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Species-Specific Responses of Baikal Amphipods to Artificial Lighting of Varying Intensity and Spectral Composition

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Abstract: Light pollution can have a variety of effects on aquatic organisms. Despite the fact that amphipods are one of the model organisms for studying the effects of light among macroinvertebrates, data on the reaction of Baikal amphipods to artificial lighting are limited and contradictory. In this study, we examine the response of Baikal littoral and sublittoral amphipod species to artificial lighting of varying intensity and spectral composition. In the experiments, amphipods were exposed to warm and white light at three different intensity ranges (5–15, 20–35, and 80–100 lx), as well as blue and red light. As a result, it was found that the reaction of Baikal amphipods to different lighting conditions was species-specific and dependent on the spectral composition of the light more so than the intensity of the light. In particular, white LED light generally repulsed *E. cyaneus*, but tended to attract *A. godlevskii*. *P. cancelloides*, and *G. fasciatus*, suggesting that white LED light may have a greater negative impact on wildlife than warm LED light. Generally, artificial light influences the behavior of Baikal amphipods, and an increase in light pollution on Lake Baikal may lead to changes in the littoral community in certain areas of the lake subject to pollution.

Keywords: ALAN; light pollution; amphipods; Lake Baikal; LED

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1. Introduction

Light pollution is a form of environmental pollution. It occurs when there is a direct or indirect introduction of artificial light into the environment by humans. Light pollution comes from a wide variety of sources, including building lighting, street lights, boat lights, signal lights, vehicle headlights, and even underwater lights from research vessels [1–3]. Light pollution is becoming a global problem because even small amounts of artificial light can change the color of the sky and dim starlight, which can have adverse effects on wildlife. Thus, light pollution can disorient birds [4,5], disrupt the normal behavior of female sea turtles and their young [6], and also strongly attract many insects [7,8].

Artificial light has various effects not only on land but also in the aquatic environment. It is worth noting that the impact of light pollution on aquatic organisms in marine ecosystems has been studied to the greatest extent [9]. It is known that light from a ship can disrupt the behavior of fish and zooplankton down to depths of 200 m and over an area of >0.125 km^2 around the ship [10]. In addition, artificial light increases predatory behavior in fish [11], disrupts endocrine metabolism in the thyroid gland [12], suppresses melatonin production [13], and blue LED light increases cortisol levels in *Salmo salar* (Linnaeus, 1758) [14], and alters the distribution and circadian rhythms of isopods [15].

The effects of light pollution on aquatic organisms in freshwater ecosystems have been less studied, but, as with marine aquatic organisms, the negative effects of light pollution have been identified [9]. For example, it has been shown that artificial light sources increase the protective activity of *Micropterus dolomieu* (Lacepède, 1802) [16], prevent night migrations of representatives of the genus *Daphnia* [17], increase the predatory activity of fish [18], and negatively affect the rate of fish reproduction [19]. Light pollution has the greatest impact on organisms in the littoral zone. For example, one of the model organisms for studying the effects of light among macroinvertebrates in both marine and freshwater ecosystems is amphipods [1,20,21].

The circadian system and, accordingly, the behavioral characteristics of amphipods are regulated by lighting conditions [1,22–25], as in almost all life forms [3]. For example, the sandhopper *Talitrus saltator* (Montagu 1808) uses not only sunlight and moonlight to orient itself, but also the gradient of radiance and the spectral distribution across the sky [22]. Natural light also acts as a major factor controlling the daily vertical migrations (DVMs) of both zooplankton [2,17] and amphipods [1,24]. The main reasons for migration are considered to be protective and for feeding, where representatives of zooplankton and zoobenthos float to the upper layers of water to feed at night, thereby avoiding attacks by predators that rely on vision during the daytime [1,25]. It has been shown that the migratory activity of amphipods can depend on the lunar cycle and reaches a minimum on nights with a full moon, which is also associated with their avoidance of predators [23,24]. However, the natural migratory activity of aquatic organisms at night can be altered by artificial light [1,10,17] and with it the productivity and cycling of carbon and nutrients in water ecosystems [26]. It has also been shown for amphipods that, on the one hand, artificial light can reduce the activity and feeding behavior of some amphipod species [21,27], and on the other hand, increase the amount of food consumed by others [28]. In addition, it has been shown that significant light effects are achieved when amphipods actively move between the bottom and the surface of the water at night [1]. Also, earlier studies have shown that light sources with different spectral compositions have different effects on the behavior of amphipods, and this effect is species-specific [1,28–32]. There is very little data on the effects of light of varying intensities on amphipods, and the available data concern very high light intensities [33].

Lake Baikal is one of the most unique waterbodies in the world. Since December 1996, it has been a UNESCO World Heritage Site. Its flora and fauna are very diverse. The order Amphipoda in Lake Baikal is one of the taxonomically rich orders of higher crustaceans and has 354 species and subspecies, which is 61% of all freshwater amphipods living in the inland waters of Russia [34].

Data on the reaction of Baikal amphipods to artificial lighting are quite contradictory. Among the first data on the reaction to artificial lighting were obtained for the Baikal pelagic amphipod *Macrohectopus branickii* (Dybowsky, 1874). In this study, it was shown that this species avoids light levels brighter than 0.0001 lx [35]. However, as it turned out relatively recently, the reason for avoidance is not the brightness of the artificial light, but its spectral composition. It was found that *M. branickii* reacts differently to different

wavelengths of artificial light. Light with wavelengths from 750 to 1131 nm attracts *M. branickii* individuals, while visible light and shorter wavelengths repel them or have a neutral effect on them [36]. During a series of experiments with benthic amphipods, it was found that they actively avoided both bright daylight (300–400 lx) and weak artificial light (35–40 lx) [37]. However, benthic amphipods have been studied for a long time as part of a project to study diurnal vertical migrations, which found that artificial light sources attract them. Thus, an increase in the number of amphipods after turning on the spotlights was observed in any part of Lake Baikal. They had a positive taxis to artificial light, in contrast to sunlight [38]. Also, laboratory experiments were previously conducted with several species of Baikal amphipods using colored diodes, as a result of which the amphipods avoided all types of light to varying degrees, or showed a neutral attitude [31,32]. But in the field, traps with the same colored diodes attracted amphipods to varying degrees [31].

Therefore, the drivers of intra- and inter-specific variation in behavioral responses to artificial light have not been fully elucidated for Baikal littoral and sublittoral amphipods. Meanwhile, we hypothesized that the response of Baikal amphipods to light would vary among species and depend on two factors, spectral composition and light intensity [29,30,32]. In this study, based on the inconsistency of the available data, we decided to test whether Baikal littoral and sublittoral amphipod species could demonstrate different responses to artificial lighting, both of different brightness and with different spectral compositions. Therefore, the aim of our work was to compare the responses of six species of Baikal amphipods to warm and white light of three intensities (5–15, 20–35, 80–100 lx) and red and blue light within the same species and between different species. As a result of this work, the species-specificity of amphipod reactions to different lighting conditions was confirmed, including species yet to be tested in the literature. The spectral composition was an important predictor of amphipod behavior, with white light being the only light in this study that significantly influenced the behavior of four out of six species. The effect of different light intensities on amphipod behavior has not been confirmed.

2. Materials and Methods

All experiments were approved by the Commission for Experimental Research Using Animals of Research Institute of Biology of Irkutsk State University (Protocol no. 14, dated 22 August 2024). All experiments were conducted in accordance with international ethical standards documented in the regulations of the Russian Federation, the Declaration of Helsinki, and the European Union Directive 2010/63/EU [39] on the treatment of animals in scientific research.

The amphipods for the experiment were caught near the village of Bolshiye Koty, as well as from the research vessel "M.M. Kozhov" in South Baikal while traveling from the village of Bolshiye Koty to Peschanaya Bay. A total of 6 species were caught, with at least 20 individuals of each species (Figure 1). Despite the fact that in this case we caught amphipods in different places (this was carried out for the convenience of the catch), the complex of these species is found almost everywhere on the southern and western sides of Lake Baikal (Table 1).]

Eulimnogammarus cyaneus (Dybowsky, 1874), *Eulimnogammarus verrucosus* (Gerstfeldt, 1858), and *Gmelinoides fasciatus* (Stebbing, 1899) were caught with a net in the area of Bolshiye Koty Bay (Figure 2c). Near the village of Bolshoye Goloustnoye (Figure 2a), *Acanthogammarus godlewskii* (Dybowsky, 1874) were caught using a beam trawl, and *Pallasea cancelloides* (Gerstfeldt, 1858) were caught using an Agassiz trawl. Another species, *Brandtia parasitica* (Dybowsky, 1874), was caught in the Peschanaya Bay area (Figure 2b) using an Agassiz trawl.

