The connection of the intensity of the plankton community luminescence and the age distribution of horse mackerel in the coastal waters of the south-western Crimea

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Abstract
The analysis of the seasonal and interannual variability of the luminescence intensity of the plankton community in the coastal waters of the south-western Crimea and its interrelation with the age distribution of horse mackerel in spring-summer catches are investigated. In 2012, 2013 and 2014, the intensity of glow of organisms in winter was 2-10 times lower than the mean value (193 pW ∙ cm^(-2) ∙ dm^-3), which indicates a worsening of the state of the plankton community of pelagic in these years, which led to a deterioration of the food reserve in the subsequent (spring) period. In the years with a high intensity of hydrobionts glow in winter (2010, 2011 and 2015), the rapid spring grown of plankton led to an increase in the intensity of organisms’ glow in May by almost 6 times compared with the winter period. Such situation affects the relative age of pelagic fish in the coastal waters. The relative number of yearlings and two-year-old Trachurus mediterraneus and changes in the luminescence intensity of the plankton community are characterized by a negative correlation coefficient, that means that when the intensity of plankton luminescence decreases in the winter, the relative number of 1 and 2 -year old fish in spring-summer catches increases. In the years characterized by a higher intensity of glow in organisms in May, growth of horse mackerel in the spring-summer period is more intensively. The coefficient of correlation with the average weight of individuals of horse mackerel of different age groups is in the range 0.73 – 0.84.

Key words: horse mackerel Trachurus mediterraneus, age composition, Black Sea, intensity of glow, plankton community, seasonal changes.

Introduction
At the studies of the Black Sea biota state, a special place is focused by investigation of seasonal changes in the intensity of glow in marine hydrobionts and the total light effect produced by them in the water column (also named bioluminescence), that is an important element in the plankton community functioning. At the same time, on the one hand, the intensity of phytoplankton emission can be measured by fast reacting physical instruments, and on the other hand, it characterizes both own biological state and concentration in the marine environment. There are about 30 luminous species in the Black Sea pelagic species (Tokarev
Phytoplankton, including luminous species, directly related to the justification of the primary production role at providing the food base of commercial resources and, first of all, pelagic fish. On the basis of long-term data, a direct relationship between the biomass of phytoplankton, which forms the primary productivity of the Black Sea pelagic, and the fat content of pelagic fish associated with their food supply is determined (Safyanova & Revina 1967; Tkacheva & Fedorina 1973; Shulman & Urdenko 1989; Kayali, 1998; Cherepanov et al. 2007; Yankova et al. 2009).

Monitoring works are the information base for assessing the influence of abiotic and biotic factors on the state of the Black Sea's aquatic biological resources and allow to predict the nature of changes in the biological state of marine organisms in the coming years. There are studies (Tokarev et al. 2000; Melnikova et al. 2012), dedicated to the identification of the relationship between the characteristics of luminous hydrobionts with species diversity and the distribution of plankton communities, the influence of abiotic and biotic factors of the environment on the intensity of glow of organisms. However, the relationship between the intensity of luminescence of the plankton community and the age distribution of pelagic fish, including the Mediterranean horse mackerel *Trachurus mediterraneus* (Steindachner, 1868), one of the mass pelagic fish species of the Black Sea, has not been fully studied.

The aim of the study was to study the relationship between the luminescence intensity of the plankton community in the winter and spring periods with the age composition and size and weight characteristics of the Mediterranean horse mackerel inhabiting the coastal waters of the south-western Crimea in the Black Sea.

**Material and Methods**

Investigations of the seasonal and interannual variability of the vertical distribution of the luminescence intensity of planktonic organisms and the catching of the Black Sea horse mackerel were carried out in the coastal waters of the south-western part of the Crimean peninsula shelf: in the area of the Sevastopol Bay, in the Konstantinovskaya, Aleksandrovskaia, Karantinnaya, Streletskaya bays, on the abeams of Pesochnaya and Kruglaya bays (Fig. 1).
To analyze the interannual variability in the intensity of hydrobionts glow and the changes in the age structure of the horse mackerel, data were analyzed for a six-year period (2010-2015). The vertical distributions of the luminescence intensity of hydrobionts, as well as the temperature and electrical conductivity of the sea water, which were then recalculated into salinity data, were investigated by bathymetric probing using the hydrobiophysical complex «Salpa-M». At the vertical sounding regime, the «Salpa-M» device moves with a speed of 1.2 m/s, the discreteness of measurements is 1 m. (Tokarev et al. 2009). Measurements at all stations were carried out from the surface to near-depth depths. The ichthyological samples and their cameral treatment was carried out in accordance with standard methods in the practice of ichthyological studies (Pravdin 1966). A total of 3258 copies were analyzed. The fish length was measured with an error not exceeding 0.1 cm. Standard length measurements (distance from the beginning of the snout to the end of the spine) were performed and integrated into dimension classes with 0.5 cm intervals. In all calculations, only standard length (SL) was used.

