as a result, its quantity reduces steadily in this period till the next reproduction period (Finenko et al., 2011). And, from those remaining, some specimen fall into the anabiosis (their motion activity weakens as well as metabolic processes) (Kharchuk, 2005), other migrate vertically, over wintering under thermocline or are transferred to the other Black sea regions (Khoroshilov, 1993). The mnemiopsis luminescence amplitude-energy parameters reduce in this period.

On the other hand, *M. leidyi*, if compare to other jelly-body species inhabiting the Black sea, are more thermophilic. *M. leidyi* ability to maintain the exchange high intensity under the temperature, usual for the Black sea surface horizons in the summer time, could be of importance for this species mass development (Anninsky & Abolmasova, 2000). Mass juveniles stages degeneration and ctenophores population abundance decrease, observed in November, occurs due to the fact of water temperature fall in the autumn period to 14 – 16 ºC. The ctenophores luminescence intensity and energy decrease are observed exactly in the given period.

***BEROE OVATA* BIOLUMINESCENCE CHARACTERISTICS SEASONAL VARIABILITY**

In the general case, the beroe bioluminescence signal is represented by a number of running flashes, superimposing on one another, with one or several intensity peaks, sharp increasing background and the same damping decrement. At that, it is important to mention the pronounced *B. ovata* bioluminescence signal seasonal differences (Mashukova & Tokarev, 2010).

Thus, several weak signals may be observed for ctenophore, luminous in the winter period (fig. 4), followed by the flash of negligible intensity with the greatest amplitude ($56.7 \pm 2.83 \cdot 10^8$ $quant \cdot s^{-1} \cdot cm^{-2}$). The ctenophore bioluminescence is depressed even more in the spring period, with the minimal values in May: one – two weak signals are observed with the amplitude up to $35.96 \pm 1.79 \cdot 10^8$ $quant \cdot s^{-1} \cdot cm^{-2}$.

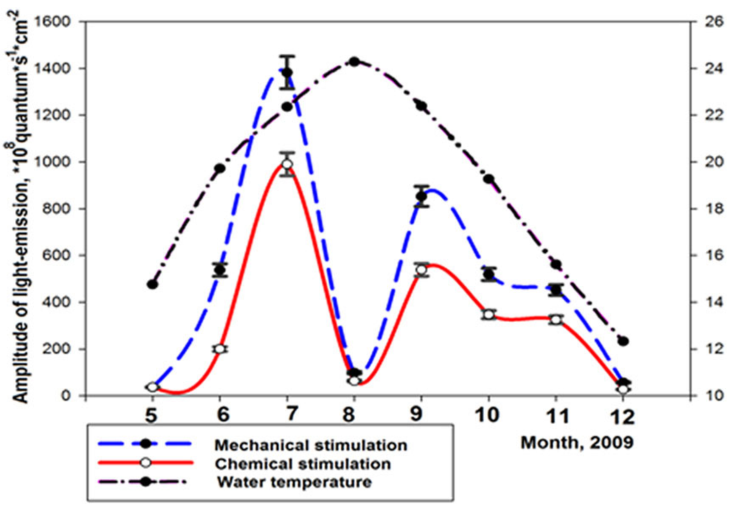

Figure 4: *Beroe ovata* light emission amplitude seasonal dynamics under different stimulation types.

The bioluminescence intensity increase up to $537.6 \pm 26.88 \cdot 10^8$ $quant \cdot s^{-1} \cdot cm^{-2}$ is observed in the summer period. Signal character changes as well: number of running flashes of the same intensity forms the plateau at the level of 0.5 of the maximal amplitude under the light emission maximal continuance, achieving 2.86 ±

0.14 s. Beroe luminescence maximum is observed in July, signals amplitude achieves 1382.25 ± 69.11·10^8 quant·s^{-1}·cm^{-2}. At that, ctenophore light emission intensity is 1.5 times higher ($p < 0.05$) under the mechanical stimulation than under the chemical one.