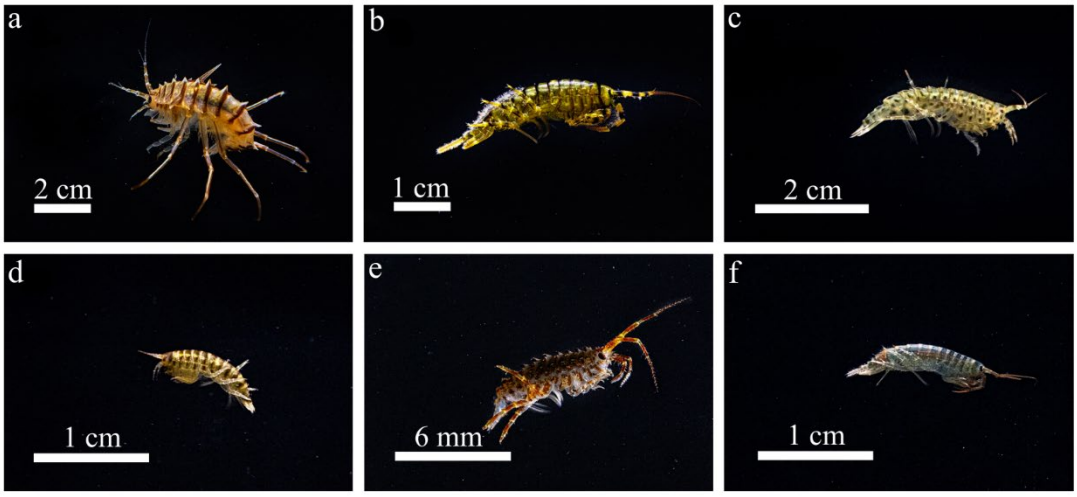

Figure 1. Amphipod species used in the study: (**a**) *A. godlewskii*; (**b**) *E. verrucosus*; (**c**) *P. cancelloides*; (**d**) *G. fasciatus*; (**e**) *B. parasitica*; and (**f**) *E. cyaneus*.

Table 1. Characteristics of habitats and ecology of selected species [38,40].

Species	Habitat	Depth	Soil Type	Movement Ecology
A. godlewskii	All of Baikal, except for the Selenginsk shallows. The species is most often found in the northern part of the lake.	2–180 m, more often 10–60 m	Sandy and silty-sandy soil	Sublittoral, no migration activity was noted.
B. parasitica	All of Baikal, except for the Selenginsk shallows.	1–60 m	Large and medium pebbles	Littoral, sublittoral, lives on sponges, migratory activity was noted for the genus.
E. cyaneus	All of Baikal and the Lower Angara River to the village of Kamenka.	0–5 m	Large pebbles	Littoral, migratory activity was noted, immature individuals actively migrate.
E.verrucosus	All of Baikal, except for the Selenginsk shallows. In the Angara River from its source to the village of Budakovskaya (432 km from Baikal); the mouth of the Barguzin River; the Turka River.	0–10 m	Large pebbles	Littoral, migratory activity was noted.
G. fasciatus	All of Baikal.	0–5 m	Large pebbles and sand	Littoral, actively migrate.
P. cancelloides	All of Baikal. In the Lower Angara River to Marituy Island (about 220 km from Baikal).	0.3–178 m, usually 1–10 m	Sand and, less often, stones and silt	Littoral, sublittoral, migratory activity was noted for the genus.

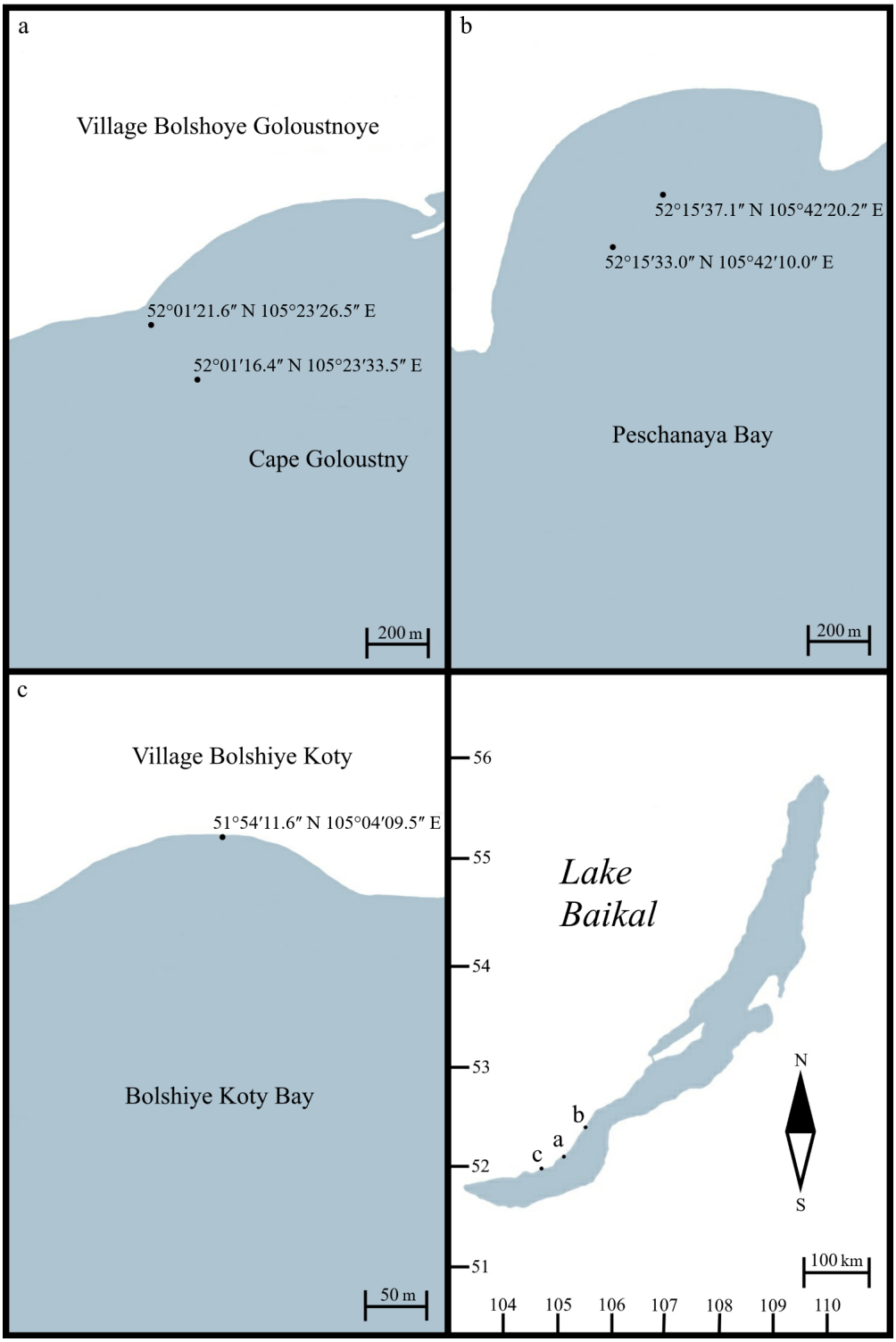

Figure 2. Places where amphipods were caught: (**a**) near the village of Bolshoye Goloustnoye; (**b**) Peschanaya Bay; and (**c**) Bolshiye Koty Bay. The x- and y-axis labels in the right bottom panel are degrees of longitude and latitude, respectively.

The collected amphipods were separated by species and placed in different tightly sealed 2 L containers. These containers were in turn placed in thermal containers with cold blocks and transported to the laboratory for further acclimation of amphipods and experiments.

All organisms were acclimated during the first week under the following conditions: constant aeration, t = 12 °C; day–night light regime—8:16. All amphipod species were kept separately from each other in 18 × 11.5 × 12 cm aquariums. The number of individuals

in one aquarium did not exceed 10 for *A. godlewskii*, *E. verrucosus*, 15 for *P. cancelloides*, and 20 for *G. fasciatus*, *B. parasitica*, and *E. cyaneus*. During acclimation, tap water that had been left to stand for 24 h was used, and was completely changed in the aquariums every 3 days. After changing the water in the aquariums, the amphipods were fed dried *Gammarus* sp. This diet is considered acceptable and is often used when keeping Baikal amphipods and does not significantly change the total carotenoid content in crustaceans for at least two months [41]. This method of keeping amphipods after a week of acclimation was maintained for about another week during the experiments.

Warm (Uniel air DIMMABLE: 3000K (Uniel Lighting Co., Hangzhou, China)) and white (Uniel air DIMMABLE: 4000K (Uniel Lighting Co., Hangzhou, China)) LEDs were used as a light source for the experiment, as well as blue and red LEDs (Figure 3). The illumination level generated by the light sources was measured using a lux meter DT–8809A (CEM, Macao, China), and the spectral composition was measured directly using a fiber-optic spectrometer QE Pro (OceanOptics, Dunedin, FL, USA).