Weight characteristics (body weight) were determined by weighing on electronic libra Sartorius excellence E-2000D with an error not exceeding a few hundredths of a gram.

The age was determined on binocular microscope MBS-10 with a 16-fold increase in transmitted light after preliminary clarification in glycerol using the otoliths (Chugunova 1952).

The reliability of results obtained was evaluated by the appropriate statistical methods (Rokitskii 1961).

**Results and discussion**

The changes in the intensity of luminescence of plankton communities in the coastal waters of the south-western Crimea in the winter (January-February), spring (May), and summer (June-July) periods for 2010-2015 are showed in Fig. 2.

<table>
<thead>
<tr>
<th>Year</th>
<th>Winter (Jan-Feb)</th>
<th>Spring (May)</th>
<th>Summer (June-July)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>1500 pW cm⁻² dm⁻³</td>
<td>2000 pW cm⁻² dm⁻³</td>
<td>2500 pW cm⁻² dm⁻³</td>
</tr>
<tr>
<td>2011</td>
<td>2000 pW cm⁻² dm⁻³</td>
<td>2200 pW cm⁻² dm⁻³</td>
<td>2800 pW cm⁻² dm⁻³</td>
</tr>
<tr>
<td>2012</td>
<td>2500 pW cm⁻² dm⁻³</td>
<td>2800 pW cm⁻² dm⁻³</td>
<td>3300 pW cm⁻² dm⁻³</td>
</tr>
<tr>
<td>2013</td>
<td>3000 pW cm⁻² dm⁻³</td>
<td>3200 pW cm⁻² dm⁻³</td>
<td>3500 pW cm⁻² dm⁻³</td>
</tr>
<tr>
<td>2014</td>
<td>3500 pW cm⁻² dm⁻³</td>
<td>3600 pW cm⁻² dm⁻³</td>
<td>3700 pW cm⁻² dm⁻³</td>
</tr>
<tr>
<td>2015</td>
<td>4000 pW cm⁻² dm⁻³</td>
<td>4100 pW cm⁻² dm⁻³</td>
<td>4200 pW cm⁻² dm⁻³</td>
</tr>
</tbody>
</table>

**Figure 2.** The average monthly intensity of glow organisms 1 – in the winter (January-February); 2 – in the spring (May); 3 — in the summer (June-July) in the 2010-2015.

It was obtained, that the nature of the development of plankton during the year is largely determined by its state in the coldest period of the year (January-February).

The intensity of in the plankton community glow, which closely correlates with the concentration of plankton and characterizes its biological state, averaged about 193 pW cm⁻² dm⁻³ in the winter. In addition, in 2010, 2011 and 2015, the intensity of luminescence exceeded the mean value, that indicates the good condition of the water inhabitants of pelagic in these years. In 2012, 2013 and 2014, the intensity of glow of organisms in winter was 2-10 times lower than the mean value, which indicates a worsening of the state of the plankton community of pelagic in these years, which led to a deterioration of the food reserve in the subsequent (spring) period.

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Horse mackerel feeds poorly in winter, the fatness by the end of wintering in all years is greatly reduced. Therefore, the state of phyto- and zooplankton complexes during the winter period does not directly affect the biological condition of the horse mackerel and its condition factor.

Usually, in winter, the horse mackerel forms dense benthic wintering clusters on the south-western shelf of the Crimea, that provide the main share of the annual harvest of horse mackerel during this period. However, in warm winters (such as in 2013 and 2014), this species continues to feed, moving in search of food, does not form stable accumulations, so it does not caught easily, that cause significantly reduced catches.