But ctenophore bioluminescence amplitude-energy indices decreases up to 98.75 ± 4.93·10^8 quant·s^{-1}·cm^{-2} in August already. The ctenophore luminescence intensity rises again in the autumn period, forming bioluminescence intensity maximum with the amplitude, achieving 852.56 ± 42.62·10^8 quant·s^{-1}·cm^{-2} in September. It is necessary to mention ctenophore bioluminescence signal form change in September: first it achieves plateau at the level of 250.0 ± 12.5·10^8 quant·s^{-1}·cm^{-2}, and than the light emission peak may be observed.

Than gradual luminescence intensity decrease is observed. Its amplitude reduces 15 times by December, if compared with the autumn peak and makes 56.7 ± 2.83·10^8 quant·s^{-1}·cm^{-2} under the mechanical stimulation and 27.01 ± 1.35·10^8 quant·s^{-1}·cm^{-2} under the chemical one.

Beroe bioluminescence energy indices seasonal changes occur in the same way (fig. 5).

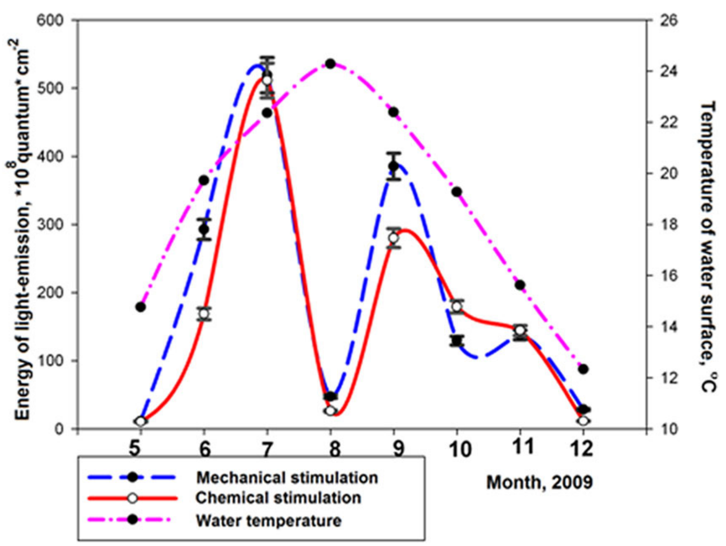

Figure 5: *Beroe ovata* light emission energy seasonal dynamics under different stimulation types.

Thus, winter-spring period is characterized by the light emission low energy indices, with minimal values in May. Beroe light emission energy values are maximal in the summer period, especially in July, making 518.94 ± 25.94·10^8 quant·cm^{-2} under the mechanical stimulation and 511.88 ± 25.59·10^8 quant·cm^{-2} under the chemical one. Sharp decrease (11 times) ($p < 0.05$) of the luminescence energy indices is observed in August, if compared with the previous month.

The ctenophore luminescence intensity as well as energy rises again in autumn, having its maximum in the middle of September, but if we compare it with the summer period, it decreases 1.5 times ($p < 0.05$). Ctenophore bioluminescence energy indices decrease 11 times ($p < 0.05$) by December.