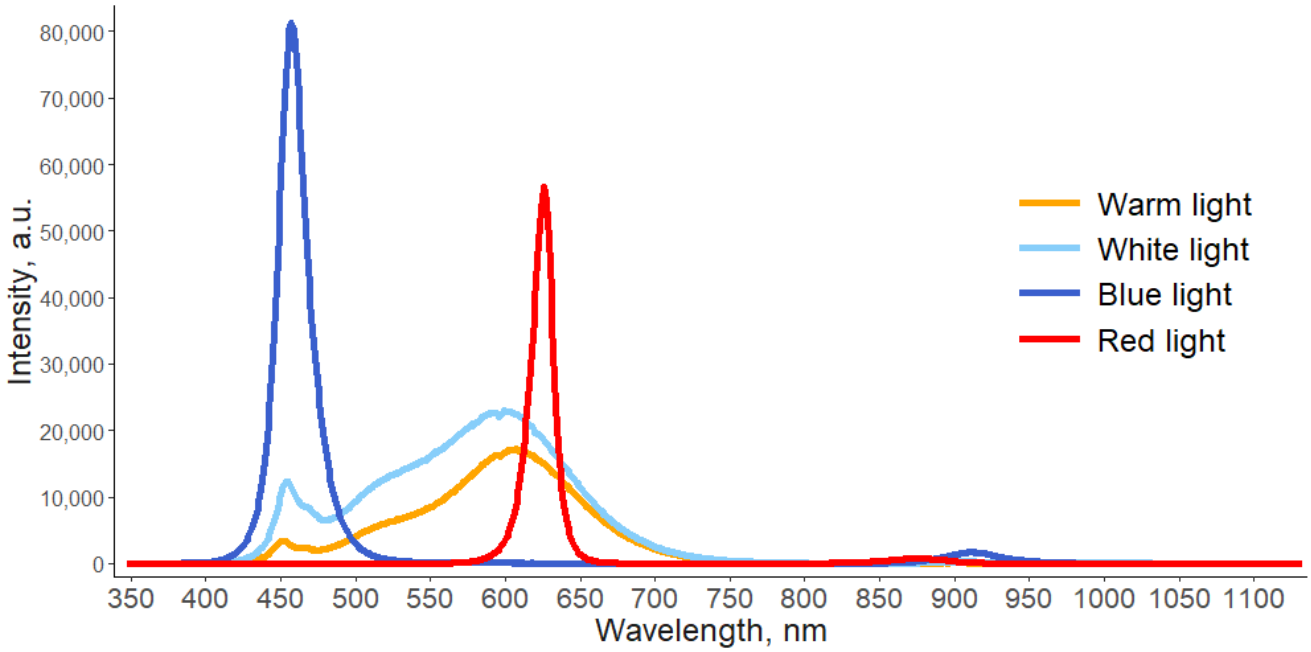

Figure 3. The spectral composition of the light sources used in the experiments. For warm light, the peak values were 451 nm and 607 nm, and for white light they were 455 nm and 599 nm. The peaks were 457 nm and 626 nm for blue and red light, respectively.

The following light intensities were used in the experiment: 5–15 (the level of light pollution approximately registered in certain areas of Lake Baikal (Figure 4a,b), 20–35 and 80–100 lx for warm and white light (the ranges of light intensities were chosen specifically to simulate the light of headlights of a car moving near the shoreline, or the lights of a passing vessel (Figure 4c); the intensity was the same for blue and red light and was 30 lx.

The experimental setup consisted of a rectangular aquarium (19 × 52 × 10 cm) (Figure 5), inside which, in the center, starting from the end of the aquarium, there was a 30 cm central partition (distance AB in Figure 5). On one side of the aquarium, there was warm or white light, and the other side was darkened and excluded any light, due to which the amphipods had the opportunity to choose between the dark side of the aquarium and the illuminated one. Blue and red light were used simultaneously: on one side of the partition the aquarium was illuminated by one LED, and on the other by another. Thanks to the long central partition (distance AB in Figure 5), a mixed zone (distance BC in Figure 5) with a clear visible boundary of the passing light was created at the beginning

of the aquarium. When warm or white light was used, one-half of the mixed zone was brightly lit, while the other remained darker. However, due to the reflective nature of the light, the second, darker half of this area was still illuminated to some extent, especially when using higher light intensities. But even under these conditions, the boundary of the passing light was visible, and one half of the mixed zone remained much more shadowed than the other. In the case of the use of red and blue light in a mixed zone, the boundary between them was also clearly visible—one half was illuminated in red, the other in blue. The light intensities chosen for the experiment were measured and maintained at the start of the aquarium (point C in Figure 5). Accordingly, at the end of the aquarium with light sources (point A in Figure 5) the intensity was higher than at the start (point C in Figure 5). For the experiments, as well as for keeping amphipods, settled tap water was used. The water level in the aquarium was 8 cm. All experiments were carried out in a completely shaded room (0 lx) during the dark hours of the day in accordance with the maintained daylight regime when keeping amphipods.

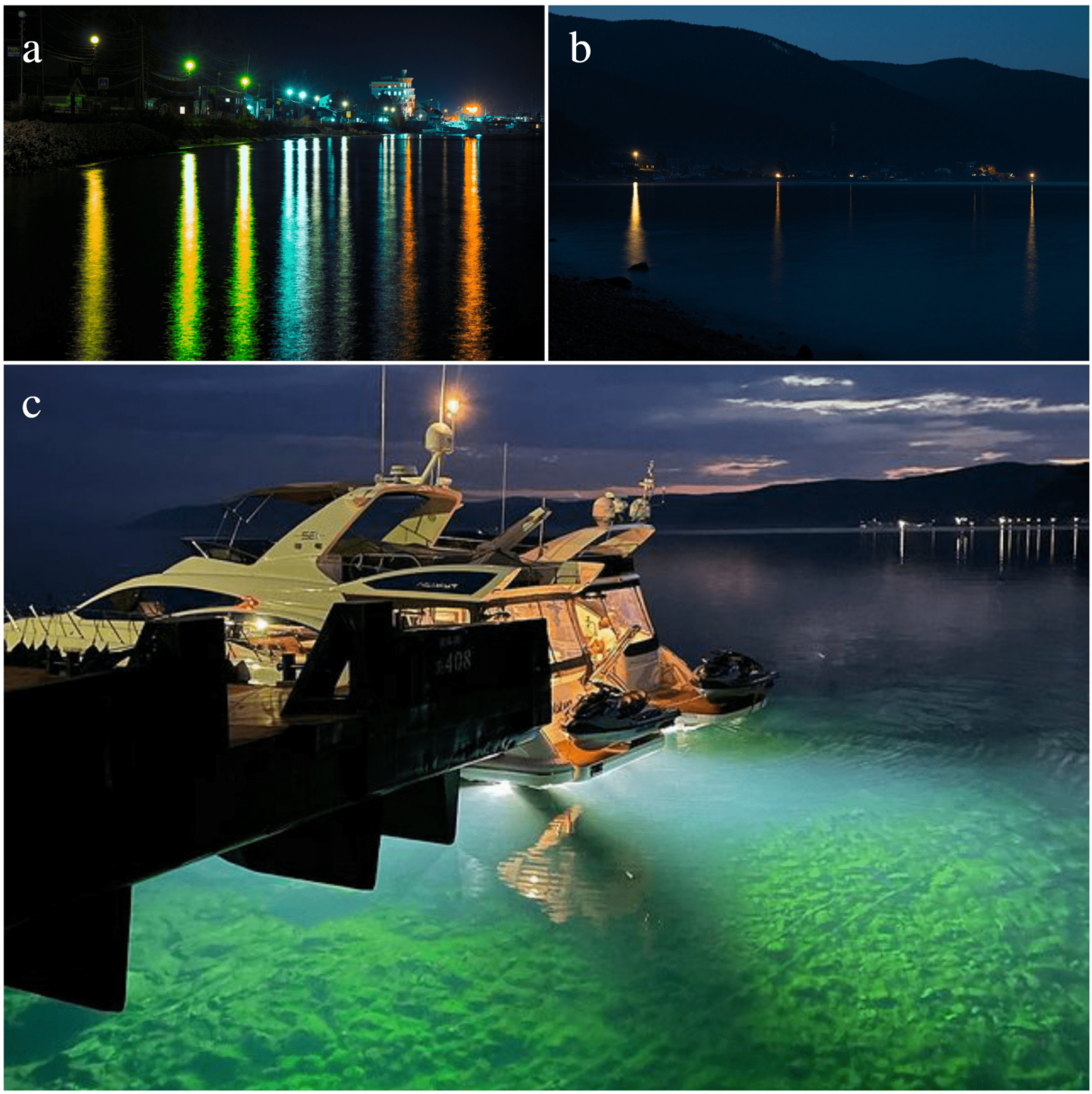

Figure 4. Light exposure levels on the shore of Lake Baikal: (**a**) Listvyanka village—2.5–5 lx; (**b**) Bolshiye Koty village—1.2–2.5 lx; (**c**) local pollution in Listvyanka village—>50 lx.