In the spring period, as the water warms up to an average of 15° C (usually this temperature is typical for the May), fish rises to the upper sea layers and migrate to the feeding and spawning areas.

The availability of food for horse mackerel, as well as its biological processes (including features of feeding and reproduction in the spring period) are largely determined by the nature of the preceding winter period.

In the years with a high intensity of hydrobionts glow in winter (2010, 2011 and 2015), the rapid spring grown of plankton in the coastal waters of the south-western Crimea led to an increase in the intensity of organisms’ glow in May by almost 6 times compared with the winter period (Fig. 2b). In coastal waters, due to the shallow depths, the spring warming along the entire thickness of the water takes place quickly. The average monthly water temperature in the bays in May increased by an average of 8 °C compared to the winter period.

In May, the mackerel for feeding uses coastal areas. In particular, T.V. Dehnik (1979) and R.M. Pavlovskaya (1973) noted that spawning at the beginning period occurs in the coastal waters, which affects the character of the oscillation of the age structure (Arkhipov 1993; Salekhova & Gordina 2005).

In years with a low intensity of organisms glow in the winter (2012, 2013 and 2014), the intensity of glow in organisms increased 10-80 times in May compared to January-February, but was lower than in 2010, 2011 and 2015, characterized by a high intensity of luminescence in the winter.

In spring of 2012-2014, water was heated to a temperature of 18-19 °C. In the summer period (June-July), the intensity of glow of organisms decreased by 1.5-2 times compared with the spring period (Fig. 2). The state of phytoplankton and zooplankton complexes of the pelagic in the spring-summer period depends on its state in the previous winter period.

In the years when the intensity of bioluminescence exceeded the average values of long-term values during the winter, a high intensity of organisms’ luminosity was also observed in summer (about 2 times higher than in other years). This indicates a fairly good state of phyto- and zooplankton complexes, which contributes to the further development of the food reserve in the spring-summer periods of these years.

The main time of reproduction of horse mackerel, which lives in the coastal waters of the south-western Crimea, is from May to July. It should be noted that during the spawning and after it, the horse mackerel continues to actively feed (Aleev 1952; Pavlovskaya 1973; Kostyuchenko et al. 1979; Pora 1979; Yankova et al. 2009) and its feeding continues until the fall.

Let us consider how the age composition of the horse mackerel varied depending on the state of the phytoplankton and zooplankton complexes of the pelagic, determined by the intensity of the luminescence of organisms.

The relative age distribution of horse mackerel in spring-summer (May-July) catches in coastal waters of the south-western Crimea in demonstrated in Fig. 3.

In the years characterized by a good plankton state in winter, determined by the high luminescence intensity of organisms (2010, 2011 and 2015) (see Fig. 2, curve 1), in the subsequent spring-summer period in the coastal waters of the investigated area, *Trachurus mediterraneus* was attended by individuals of fish of five age groups: yearlings, two-, three-, four- and five-year-olds with a predominance of two- and three-year-olds (more than 60%) (Fig. 3). The older age groups (four- and five-year-olds) accounted for up to 30% of the total number of fish in the catches.

In the years characterized by a poor planktonic state (2012-2014) in winter (in these years the intensity of glow of organisms is lower than the average long term period), the intensity of luminescence of organisms in the next spring-summer period was 1.5-2.0 times lower than in June-July 2010, 2011 and 2015, which characterizes the decrease of quantity and biomass of feed phytoplankton and zooplankton. In these years, the ratio of numbers and the amount of age groups (see Fig. 3) is changing compared to years, characterized by a high intensity of glow organisms in the winter.
So, in the spring-summer of 2012 the share of four-year-olds fish has significantly decreased, it accounted for only 5% of the total number. Five-year-olds individuals were absent. At the same time, the relative number of two- and three-year-olds fish increased, and it accounted for 85% of the total number. The 1 year-old horse mackerel were 10%. The older age groups (four- and five-year-olds) were almost absent in the catch of 2013 and 2014. In the age distribution, younger age groups (1-2 year-old) predominated (the total relative number was more than 95%), and the number of three-year-olds individuals did not exceed 3-4% (Fig. 3).