B. ovata signals duration in the different seasons under both stimulation methods will change considerably (fig. 6).

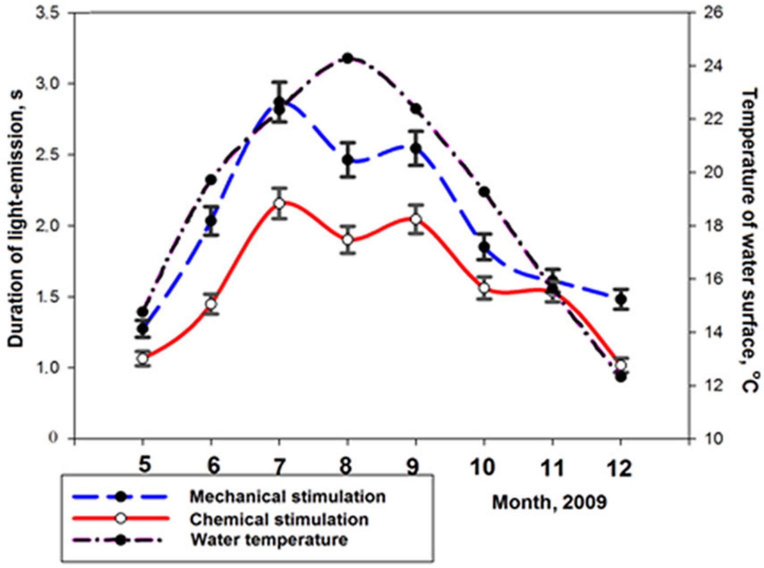

Figure 6: *Beroe ovata* light emission duration seasonal dynamics under different stimulation types.

And the shortest signals are observed by ctenophore in May (1.06 – 1.27 s) and in December (0.9 – 1.36 s), more prolonged signals are observed in July – August (2.54 – 2.86 s) ($p < 0.05$).

Trophic state of beroe as well as of mnemiopsys is depressed in the winter-spring period (Finenko et al., 2006; Mashukova & Tokarev, 2009), and it reveals itself in reducing its luminescence amplitude-temporal characteristics. But *B. ovata* nutritive conditions are the most favorable in early-autumn period, in September especially (Finenko et al., 2003), which affects the ctenophore bioluminescence activity increase in the given period.

B. ovata, if compared to other jelly-fish, is the species sensitive to the temperature swings more than others (Shiganova et al., 2001). The water temperature rise in the spring period (in May up to 16 – 18 ºC) leads to beroe early findings in the samples, but ctenophore bioluminescence indices are low in the spring.

July temperature rise up to 20 ± 2 ºC is favorable for the beroe abundance early growth, and stipulates its bioluminescence maximal indices.

Population abundance of beroe prey – mnemiopsis grow under the following water temperature rise in the summer period up to 24 – 26 ºC. And its maximal abundance number is observed in August, when beroe light emission amplitude sharply decreases. Mass increase of the beroe population abundance occurs in September, due to the water temperature fall to 20 ± 2 ºC (Khoroshilov, 1993). The second by intensity peak of beroe bioluminescence is observed exactly in this period. The beroe breeding achieves its maximum in the period from the middle of October till November. In the given period, according to the investigations results we can asses the ctenophore state as depressed. Food supplies reduce and mass spawning conduce that. All these factors affect unfavorably the *B. ovata* functional state as well as its bioluminescence indices, which reduce in 2. 5 times if compare with September.

The beroe population and abundance reduces sharply up to ctenophore complete disappearance in the plankton in the late-autumn period and till the end of December, when mnemiopsis low biomass can't meet *B. ovata* needs for food for its population maintaining and reproducing (Vostokov et al., 2001; Finenko et al., 2006). *B. ovata* bioluminescence amplitude-energy indices are the lowest just in this period.

CONCLUSION

Number of peculiarities of the main bioluminescence seasonal changeability characteristics (amplitude, energy and light emission duration) for the Black sea ctenophore-invaders *M. leidyi* and *B. ovata* were studied during the investigations conducted. The highest amplitude-energy luminescence indices for *M. leidyi* are observed in the summer period (with its maximum in August), while *B. ovata* maximal luminescence is observed twice – in July and in September. Minimal indices for both species were registered in the winter-spring period.

The seasonal differences revealed in the ctenophore bioluminescence are stipulated by the seasonal dynamics of their biochemical composition, connected with the food supply and seasonal changeability of the hydrological parameters (water temperature, before anything else) in the Black sea. Thus, once again we had proved the environmental load, which is carried by the ctenophore bioluminescence parameters and which was described by us and our colleagues for the different species organisms (Bitukov, 1966; Gitelzon et al., 1992; Tokarev & Evstigneev, 2009). That allows using our experiments results in different variants of the ecological monitoring of the coastal water area.

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