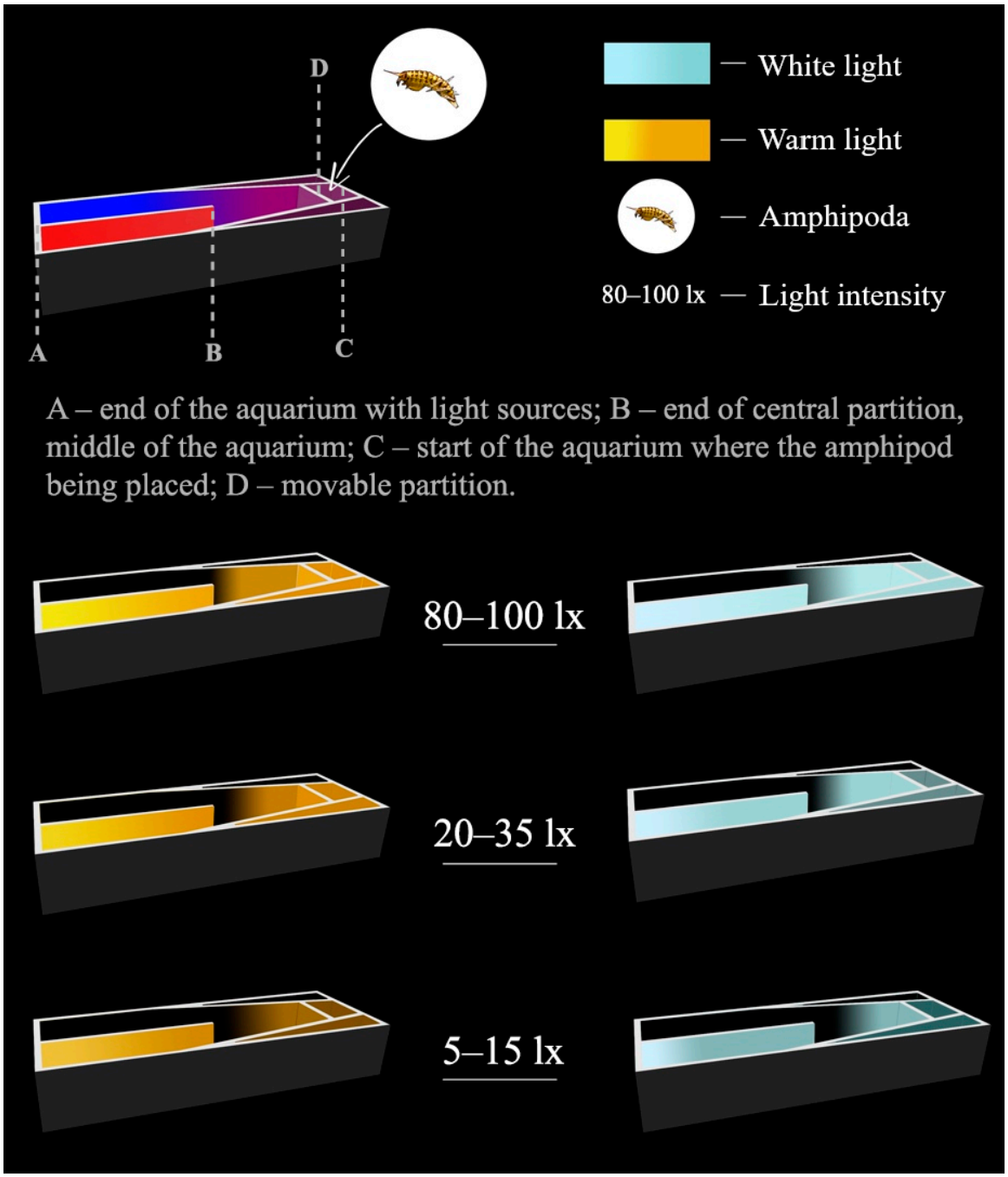

Figure 5. The experimental setup and experimental conditions. The sample size for each type of experimental treatment was 10 replicates.

The experiment began with one individual of one species or another being placed in the mixed zone at the start of the aquarium (point C in Figure 5) and its movement being restricted using a movable partition across the entire width of the aquarium (point D in Figure 5), thereby allowing it to become used to certain light conditions. In this zone (distance CD in Figure 5), the amphipod could move freely between the illuminated and shaded halves in the warm or white light experiments, or between the red and blue halves. After 3 min, the partition (point D in Figure 5) was removed and the amphipod was given 2 min to choose its preferred zone. If, after 2 min, the amphipod moved behind the central partition into the zone with or without light (distance AB in Figure 5), this was counted as "Movement to the light" or "Movement to the dark", respectively. If, at the end of the time, the amphipod was in the mixed zone (distance BC in Figure 5), this was counted as "Stayed

in place". The same boundaries were used in the experiments with red and blue light. In addition, control experiments were conducted in which there was no lighting at all, but the movement of individuals into one or another area of the aquarium was also noted.

In total, 10 replicates were carried out for each type of experiment and amphipod species (10 individuals were used). That is, 80 tests were conducted for each species (8 lighting conditions × 10 replicates = 80), and a total of 480 tests were conducted during the study (80 tests × 6 species = 480). All experiments were carried out in a little more than a week; that is, all types of experiments for one species were carried out in about 1–2 nights. However, we were unable to collect sufficient numbers of *G. fasciatus* individuals, so we had to reuse some individuals during the experiments. In this case, we tried not to reuse individuals within experiments with the same light spectrum. For example, if an individual participated in the experiment with warm 5–15 lx light, then it was no longer used in the experiments with warm 20–35 lx and 80–100 lx light (or was used, but on the next night), but could be used in experiments with white light or red and blue light, but after at least one experiment. In addition, each type of experiment took us at least 50 min (5 min per individual, 10 replicates in one experiment), and we considered this time sufficient for the individuals to recover after participating in the experiment.

Data processing and analysis were carried out using the R (version 4.4.2) programming language (https://www.R-project.org/ (accessed on 15 March 2025)) in the RStudio program. The data were first checked for normal distribution using the Shapiro–Wilk test. Considering that our data are not normally distributed and all samples are small in size, we used a generalized Fisher's exact test to compare them. A Benjamani–Hochberg correction for multiple comparisons was used in the analysis [42]. Differences were considered statistically significant at a p-value < 0.05.

3. Results

We first compared different lighting conditions with a control (no lighting at all) to understand whether artificial lighting is a factor that induces locomotor activity in amphipods (Figure 6). Statistically significant differences were found in five cases for four species (*E. cyaneus*, *P. cancelloides*, *A. godlevskii*, *G. fasciatus*) and two different light conditions (Table 2).

Table 2. Statistical significance levels (p) obtained from generalized Fisher's exact test with Benjamani–Hochberg correction for multiple comparisons of light conditions with control.

Type of Experiment	Species	Value of the Fisher Criterion	p-Value
White light 5–15 lx	*E. cyaneus*	0	0.03
	P. cancelloides	0	0.03
White light 20–35 lx	*A. godlevskii*	0	0.009
	E. cyaneus	0	0.009
	G. fasciatus	0.05	0.03

When comparing the results within species and between experiments, no statistically significant differences were found. However, we obtained $p = 0.0506$ for *E. verrucosus* when using warm light with an intensity of 5–15 and 20–35 lx or 5–15 and 80–100 lx (Figure 7).

