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Articles

Locomotor activity of the Holarctic molluscs Radix auricularia (from Lake Baikal) in various light pollution conditions

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Light pollution is a modern environmental problem. The scale of light pollution is increasing yearly and is negatively affecting the functioning of terrestrial and aquatic ecosystems. Of the aquatic ecosystems, marine ecosystems are the most studied, while there is very little information on the effect of artificial lighting on freshwater ecosystems. Among freshwater aquatic organisms, there are relatively little data on the effect of artificial light on crustaceans and fish, while we could find no meaningful data on the effect of artificial light on molluscs are practically absent. Here we test whether different types of artificial lighting, differing in their spectra, affect the activity of the Holarctic mollusc *Radix auricularia*. For this, we used two light sources (with warm and cold light) and a 1-m long aquarium. We found that both light sources affect individuals of this species, but the effects of this exposure are different. Artificial lighting (depending on the spectral characteristics) can increase the activity of molluscs of this species or reduce it. In the long term, the impact on the ecosystem will depend on the type of water body where light pollution is present, where individuals of this species live, and the type of light sources.

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Keywords

ALAN, Artificial light at night, Lake Baikal, light sources, *Radix auricularia*.

Introduction

Light pollution is inappropriate and excessive artificial lighting that affects the ecosystems. Billboards, building lighting, streetlamps and highways lights are the main sources of light pollution on land (Hölker et al. 2010; Luarte et al. 2016; Ściężor 2021). With the growth of the population and urbanization, the number of lighting sources continues to increase. For example, the number of streetlamps is predicted to increase by 6% yearly (Hölker et al. 2010). The lighting of the coastline and water transport is the main source of light pollution at water bodies (Navarro-Barranco and Hughes 2015). Artificial lighting can have a variety of effects on aquatic organisms (Moore et al. 2000; Luarte et al. 2016; Duarte et al. 2019; Pulgar et al. 2019). It can affect both reproduction (Bruning et al. 2010) and behavior of fish, such as the protection of laid eggs (Foster et al. 2016). Light pollution can change the composition of aquatic communities (Davies et al. 2012) and slow down the locomotor activity of daphnia at night (Moore et al. 2000). In addition, it affects the locomotor activity and growth rate of some organisms (Luarte et al. 2016). Molluscs is one of the numerous groups of aquatic organisms, ranked second in species diversity after arthropods (Giribet et al. 2006). However, scanty data is available on the effect of light pollution on molluscs. There are data on the effect of different ranges of the light spectrum on the fertility of *Lymnaea acuminata* (Kumar et al. 2017) and the effect of prolonged exposure to light on the shadow reflex of *Radix auricularia* (Hussein et al. 2021). This group of aquatic organisms is sensitive to anthropogenic impact, making many gastropods model objects of bioindication (Bouchet et al. 2005; Akindele et al. 2019; Chukaeva and Petrov 2022).

Nearly 180 species of molluscs have been recorded in Lake Baikal, of which 82% are gastropods. More than 60% of gastropods are endemic to the lake (Kulikova et al. 2007; Zhuykova 2020; Schniebs et al. 2022), and the peak of the total diversity of most endemic gastropods is observed at depths of 5–20 m (Sitnikova 2006). Unlike some Baikal molluscs, the upper part of the littoral (0-5 m) is inhabited by a widespread Holarctic species such as *Radix auricularia* (Linnaeus, 1758) (Aksenova 2017). The maximum habitat depth of this species in Lake Baikal is 30 meters (Schniebs et al. 2022). Previous studies show that the littoral part of Lake Baikal is exposed to light pollution (Karnaukhov et al. 2021), making the species of molluscs potentially susceptible to light pollution.

Various sources of artificial lighting (LED and halogen lamps) have been installed along with Lake Baikal; these sources can have different effects on aquatic organisms (Navarro-Barranco et al. 2015). Thus, studying the effect of lighting on such a widespread species such as *R. auricularia* is actual. This study aims to investigate whether the reaction of *R. auricularia* to artificial lighting depends on its spectral characteristics.