![Figure 3](image)

**Figure 3.** Relative quantity of the age groups the *Trachurus mediterraneus* (1-yearlings. 2 - two-year-olds. 3 - three-year-olds. 4 - four-year-olds. 5 - five-year-olds) in the spring-summer period in the coastal waters of the south-western Crimea.

It can be assumed that, with poor food supply observed in a year with a low bioluminescence intensity, older age classes whose dietary spectrum is broader (Safyanova & Revina 1967; Tkacheva & Fedorina 1973; Kostyuchenko et al. 1979), migrated from coastal areas to open sea areas.

To determine the relationship between the luminescence intensity of organisms in the winter and the biological state of the plankton complex in the subsequent (spring and summer) periods and their influence on the age composition of the horse mackerel, a correlation coefficient was calculated between the luminescence intensity of the plankton community in January and February and the relative number of yearlings and two-year-olds fish in the coastal waters of the south-western Crimea in May-July. As a result of the calculation, negative correlations were obtained: for 1 year-old individuals \( r_1 = -0.45 \) and for 2 years-old fish \( r_2 = -0.67 \). It follows from this that when the state of phyto- and zooplankton complexes is deteriorated, fixed by the intensity of the glow of the hydrobionts, the relative number of younger age groups (1 and 2 year-old) of horse mackerel increases in the coastal waters, which leads to a corresponding decrease in the number of older age classes. In addition, on the contrary, with a good food base (with an increase in the intensity of organisms glow in the winter), the relative number of four-year-olds increases. The correlation coefficient is positive \( r_4 = 0.84 \). Consequently, with good food state in coastal waters, including the anchovy forthcoming, which is the main food object of adult horse mackerel, there are both younger and older age classes of *Trachurus mediterraneus*.

Let us consider how the changes in the food base, determined from the intensity of the luminescence of the plankton community in the period investigated, affected the size and weight characteristics of horse mackerel in the coastal waters of the south-western Crimea during the spring-summer period.

The average values of the standard length and mass of horse mackerel and their mean quadratic deviations in age groups in the spring-summer period of 2010-2015 are given in Table 1.
Table 1. Average standard length (SL) and weight (W) of different age groups of horse mackerel in the spring-summer period of 2010-2015.

<table>
<thead>
<tr>
<th>age group</th>
<th>parameters</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SL±SD, cm</td>
<td>10.8±0.91</td>
<td>9.8±0.91</td>
<td>9.7±0.07</td>
<td>8.2±0.52</td>
<td>8.1±0.30</td>
<td>10.1±0.85</td>
</tr>
<tr>
<td></td>
<td>W±SD, g</td>
<td>14.95±3.01</td>
<td>11.10±1.35</td>
<td>10.14±0.93</td>
<td>6.44±1.30</td>
<td>6.01±0.75</td>
<td>11.0±2.28</td>
</tr>
<tr>
<td>2</td>
<td>SL±SD, cm</td>
<td>11.8±0.59</td>
<td>12.0±1.22</td>
<td>10.9±0.46</td>
<td>9.0±0.88</td>
<td>9.1±0.43</td>
<td>11.5±0.63</td>
</tr>
<tr>
<td></td>
<td>W±SD, g</td>
<td>19.91±2.72</td>
<td>20.73±6.30</td>
<td>15.38±1.84</td>
<td>8.36±2.35</td>
<td>7.82±1.27</td>
<td>18.22±4.05</td>
</tr>
<tr>
<td>3</td>
<td>SL±SD, cm</td>
<td>12.5±0.72</td>
<td>13.6±0.84</td>
<td>11.6±0.36</td>
<td>10.5±0.42</td>
<td>10.4±0.35</td>
<td>12.9±1.0</td>
</tr>
<tr>
<td></td>
<td>W±SD, g</td>
<td>24.18±4.56</td>
<td>29.81±3.70</td>
<td>18.09±2.33</td>
<td>13.92±0.50</td>
<td>11.72±1.77</td>
<td>28.79±7.60</td>
</tr>
<tr>
<td>4</td>
<td>SL±SD, cm</td>
<td>13.8±0.93</td>
<td>14.0±0.28</td>
<td>12.7±0.13</td>
<td>–</td>
<td>–</td>
<td>14.5±1.05</td>
</tr>
<tr>
<td></td>
<td>W±SD, g</td>
<td>32.13±5.59</td>
<td>39.19±2.88</td>
<td>25.13±1.53</td>
<td>–</td>
<td>–</td>
<td>42.47±9.02</td>
</tr>
<tr>
<td>5</td>
<td>SL±SD, cm</td>
<td>14.9±0.67</td>
<td>15.0±0.42</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>15.2±1.25</td>
</tr>
<tr>
<td></td>
<td>W±SD, g</td>
<td>38.55±4.38</td>
<td>43.08±0.87</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>48.48±9.07</td>
</tr>
</tbody>
</table>