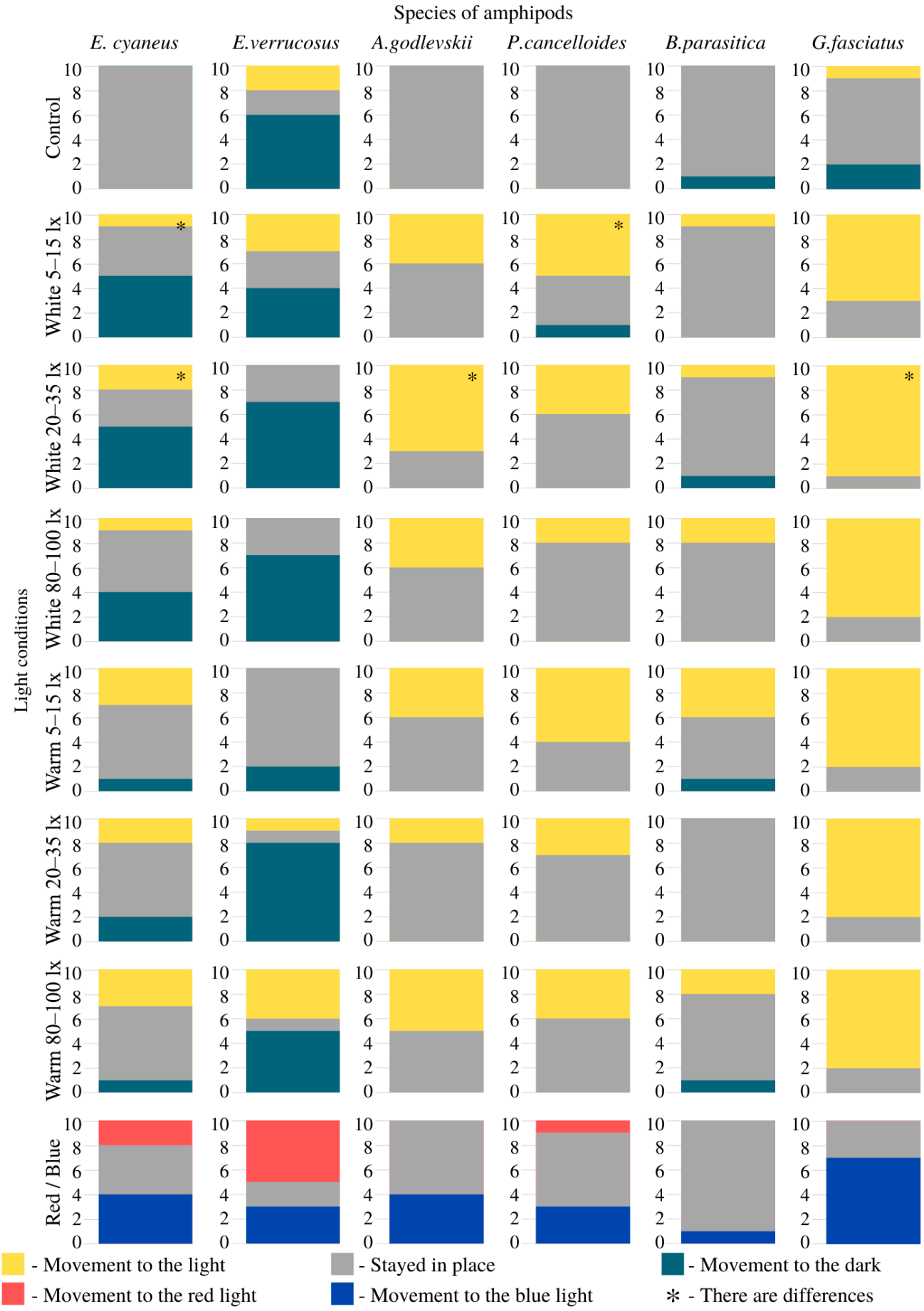

Figure 6. Locomotor activity of Baikal amphipods under different light conditions.

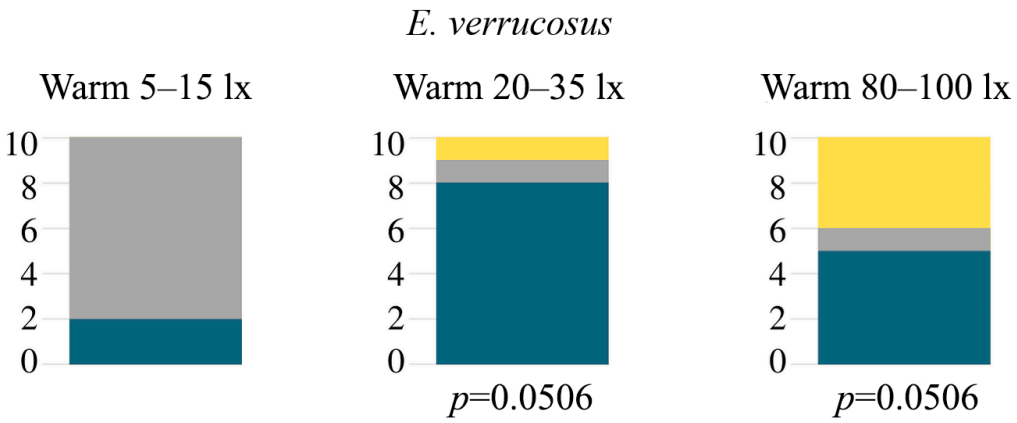

Figure 7. Differences in warm light in *E. verrucosus* obtained from generalized Fisher's exact test with Benjamani–Hochberg correction for multiple comparisons (*p*-values show differences compared to warm 5–15 lx light).

When comparing the responses of the different species used in this study, there are statistically significant differences between species under the same light conditions (Table 3).

Table 3. Differences between species under the same light conditions, obtained from generalized Fisher's exact test with Benjamani–Hochberg correction for multiple comparisons.

Type of Experiment	Species 1	Species 2	*p*-Value
Blue/red	*B. parasitica*	*E. verrucosus*	0.004 *
Warm light 5–15 lx	*E. verrucosus*	*G. fasciatus*	0.01 *
Warm light 20–35 lx	*A. godlevskii*	*E. verrucosus*	0.002 *
	B. parasitica	*E. verrucosus*	0.002 *
	B. parasitica	*G. fasciatus*	0.003 *
	E. verrucosus	*G. fasciatus*	0.002 *
	E. verrucosus	*P. cancelloides*	0.004 *
White light 20–35 lx	*A. godlevskii*	*B. parasitica*	0.05
	A. godlevskii	*E. cyaneus*	0.05
	A. godlevskii	*E. verrucosus*	0.001 *
	B. parasitica	*E. verrucosus*	0.05
	B. parasitica	*G. fasciatus*	0.006 *
	E. cyaneus	*G. fasciatus*	0.009 *
	E. verrucosus	*G. fasciatus*	0.0007 *
	E. verrucosus	*P. cancelloides*	0.007 *
White light 80–100 lx	*A. godlevskii*	*E. verrucosus*	0.01 *
	B. parasitica	*E. verrucosus*	0.01 *
	B. parasitica	*G. fasciatus*	0.05
	E. cyaneus	*G. fasciatus*	0.01 *
	E. verrucosus	*G. fasciatus*	0.001 *
	E. verrucosus	*P. cancelloides*	0.01 *
	G. fasciatus	*P. cancelloides*	0.05

* Statistically significant differences.

The obtained data demonstrate that white light, especially with intensities of 5–15 lux (p = 0.03) and 20–35 lux (p = 0.009), forces *E. cyaneus* to move more often towards the unlit side than towards the light. However, in the case of warm lighting, in most cases individuals of this species remained in place. At the same time, such locomotor activity is not confirmed in the experiment with red and blue lighting. In natural conditions, *E. cyaneus* hides under stones during the day. The white light used in the experiments can be perceived by individuals as daylight, as a result of which they seek shelter from it. Warm

light, compared to the control, may possibly force individuals to move, including towards the light. Considering that in natural conditions warm light can be observed during sunrise and sunset [43], it may be a signal for the movement of individuals associated with DVM. It is possible that, in experiments with warm lighting, individuals tend not so much to be attracted to the light, but rather to move. In experiments with red and blue LEDs, it is also possible to reliably say that the presence of light forces individuals to move, but it is impossible to reliably establish preferred lighting conditions. One previous study showed that *E. cyaneus* were attracted to red LED traps placed in Lake Baikal and were not attracted to traps with other colored LEDs [31]. The same study showed that in laboratory conditions, *E. cyaneus* tend to avoid light from red, yellow, green, and, especially, blue LEDs. Although the peaks of the red and blue spectra are identical in the mentioned studies and in our study, the inconsistency of the results may be caused by the use of different light intensities in the experiments. Reducing the intensity of the blue LED using additional filters to equalize it with the red led to the cancellation of the effect of avoidance of previously too-bright blue light by *E. cyaneus* individuals [31]. These data are already more comparable with ours, where the intensity of red and blue light was set to the same 30 lux, and individuals were attracted to the light of both LEDs.

The closely related species *E. verrucosus* moves actively in the absence of light. The absence of statistically significant differences between the effects of any light and the control may indicate that light does not affect the motor activity of this species. It is possible that this species may be vulnerable to warm 5–15 lux light, because this lighting appears to limit the motor activity of individuals compared to the control (although not in a statistically significant manner). A decrease in locomotor activity in the presence of artificial lighting was also observed in isopods [15]. However, in our experiments, this effect disappears with an increase in light intensity, as a result of which individuals resume motor activity close to the results obtained in the control. When comparing different lighting conditions, we almost obtained statistically significant differences for warm light between 5–15 lx and 20–35 lx ($p = 0.0506$) and 5–15 lx and 80–100 lx ($p = 0.0506$). Based on the results obtained, we theorize that warm light intensity may be important for *E. verrucosus*, but at the moment there are not enough data to confirm this assumption.

In turn, *A. godlevskii* and *P. cancelloides* do not show activity in the dark, but some individuals are attracted to both white and warm light, of all the intensities presented. At the same time, *G. fasciatus* shows little activity in the dark and a more active movement towards light, both white and warm. In this case, white 5–15 lx has a significant effect on *P. cancelloides* ($p = 0.03$) and white 20–35 lx has a significant effect on *A. godlevskii* ($p = 0.009$) and *G. fasciatus* ($p = 0.03$). It is also possible to speculate that *A. godlevskii* is slightly more attracted to blue light than to red light, but this question remains open. Also, the results indicate a potential attraction of *G. fasciatus* to blue light, but more data are needed to confirm this finding. However, as for *E. cyaneus*, avoidance responses to light with specific wavelength peaks, including blue LEDs, have previously been demonstrated for *G. fasciatus* [31]. Above we suggested that the inconsistency of the obtained data may be associated with the use of different light intensities in the experiments.

The low locomotor activity of *B. parasitica* may be related to its sedentary lifestyle [44] and, perhaps, in our experiment, this species needed more time to react in order to select a preferred zone. But still, single individuals were attracted by white and warm light (though not in a statistically significant manner). Blue and red light do not appear to have an effect on this species.