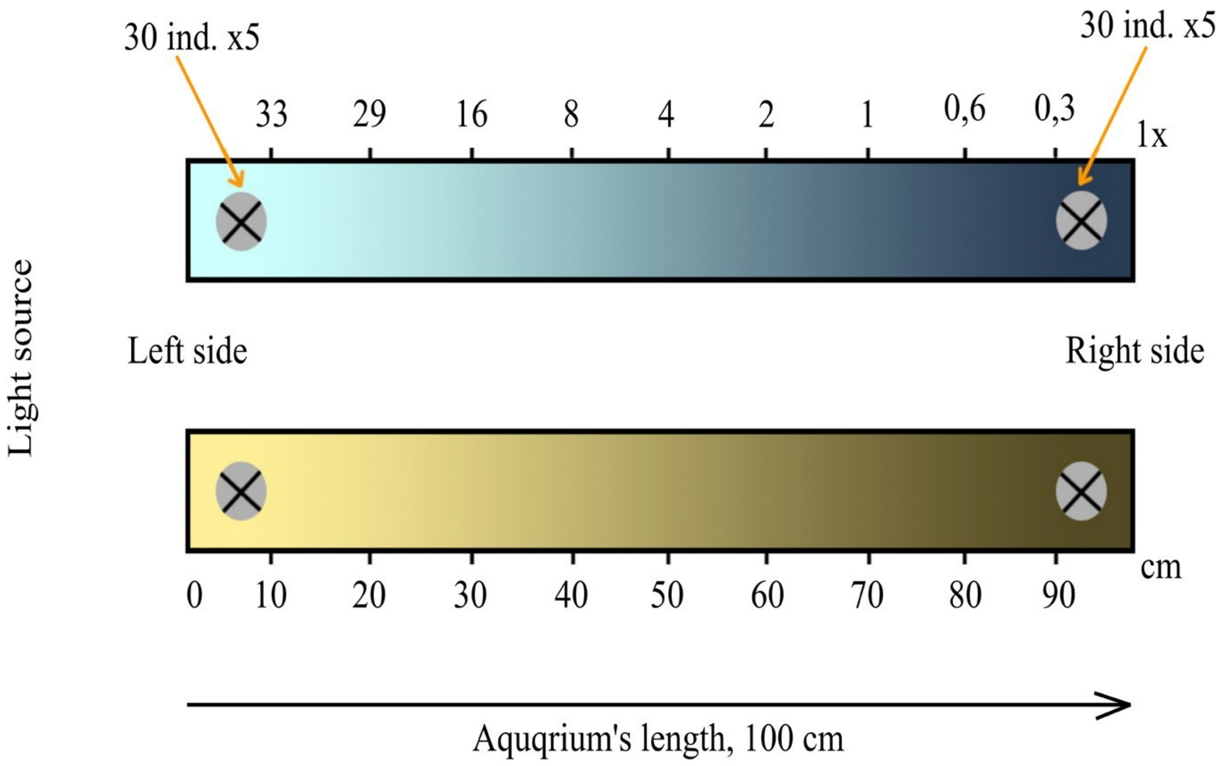
Materials and methods

Molluscs (shell size: 16.4±0.3 mm) were collected on September 15, 2021, in the southern part of Lake Baikal near Bolshiye Koty village (51°54'11.2"N 105°04'12.8"E; there is no lighting in this place). Two weeks before the experiment, the individuals were acclimated under the following conditions (t = 8 ^{0}C, daylight hours - 8L(5000 lx):16D).

The experiment began at the same time (beginning at 10 a.m.) to exclude the influence of circadian rhythms or kinesis. In addition, the character of the individual's movement was noted for the same purpose. We used 4 lighting variants (daylight 58000 lx, darkness 0 lx, warm yellow light with a gradient from 0.3 to 33 lx and cold light with a similar gradient for the experiment (Near the coastline of Lake Baikal, light pollution from 1.2 to 50 lux is currently observed in some areas.). For lighting variants with warm and cold light, a light source (led video light CN-20FC: 5600K-3200K) was installed above the aquarium (30 cm), to create an illumination gradient along its length (Fig. 1). The amount of emitted light was measured using a luxmeter (CEM DT – 8809A), and a fibre-optic spectrometer QE Pro (OceanOptics, USA) was used to measure the spectral characteristics of the light source.