The table 1 shows that in years with a good developed food base (in years with a high intensity of glow organisms (2010, 2011 and 2015)), the horse mackerel grows well and weight increases. The average weight of horse mackerel grows in these years, but in years with a low intensity of organisms luminescence fish length-weight characteristics are less. So, in years with a low intensity of luminescence, in the winter period, the average weight of *Trachurus mediterraneus* is on average 17-50% less than in years with a high intensity of organisms glow.

The correlation coefficient between the change in the luminescence intensity of organisms in May and the average weight of fish in the different age groups was calculated.

Calculations showed, that for the one-year-olds fish the correlation coefficient is $r_1 = 0.84$; for two-year-olds $r_2 = 0.73$; for three-year-olds $r_3 = 0.73$. That is, the change in the average weight of the horse mackerel in the coastal waters of the south-western Crimea highly correlated with a change in the intensity of organisms glow during this period. In the years in which a higher intensity of glow of hydrobionts is observed in May, the average weight of *Trachurus mediterraneus* in spring-summer catches increases.

The correlation coefficients of the luminescence intensity of the plankton community in winter and the number of age groups of fish, as well as the intensity of glow of hydrobionts and weight characteristics of horse mackerel in the spring-summer period, confirm the assumptions made about the character of the effect of the winter period, determined by the intensity glow of the plankton complex of the pelagic, on the growth and development of the horse mackerel, as well as on its age composition in the spring-summer catches.

It was obtained in some works (Aleev 1952; Tkacheva & Fedorina, 1973; Kostyuchenko et al. 1979; Shul’man & Urdenko 1989; Arkhipov 1993; Pora 1979), that the number of populations of commercial fish species in the Black Sea depends on a number of factors, mainly on food base. The fluctuation in the magnitude of plankton production causes changes in the reserves of plankton-eating fish and predators feeding mainly on plankton phages. The patterns of change in the rate of growth, depending on environmental conditions in different years, was studied for horse mackerel in a number of works (Safyanova & Revina, 1967; Tkacheva & Fedorina, 1973; Arkhipov 1993; Zuev & Melnikova 2003; Salekhova & Gordina 2005). In these studies, it was shown that the rate of growth of horse mackerel depends
on the features of the development of phyto- and zooplankton. In the years with high productivity of food phytoplankton and zooplankton, the growth rate of horse mackerel of all age groups increases and the number of generations increases also. In years with low productivity, the state of horse mackerel populations is worse: condition factor and growth rate, as well as number and biomass of populations decrease.

Our investigations showed that the biological state of plankton and its products can be estimated from the intensity of the luminescence of the plankton community during the winter and spring periods measured by high-speed physical instruments and, as a result, a study of the intensity of organisms' glow in the winter and spring periods can be used for predicting the age composition and size and weight characteristics of horse mackerel in spring-summer catches. These results can be used in the fishing industry.

**Conclusions**

1. The intensity of glow in the plankton community during the winter determines the features of its development in the subsequent spring and summer periods, and as a result, characterizes the state of the food base of plankton-eating pelagic fishes and the relative numbers of horse mackerel of different age in the spring-summer period in coastal waters of south-western Crimea.

2. The relative number of yearlings and two-year-olds *Trachurus mediterraneus* and changes in the glow of hydrobionts during the period of research (2010-2015) are characterized by a negative correlation coefficient ($r_1 = -0.45$, $r_2 = -0.67$), that is, at decreasing in the luminescence intensity of plankton in winter period, the relative number of yearlings and two-year-olds horse mackerel is increasing in the spring-summer catches.

3. In the years characterized by a higher intensity of luminescence of organisms, the development of horse mackerel in the spring-summer period occurs more intensively. The coefficient of correlation for the average weighted fish of different age groups is in the range 0.73–0.84.

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**References**