4. Discussion

In this study, we hypothesized that the response of Baikal amphipods to light would vary among species and depend on two factors: spectral composition and light intensity. Our results confirm the species-specificity of amphipods' response to different lighting conditions (Figure 6, Table 3). These data are consistent with other previous studies that have shown different responses of amphipod species to light sources with different spectral compositions [1,28,29,31,32]. Furthermore, when considering the overall response to light of the studied species, statistically significant differences with control conditions without illumination were found only for white light of two intensities (5–15 lux and 20–35 lux) and were absent for warm and red/blue light. This may tell us that even if individual species responded differently to different lighting conditions in this study, for the amphipod community as a whole, white light may have a more negative effect than warm light under natural conditions. Similar conclusions have been reached by other researchers previously when comparing the effects of LED and halogen or HPS light on amphipods, with LED light having a greater effect on wildlife [1,28]. However, in our study, all light sources used in the experiments were, firstly, LED, and secondly, with the same intensities. Based on this, we can assume that the degree of influence of LED light on amphipods may be determined by its spectral composition, namely its color temperature, and warm LED light appears to be less harmful.

If we consider the species we studied separately from each other, white light significantly influenced the behavior (statistically significant differences with control conditions were found) of four of the six species, namely *E. cyaneus*, *A. godlevskii*, *P. cancelloides*, and *G. fasciatus*. White light appears to be particularly important for *E. cyaneus*, as statistically significant differences were found in two of three white light intensities. It can be reliably established that white light with intensities of 5–15 lux and 20–35 lux forces *E. cyaneus* individuals to move, more often into the unlit zone.

Regarding the effect of light intensity on the behavior of amphipods, we did not find statistically significant differences when comparing intensities of 5–15 lx, 20–35 lx, and 80–100 lx in any of the studied species, either under warm or white lighting. Based on this, we can assume that light intensity is not a determining factor in the reaction of Baikal amphipods to light. However, we obtained borderline *p*-values ($p = 0.0506$) for *E. verrucosus* when comparing warm light intensities. It is possible that by repeating these experiments, but with larger samples, or by conducting other experiments, the hypothesis about the influence of light intensity on the behavior of amphipods can be confirmed. However, in the context of this study, we were unable to confirm the role of light intensity in the amphipod response.

In our study, individuals of the species *A. godlevskii*, *P. cancelloides*, and *G. fasciatus* were attracted to LED light in experiments to varying degrees. Artificial light makes aquatic organisms visible to their natural predators, as a result of which these species can become easy prey for predators [45–47], in particular cottoid fishes, and as a result, light pollution can lead to the depletion of both the qualitative and quantitative composition of amphipods.

Artificial lighting at night can influence both the quantitative and qualitative composition of amphipods [1,48]. Individuals that are nocturnal or participate in DVM are particularly susceptible to this effect [1]. In Lake Baikal, the phenomenon of DVM is widespread among benthic amphipods [38]. Of the actively migratory species, we used *G. fasciatus* and *E. cyaneus* (migratory to a lesser extent), which live at depths of up to 5 m. The data obtained show that both migrants are able to be exposed to artificial lighting. However, this effect will differ depending on the species. Most individuals *G. fasciatus*, regardless of the spectrum of illumination and its intensity, move to the illuminated zone.

In turn, individuals of *E. cyaneus*, under white lighting of any intensity, move into the unlit zone or remain in place. The different reactions to light in these species may be due to their habitat. *E. cyaneus* lives only on the ground with large stones, under which individuals actively hide almost all the time (especially during the day) [40]. *G. fasciatus* lives both on rocks and on sandy soils, often burrowing into the sand; however, this species has been noted to actively swim near the shore at the surface of the water even during the day [40].

It has been previously noted that artificial lighting can have a negative impact on biodiversity in marine waters [20]. Lake Baikal has some similarities with marine ecosystems (transparency and biodiversity). The maximum transparency of the lake is 40 m, which allows light to penetrate to depths of 400 m [49]. Such conditions in the lake potentially contribute to the fact that the littoral and sublittoral zones will be exposed to light pollution. In turn, if we consider the types of light sources, LED lights have a stronger impact than other light sources. This is because they emit light that covers the full visible spectrum and typically contains a lot of blue light, which is known to regulate the biological clock of almost all organisms on Earth [50]. If LED lights are installed permanently, this increases their impact [27]. There are both permanent and temporary lighting sources on Lake Baikal (Figure 4).

To date, no measures have been taken to reduce light pollution on the shorelines of Lake Baikal. Meanwhile, according to remote sensing data, more than 10% of the lake's coastline is already subject to this pollution (unpublished data). As we have found out, the reaction to light pollution is species-specific. The same light sources can have completely different effects on Baikal amphipods. Therefore, for reservoirs with high biodiversity such as Baikal, the best solution would be to install a special screen to minimize the light entering the reservoir from light sources located near the shoreline. However, this method will be very expensive and can only be used in certain areas with severe light pollution. The main problem is rather the development of infrastructure in settlements located near the lake and the corresponding increase in the effect of sky glow [5,9]. Consequently, protective measures such as improving luminance distribution or reducing light levels and duration are likely to be much more effective at minimizing negative consequences for freshwater biodiversity and ecosystems [9].

Perhaps the main drawback of our study is the very small sample sizes. For each species and lighting type, the behavior of only 10 individuals was taken into account, whereas individual behavioral characteristics of amphipods can vary greatly within a species [51]. In addition, small sample sizes severely limit the choice of statistical criteria for their comparison. Also, although the Benjamani–Hochberg correction for multiple comparisons [42] preserves the power of the statistical test well, our study had too many comparisons of small sample sizes. On the other hand, one of the main ideas of this study was to compare several species and lighting conditions at once over a relatively short period of time (approximately 1 week) in order to reduce the influence of the time factor on differences in the behavior of species when kept in laboratory conditions. Therefore, we allocated 5 min for each individual, of which 3 min were spent on the individual becoming used to the light, and 2 min on demonstrating a response. In general, as shown by other studies related to the study of amphipod responses to light, 2 min tests are sufficient to record a response [33,51,52]. However, we think that 2 min was not enough time for *B. parasitica* individuals to register their response to light. In natural conditions, this species mainly lives on Baikal sponges, due to which Dybowsky gave it the name "parasitica" in 1874. In the literature, this species is described as "Slowly moving crustaceans tightly attach to a sponge with strong dactylae of legs projecting laterally and do not leave the sponge even when lifted from the water" [44]. It is likely that the slow response of the individuals,

in addition to their natural slowness, was also associated with the absence of their usual living conditions.

In order to smooth out the contradictions and shortcomings that have arisen in the current study for future similar studies, we would recommend focusing primarily on 2–3 species. This amount is sufficient to identify behavioral characteristics within species in a short period of time and compare them with each other. In addition, we would recommend that studies pay attention to the light intensities used in experiments with amphipods, since there is insufficient literature data on this issue. We would also recommend focusing on studies that could identify the effects of long-term light pollution on amphipods. At present, a few such studies have been conducted for birds [53], insects [54,55], fish [56–58], and cladocerans [59]. To identify the long-term effects of light on amphipods, the behavioral characteristics of individuals from light-polluted areas (e.g., near populated areas) and unpolluted areas can be compared; however, it must be borne in mind that behavioral characteristics may be influenced by other anthropogenic factors [60]. Another option is to create light pollution and track changes in parameters in individuals over the long term, which can be measured in months and years or over the course of several generations. However, these studies will require, in addition to a large amount of time, fairly large material costs for the long-term maintenance of more or less comfortable conditions for individuals.

5. Conclusions

As a result of the study, we confirmed the species-specificity of the reaction of Baikal littoral and sublittoral amphipods to different light conditions. When considering the overall response to light of the six species studied, we found statistically significant differences for white light and none for warm and red/blue light. These results may suggest that the degree of influence of LED light may be determined by its spectral composition, and perhaps that warm light has less of an effect on wildlife than white light. We also found that the spectral composition of light significantly affected the behavior of four out of six species, namely *A. godlevskii*, *P. canceroides*, *G. fasciatus*, and especially *E. cyaneus*. Regarding the influence of different light intensities in this study, we were unable to confirm the role of this factor in the effect of light on the behavior of Baikal amphipods. However, on this issue we obtained borderline results, which can become the basis for further research. In general, artificial light has an effect on Baikal littoral and sublittoral amphipods. And the development of infrastructure along the shorelines of Lake Baikal, which entails an increase in light pollution, can lead to changes in the structure and composition of hydrobionts in certain areas of the lake.

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Data Availability Statement: All the data used are included in the article. In addition, any data used for this study will be provided upon request by the corresponding author.