The experimental setup was an aquarium (length 100 × width 10 × height 10 cm). A lined sheet was placed under the aquarium with a distance of 1 cm between the lines. In total, we used 30 individuals of *R. auricularia*. At the beginning of the experiments, all 30 individuals were planted at the aquarium, and the time was recorded. After 15 minutes, the distance travelled by the molluscs was recorded on a lined sheet of paper. For each lighting variant, the molluscs were planted 5 times on one side and 5 times on the opposite side. With an additional source of illumination, the molluscs were planted 5 times at the least illuminated side and 5 times at the most illuminated side (Fig. 1). There were 5 minutes between side changes. As an additional control, a video camera with night vision mode was used.

The control group also consisted of 30 individuals. This group was kept and acclimated under the same conditions. The values of locomotor activity obtained using the control group were identical to the values of day and night during the experiment.


30 ind. x5
30 ind. x5
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29
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8
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Light source
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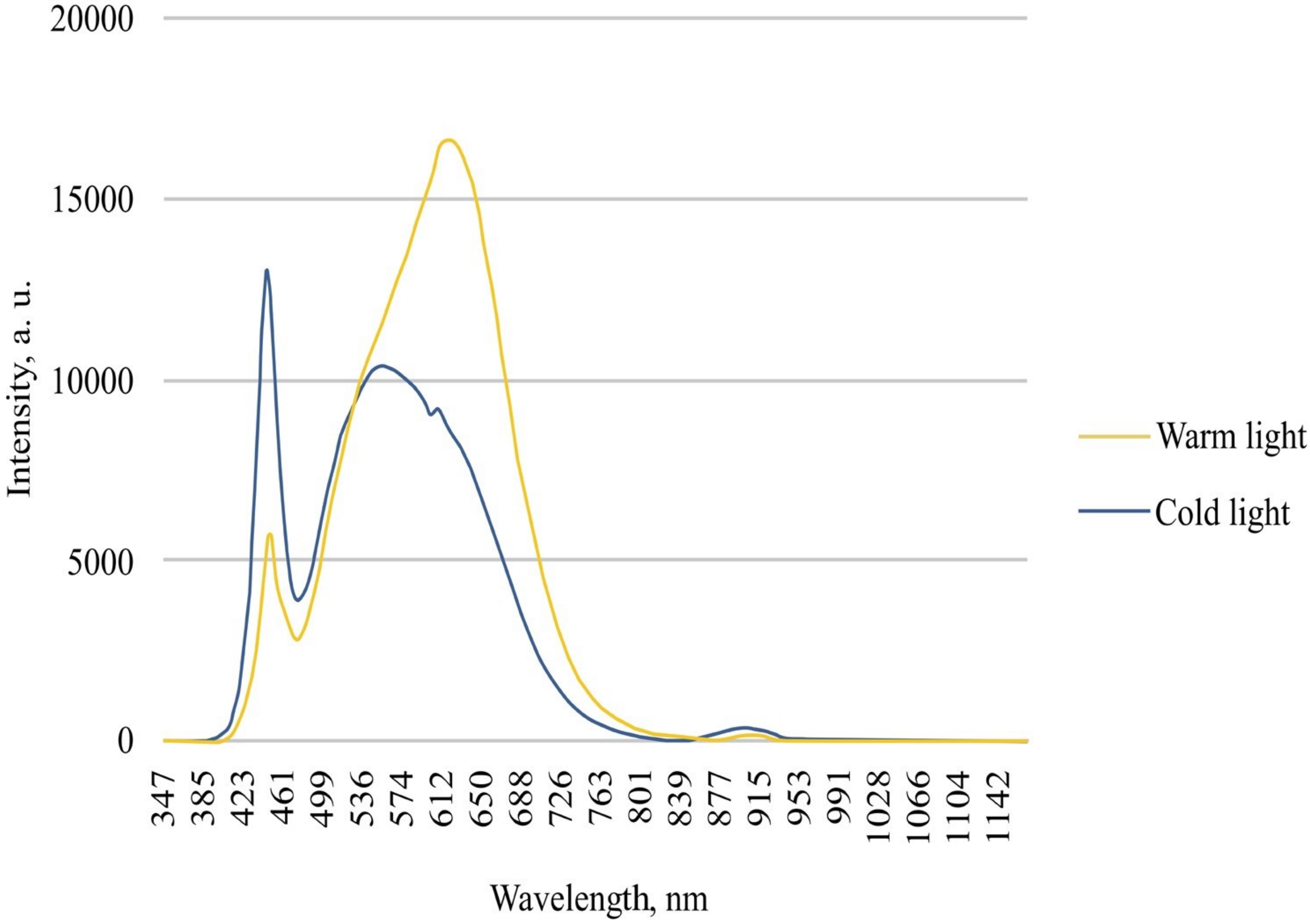
Aquqrium's length, 100 cm


20000
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Intensity, a. u.
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839
877
915
953
991
1028
1066
1104
1142
Wavelength, nm
Warm light
Cold light

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Figure 1. *Experimental conditions (The scale on the graph at the top shows the illumination gradient depending on the length of the aquarium. The lower part of the graph shows the spectral characteristics of the light sources).*

Statistical analysis was conducted in the programs Past 3.x and R. The data were first checked for normal distribution using the Shapiro-Wilk test. Since the data turned out to be nonparametric, we used the Dunn's post hoc test (Table 1). However, it should be noted that the combination of the Kruskal-Wallis test with the Mann-Whitney U-test with Bonferroni correction showed similar results.

		Day	Night		Warm light		Cold light	
		Right side	Left side	Right side	Left side	Right side	Left side	Right side
Day	Left side	0.5539	7.55E-12	6.25E-12	0.598	1.16E-06	0.9621	0.03909
	Right side		5.97E-14	4.86E-14	0.893	3.29E-08	0.539	0.1611
Night	Left side			0.9751	1.67E-17	0.02199	1.71E-15	7.94E-25
	Right side				1.27E-17	0.02025	1.33E-15	5.74E-25
Warm light	Left side					4.83E-10	0.5795	0.07615
	Right side						1.42E-08	1.26E-15
Cold light	Left side							0.01994

Table 1. *Levels of statistical significance (p) of pair wise comparisons calculated (different lighting modes and sides of the gradient were compared as part of the analysis)*

Results and discussion

After evaluating molluscs activity, no difference was observed between the right and left sides of the aquarium in daylight and without light (Fig. 2). Therefore, the side of the aquarium did not influence the results of the experiments. At the same time, we observe that the molluscs move more actively in the no-light mode. In daylight, their activity is extremely low. The warm light (despite the difference in illumination at both ends of the aquarium) did not affect the locomotion of the molluscs, which remained at a low level, just like in daylight. When using cold light, we observe the relatively low activity of molluscs from the most illuminated end of the aquarium and the highest activity from the opposite side, while movement, in this case, is directed towards the light source.

Previous studies have repeatedly noted a positive reaction of some members of the Lymnaeidae family, namely *Radix peregra* (Müller, 1774) (Schepeleva 2013) *and Lymnaea stagnalis* (Linnaeus, 1758) (Van Duivenboden 1982), to artificial lighting. A similar reaction was also noted for *R. auricularia* (Rossetti and Cabanac 2006). However, these studies considered the intensity of the illumination, not its spectrum. In our study, we paid more attention to the spectrum of the light sources, revealing that both warm and cold light affect the activity of this species; but the lighting effects on molluscs is different. When the mollusc is placed on the side of the aquarium with a low intensity of cold light, it begins to actively move on the opposite side. When the intensity is higher, the mollusc demonstrates a slight increase in its motor activity (in comparison with warm light), which may indicate a preference for a higher intensity of artificial illumination of this spectrum (Rossetti and Cabanac 2006). When using warm light, activity remains at a low level both near the illuminated side and on the opposite side.