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Abbreviations

The following abbreviations are used in this manuscript:

LED	Light-emitting diode
DVM	Daily vertical migration
HPS	High-pressure sodium

References

1. Navarro-Barranco, C.; Hughes, L.E. Effects of Light Pollution on the Emergent Fauna of Shallow Marine Ecosystems: Amphipods as a Case Study. *Mar. Pollut. Bull.* **2015**, *94*, 235–240. [CrossRef] [PubMed]
2. Ludvigsen, M.; Berge, J.; Geoffroy, M.; Cohen, J.H.; De La Torre, P.R.; Nornes, S.M.; Singh, H.; Sørensen, A.J.; Daase, M.; Johnsen, G. Use of an Autonomous Surface Vehicle Reveals Small-Scale Diel Vertical Migrations of Zooplankton and Susceptibility to Light Pollution under Low Solar Irradiance. *Sci. Adv.* **2018**, *4*, eaap9887. [CrossRef] [PubMed]
3. Falcón, J.; Torriglia, A.; Attia, D.; Viénot, F.; Gronfier, C.; Behar-Cohen, F.; Martinsons, C.; Hicks, D. Exposure to Artificial Light at Night and the Consequences for Flora, Fauna, and Ecosystems. *Front. Neurosci.* **2020**, *14*, 602796. [CrossRef]
4. Lao, S.; Robertson, B.A.; Anderson, A.W.; Blair, R.B.; Eckles, J.W.; Turner, R.J.; Loss, S.R. The Influence of Artificial Light at Night and Polarized Light on Bird-Building Collisions. *Biol. Conserv.* **2020**, *241*, 108358. [CrossRef]
5. Marangoni, L.F.B.; Davies, T.; Smyth, T.; Rodríguez, A.; Hamann, M.; Duarte, C.; Pendoley, K.; Berge, J.; Maggi, E.; Levy, O. Impacts of Artificial Light at Night in Marine Ecosystems—A Review. *Glob. Change Biol.* **2022**, *28*, 5346–5367. [CrossRef]
6. Colman, L.P.; Lara, P.H.; Bennie, J.; Broderick, A.C.; De Freitas, J.R.; Marcondes, A.; Witt, M.J.; Godley, B.J. Assessing Coastal Artificial Light and Potential Exposure of Wildlife at a National Scale: The Case of Marine Turtles in Brazil. *Biodivers. Conserv.* **2020**, *29*, 1135–1152. [CrossRef]
7. Kamei, M.; Jikumaru, S.; Hoshino, S.; Ishikura, S.; Wada, M. Effects of Replacing Outdoor Lighting with White LEDs with Different Correlated Color Temperatures on the Attraction of Nocturnal Insects. *Appl. Entomol. Zool.* **2021**, *56*, 225–233. [CrossRef]
8. Fabian, S.T.; Sondhi, Y.; Allen, P.E.; Theobald, J.C.; Lin, H.-T. Why Flying Insects Gather at Artificial Light. *Nat. Commun.* **2024**, *15*, 689. [CrossRef]
9. Hölker, F.; Jechow, A.; Schroer, S.; Tockner, K.; Gessner, M.O. Light Pollution of Freshwater Ecosystems: Principles, Ecological Impacts and Remedies. *Phil. Trans. R. Soc. B* **2023**, *378*, 20220360. [CrossRef]
10. Berge, J.; Geoffroy, M.; Daase, M.; Cottier, F.; Priou, P.; Cohen, J.H.; Johnsen, G.; McKee, D.; Kostakis, I.; Renaud, P.E.; et al. Artificial Light during the Polar Night Disrupts Arctic Fish and Zooplankton Behaviour down to 200 m Depth. *Commun. Biol.* **2020**, *3*, 102. [CrossRef]
11. Bolton, D.; Mayer-Pinto, M.; Clark, G.F.; Dafforn, K.A.; Brassil, W.A.; Becker, A.; Johnston, E.L. Coastal Urban Lighting Has Ecological Consequences for Multiple Trophic Levels under the Sea. *Sci. Total Environ.* **2017**, *576*, 1–9. [CrossRef] [PubMed]
12. Kupprat, F.; Kloas, W.; Krüger, A.; Schmalsch, C.; Hölker, F. Misbalance of Thyroid Hormones after Two Weeks of Exposure to Artificial Light at Night in Eurasian Perch *Perca fluviatilis*. *Conserv. Physiol.* **2021**, *9*, coaa124. [CrossRef]
13. Brüning, A.; Hölker, F.; Franke, S.; Kleiner, W.; Kloas, W. Impact of Different Colours of Artificial Light at Night on Melatonin Rhythm and Gene Expression of Gonadotropins in European Perch. *Sci. Total Environ.* **2016**, *543*, 214–222. [CrossRef]
14. Migaud, H.; Cowan, M.; Taylor, J.; Ferguson, H.W. The Effect of Spectral Composition and Light Intensity on Melatonin, Stress and Retinal Damage in Post-Smolt Atlantic Salmon, Salmo Salar. *Aquaculture* **2007**, *270*, 390–404. [CrossRef]
15. Duarte, C.; Quintanilla-Ahumada, D.; Anguita, C.; Manríquez, P.H.; Widdicombe, S.; Pulgar, J.; Silva-Rodríguez, E.A.; Miranda, C.; Manríquez, K.; Quijón, P.A. Artificial Light Pollution at Night (ALAN) Disrupts the Distribution and Circadian Rhythm of a Sandy Beach Isopod. *Environ. Pollut.* **2019**, *248*, 565–573. [CrossRef]
16. Foster, J.G.; Algera, D.A.; Brownscombe, J.W.; Zolderdo, A.J.; Cooke, S.J. Consequences of Different Types of Littoral Zone Light Pollution on the Parental Care Behaviour of a Freshwater Teleost Fish. *Water Air Soil. Pollut.* **2016**, *227*, 404. [CrossRef]

17. Moore, M.V.; Pierce, S.M.; Walsh, H.M.; Kvalvik, S.K.; Lim, J.D. Urban Light Pollution Alters the Diel Vertical Migration of *Daphnia*. *SIL Proc.* **2000**, *27*, 779–782. [CrossRef]
18. Harrison, S.E.; Gray, S.M. Effects of Light Pollution on Bluegill Foraging Behavior. *Trans. Am. Fish. Soc.* **2024**, *153*, 152–162. [CrossRef]
19. Brüning, A.; Hölker, F.; Wolter, C. Artificial Light at Night: Implications for Early Life Stages Development in Four Temperate Freshwater Fish Species. *Aquat. Sci.* **2011**, *73*, 143–152. [CrossRef]
20. Davies, T.W.; Bennie, J.; Gaston, K.J. Street Lighting Changes the Composition of Invertebrate Communities. *Biol. Lett.* **2012**, *8*, 764–767. [CrossRef]
21. Luarte, T.; Bonta, C.C.; Silva-Rodriguez, E.A.; Quijón, P.A.; Miranda, C.; Farias, A.A.; Duarte, C. Light Pollution Reduces Activity, Food Consumption and Growth Rates in a Sandy Beach Invertebrate. *Environ. Pollut.* **2016**, *218*, 1147–1153. [CrossRef] [PubMed]
22. Ciofini, A.; Mercatelli, L.; Hariyama, T.; Ugolini, A. Sky Radiance and Spectral Gradient Are Orienting Cues for the Sandhopper *Talitrus Saltator* (Crustacea, Amphipoda). *J. Exp. Biol.* **2020**, *224*, jeb.239574. [CrossRef]
23. García-Sanz, S.; Navarro, P.G.; Png-Gonzalez, L.; Tuya, F. Contrasting Patterns of Amphipod Dispersion in a Seagrass Meadow between Day and Night: Consistency through a Lunar Cycle. *Mar. Biol. Res.* **2016**, *12*, 56–65. [CrossRef]
24. Anokhina, L.L. Influence of Moonlight on the Vertical Migrations of Benthopelagic Organisms in the Near-Shore Area of the Black Sea. *Oceanology* **2006**, *46*, 385–395. [CrossRef]
25. Fernandez-Gonzalez, V.; Fernandez-Jover, D.; Toledo-Guedes, K.; Valero-Rodriguez, J.M.; Sanchez-Jerez, P. Nocturnal Planktonic Assemblages of Amphipods Vary Due to the Presence of Coastal Aquaculture Cages. *Mar. Environ. Res.* **2014**, *101*, 22–28. [CrossRef] [PubMed]
26. Davies, T.W.; Duffy, J.P.; Bennie, J.; Gaston, K.J. The Nature, Extent, and Ecological Implications of Marine Light Pollution. *Front. Ecol. Environ.* **2014**, *12*, 347–355. [CrossRef]
27. Lynn, K.D.; Quintanilla-Ahumada, D.; Anguita, C.; Widdicombe, S.; Pulgar, J.; Manríquez, P.H.; Quijón, P.A.; Duarte, C. Artificial Light at Night Alters the Activity and Feeding Behaviour of Sandy Beach Amphipods and Pose a Threat to Their Ecological Role in Atlantic Canada. *Sci. Total Environ.* **2021**, *780*, 146568. [CrossRef] [PubMed]
28. Czarnecka, M.; Kobak, J.; Grubisic, M.; Kakareko, T. Disruptive Effect of Artificial Light at Night on Leaf Litter Consumption, Growth and Activity of Freshwater Shredders. *Sci. Total Environ.* **2021**, *786*, 147407. [CrossRef]
29. Czarnecka, M.; Jermacz, Ł.; Glazińska, P.; Kulasek, M.; Kobak, J. Artificial Light at Night (ALAN) Affects Behaviour, but Does Not Change Oxidative Status in Freshwater Shredders. *Environ. Pollut.* **2022**, *306*, 119476. [CrossRef]
30. Quintanilla-Ahumada, D.; Quijón, P.A.; Jahnsen-Guzmán, N.; Lynn, K.D.; Pulgar, J.; Palma, J.; Manríquez, P.H.; Duarte, C. Splitting Light Pollution: Wavelength Effects on the Activity of Two Sandy Beach Species. *Environ. Pollut.* **2024**, *356*, 124317. [CrossRef]
31. Drozdova, P.; Kizenko, A.; Saranchina, A.; Gurkov, A.; Firulyova, M.; Govorukhina, E.; Timofeyev, M. The Diversity of Opsins in Lake Baikal Amphipods (Amphipoda: Gammaridae). *BMC Ecol. Evo.* **2021**, *21*, 81. [CrossRef]
32. Drozdova, P.; Saranchina, A.; Timofeyev, M. Spectral Sensitivity of the Visual System of Endemic Baikal Amphipods. *LFWB* **2020**, *4*, 781–782. [CrossRef]
33. Kohler, S.A.; Parker, M.O.; Ford, A.T. Species-Specific Behaviours in Amphipods Highlight the Need for Understanding Baseline Behaviours in Ecotoxicology. *Aquat. Toxicol.* **2018**, *202*, 173–180. [CrossRef]
34. Takhteev, V.V.; Berezina, N.A.; Sidorov, D.A. Checklist of the Amphipoda (Crustacea) from continental waters of Russia, with data on alien species. *Arthropoda Sel.* **2015**, *24*, 335–370. [CrossRef]
35. Rudstam, L.G.; Melnik, N.G.; Timoshkin, O.A.; Hansson, S.; Pushkin, S.V.; Nemov, V. Diel Dynamics of an Aggregation of Macrohectopus Branickii (DYB.) (Amphipoda, Gammaridae) in the Barguzin Bay, Lake Baikal, Russia. *J. Great Lakes Res.* **1992**, *18*, 286–297. [CrossRef]
36. Karnaukhov, D.; Dolinskaya, E.; Biritskaya, S.; Teplykh, M.; Khomich, A.; Silow, E. Effect of artificial light on the migratory activity of the pelagic amphipod Macrohectopus branickii during daily vertical migration in Lake Baikal. *Ecol. Environ. Conserv.* **2019**, *25*, 208–210.
37. Bessolitsina, I.A.; Stom, D.I. Study of some behavioral reactions of Baikal amphipods under experimental conditions. *Biodivers. Baikal Reg. Proc. Biol. Soil Fac. ISU* **2001**, *4*, 30–37. (In Russian)
38. Takhteev, V.V.; Karnaukhov, D.Y.; Govorukhina, E.B.; Misharin, A.S. Diel Vertical Migrations of Hydrobionts in the Coastal Area of Lake Baikal. *Inland Water Biol.* **2019**, *12*, 178–189. [CrossRef]
39. Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the Protection of Animals Used for Scientific Purposes: Text with EEA Relevance. Available online: https://eur-lex.europa.eu/eli/dir/2010/63/oj (accessed on 27 March 2025).
40. Bazikalova, A.Y. Amphipods of Lake Baikal. In *Proceedings of the Baikal Limnological Station*; Publishing House of the USSR Academy of Sciences: Leningrad, Russia, 1945; 440p. (In Russian)