Lake Baikal is a reservoir with high water transparency (maximum 40 m) (Kozhov 1963; Kozhova and Izmesteva 1998), and since these species live at a depth of 0-30 meters, both long and short waves of visible light (Hunt, 1996) can affect them. However, the form of this impact will depend on the light sources close to the lake shoreline. A similar occurrence is true for very shallow water bodies, where representatives of this species can also be found.

Lymnaeid snails can serve as food for fish (Ivlev 1955), and if *R. auricularia* is exposed to cold light, these individuals will concentrate in an illuminated place, which will make the mollusc potentially visible to fish, which are actively attracted by artificial light in Lake Baikal (Takhteev et al. 2019).

Furthermore, the low mineral content (120 mg/l) of Baikal water can make the shell of molluscs fragile. This will facilitate the fish predation on molluscs. In warm light, a sudden appearance of a boat, (for example, when a boat with illumination from below appears in a given place) in a local place where there is a large population of molluscs, will, probably, lead to a sharp decrease in the motor activity of molluscs, making them more vulnerable to potential predators. Evidence also shows that the accumulation of snails around light sources can increase the risk of attack by predators (Hussein et al. 2021). Molluscs have neocular light receptors that are responsible for behavioural responses such as a shadow reflex, which is a defensive response to sudden falls in light, triggered by a shadow from a predator (Ramirez et al. 2011 г.). Consequently, prolonged exposure to light can cause *R. auricularia* to terminate the shadow reflex due to a large number of false positives (Hussein et al. 2021).

Exposure to longer photoperiods (than under natural lighting conditions) increases the fertility of the Lymnaeidae. For example, *L. stagnalis* individuals exposed to long daylight hours (16L:8D) produce 2-3 times more eggs than individuals under normal light conditions (12L:12D) (Ter Maat et al. 2007). With prolonged light pollution, as well as the absence of potential predators, namely large fish (this is possible in small water bodies), these factors can lead to an increase in population density, and then *R. auricularia,* as a species with a wide ecological valence, can begin to displace more vulnerable species. However, we are talking only if the increase in the photoperiod occurs due to artificial light sources with cold light, since it was shown that longer waves of visible light lead to the decrease in the fertility of representatives of this family (Kumar, Singh and Singh 2016). In our case, warm light differs from cold light precisely in that the peak of longer wavelengths of visible light is higher than that of shorter ones. In contrast, cold light has a higher peak in shorter wavelengths of visible light than longer wavelengths (Fig. 1).

At the moment, in the settlements on the shores of Lake Baikal, old incandescent lamps are being replaced with new LED lamps (or has it already happened). As we said earlier, this energy-saving trend may have a greater impact on organisms than older lamps. The Listvenichny and Kultuk bays are more affected by light pollution in Lake Baikal. However, an increase in the tourist load from the Republic of Buryatia could potentially increase the number of problem areas of the coastline.

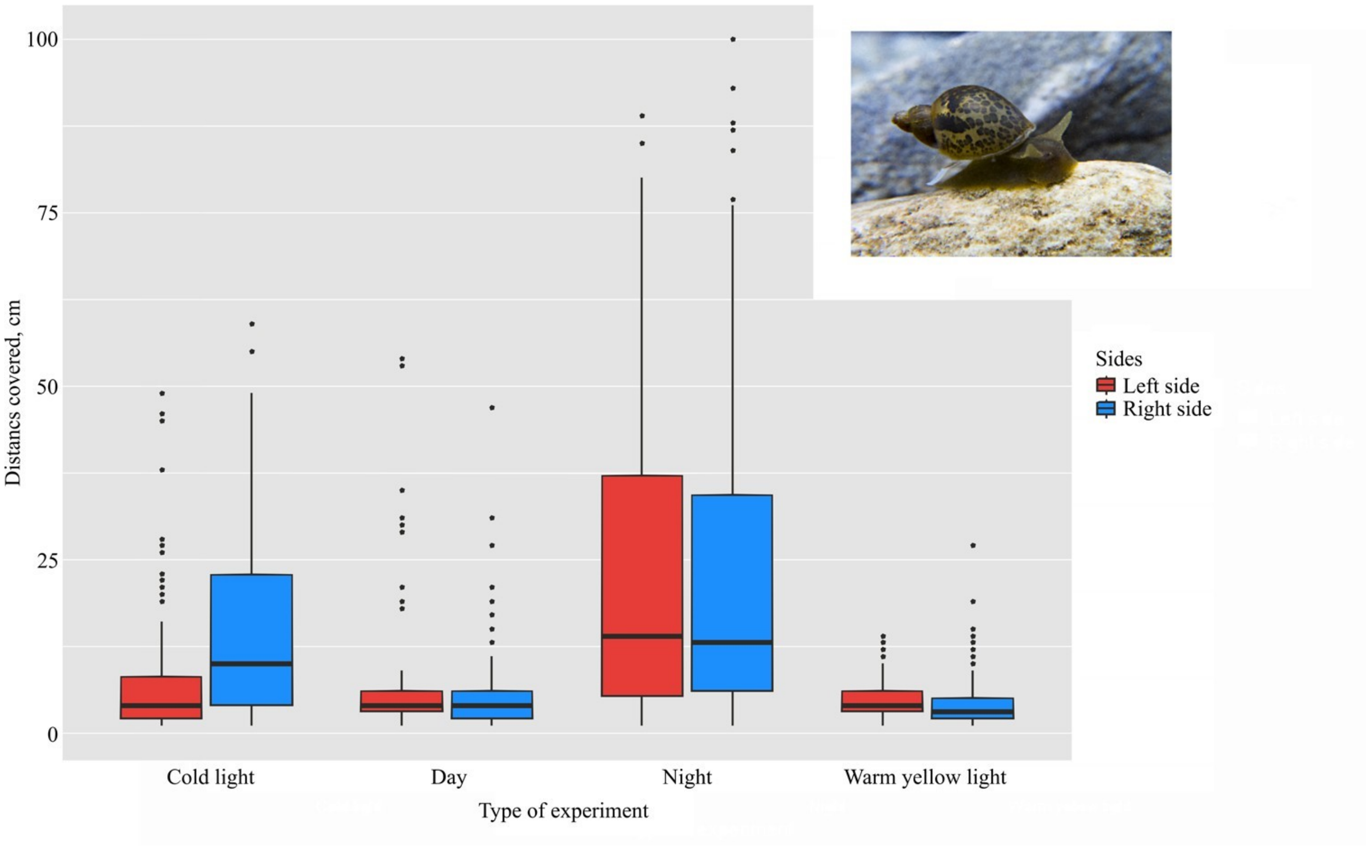

Figure 2. *R. auricularia activity under different types of illumination.*

Conclusion

Gastropods are a suitable group of animals for studying potential impacts on ecosystems, and the effects of light pollution (Manríquez et al. 2019; Manríquez et al. 2021). Exposure to light pollution can make *R. auricularia* more vulnerable to potential predators, dull protective shadow reflex. Depending on the size of the reservoir (and the presence or absence of predators), exposure to light pollution can increase their population growth, which can lead to the displacement of other species. Such behavioural changes can disrupt interspecies interactions and the functioning of the ecosystem (Underwood, Davies and Queirós 2017). In the latter case, special attention should be paid to a combination of some factors. An increase in surface water temperature or an excessive supply of organic matter from the coastline can actively contribute to the penetration of invasive species (Timoshkin 2001). These factors, when combined with light pollution, can increase the impact on the ecosystem. From our research, the intensity of artificial lighting is of particular importance and its spectrum. In future studies, it is worth paying attention to the spectral characteristics of light sources located near the shoreline of the reservoir.

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The author declare that they have no conflict of interest. All authors gave their consent to participate in this manuscript. All authors approve its publication.

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

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