41. Saranchina, A.; Drozdova, P.; Mutin, A.; Timofeyev, M. Diet Affects Body Color and Energy Metabolism in the Baikal Endemic Amphipod Eulimnogammarus Cyaneus Maintained in Laboratory Conditions. *BioComm* **2021**, *66*, 245–255. [CrossRef]
42. Benjamini, Y.; Hochberg, Y. Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *J. R. Stat. Soc. Ser. B Stat. Methodol.* **1995**, *57*, 289–300. [CrossRef]
43. Oh, S.-T.; Ga, D.-H.; Lim, J.-H. A Method of Generating Real-Time Natural Light Color Temperature Cycle for Circadian Lighting Service. *Sensors* **2023**, *23*, 883. [CrossRef]
44. Mekhanikova, I.V.; Vorobyeva, S.S. Diet of the Symbiotic Amphipod, Brandtia Parasitica Parasitica (Crustacea, Amphipoda), Living on Diseased Baikal Sponges of the Family Lubomirskiidae in Southern Lake Baikal. *Biol. Bull. Russ. Acad. Sci.* **2018**, *45*, 789–793. [CrossRef]
45. Yoon, H.S.; Park, C.W.; Soh, H.Y.; Park, I.W.; Choi, S.D. Comparative Stomach Contents and Growth of the Juvenile Black Seabream, *Acanthopagrus schlegeli*, Reared in Illuminated and Unilluminated Cages. *Aquac. Res.* **2009**, *40*, 242–245. [CrossRef]
46. Yoon, H.-S.; Park, C.-W.; Moon, S.-Y.; Han, K.-H.; Suh, H.-L.; An, Y.-K.; Choi, S.-D. Comparative Stomach Contents and Growth of the Juvenile Black Rockfish Sebastes Inermis Reared in Illuminated and Unilluminated Cages. *Fish. Sci.* **2008**, *74*, 657–661. [CrossRef]
47. Macneil, C.; Dick, J.T.A.; Elwood, R.W. The Dynamics of Predation on Gammarus Spp. (Crustacea: Amphipoda). *Biol. Rev.* **1999**, *74*, 375–395. [CrossRef]
48. Karnaukhov, D.; Teplykh, M.; Dolinskaya, E.; Biritskaya, S.; Ermolaeva, Y.; Pushnica, V.; Kuznetsova, I.; Okholina, A.; Bukhaeva, L.; Silow, E. Light Pollution Affects the Coastal Zone of Lake Baikal. *Limnol. Rev.* **2021**, *21*, 165–168. [CrossRef]
49. Hunt, D.M.; Fitzgibbon, J.; Slobodyanyuk, S.J.; Bowmakers, J.K. Spectral Tuning and Molecular Evolution of Rod Visual Pigments in the Species Flock of Cottoid Fish in Lake Baikal. *Vis. Res.* **1996**, *36*, 1217–1224. [CrossRef]
50. Grubisic, M. Waters under Artificial Lights: Does Light Pollution Matter for Aquatic Primary Producers? *Limnol. Ocean. Bull.* **2018**, *27*, 76–81. [CrossRef]
51. Van Den Berg, S.J.P.; Rodríguez-Sánchez, P.; Zhao, J.; Olusoiji, O.D.; Peeters, E.T.H.M.; Schuijt, L.M. Among-Individual Variation in the Swimming Behaviour of the Amphipod Gammarus Pulex under Dark and Light Conditions. *Sci. Total Environ.* **2023**, *872*, 162177. [CrossRef]
52. Cherry, T.-R.; Kohler, S.A.; Ford, A.T. Sex Specific Differences Recorded in the Behavior of an Amphipod: Implications for Behavioral Toxicology. *Front. Mar. Sci.* **2020**, *7*, 370. [CrossRef]
53. Dominoni, D.M.; Quetting, M.; Partecke, J. Long-Term Effects of Chronic Light Pollution on Seasonal Functions of European Blackbirds (Turdus Merula). *PLoS ONE* **2013**, *8*, e85069. [CrossRef]
54. Altermatt, F.; Ebert, D. Reduced Flight-to-Light Behaviour of Moth Populations Exposed to Long-Term Urban Light Pollution. *Biol. Lett.* **2016**, *12*, 20160111. [CrossRef]
55. Keinath, S.; Hölker, F.; Müller, J.; Rödel, M.-O. Impact of Light Pollution on Moth Morphology–A 137-Year Study in Germany. *Basic Appl. Ecol.* **2021**, *56*, 1–10. [CrossRef]
56. Georgiou, D.; Reeves, S.E.; Burke Da Silva, K.; Fobert, E.K. Artificial Light at Night Impacts Night-Time Activity but Not Day-Time Behaviour in a Diurnal Coral Reef Fish. *Basic Appl. Ecol.* **2024**, *74*, 74–82. [CrossRef]
57. Oyabu, A.; Wu, L.; Matsumoto, T.; Kihara, N.; Yamanaka, H.; Minamoto, T. The Effect of Artificial Light at Night on Wild Fish Community: Manipulative Field Experiment and Species Composition Analysis Using Environmental DNA. *Environ. Adv.* **2024**, *15*, 100457. [CrossRef]
58. Schligler, J.; Cortese, D.; Beldade, R.; Swearer, S.E.; Mills, S.C. Long-Term Exposure to Artificial Light at Night in the Wild Decreases Survival and Growth of a Coral Reef Fish. *Proc. R. Soc. B.* **2021**, *288*, 20210454. [CrossRef]
59. Li, D.; Huang, J.; Zhou, Q.; Gu, L.; Sun, Y.; Zhang, L.; Yang, Z. Artificial Light Pollution with Different Wavelengths at Night Interferes with Development, Reproduction, and Antipredator Defenses of *Daphnia magna*. *Environ. Sci. Technol.* **2022**, *56*, 1702–1712. [CrossRef]
60. Guler, Y.; Ford, A.T. Anti-Depressants Make Amphipods See the Light. *Aquat. Toxicol.* **2010**, *99*, 397–404. [CrossRef]

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