

Light pollution affects the coastal zone of Lake Baikal

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Abstract: The role of light pollution in aquatic ecosystems functioning has increased in recent times. In addition, the effect of such pollution has mostly been studied in coastal marine ecosystems, leaving freshwater ecosystems much less studied. In the present work, we investigated the effect of light pollution on the coastal zone of the ancient Lake Baikal ecosystem. Both a laboratory experiment and field research were conducted. The results of the experiment showed the presence of statistically significant differences ($p=0.009$) between fish feeding on amphipods with and without daylight conditions, while there were no such differences between daylight and artificial light conditions. At the same time, video recordings revealed both a low number of specimens and a low species diversity of amphipods near to the village with a developed system of street lights, while in the village with a nearly nonexistent light system, the species diversity and a number of amphipods were much higher. One plausible explanation for such influence of light pollution on the quality and quantity of Baikal amphipod fauna might be the sum of several factors such as high water transparency and daily vertical migrations of amphipods.

Key words: amphipods, artificial light, Lake Baikal, light pollution

Introduction

Lake Baikal is a unique freshwater reservoir that differs from other lakes by age (25–30 million years), depth, water transparency (40 m), water volume, and its high number of endemic organisms (Kozhov 1963; Kozhova and Izvest'eva 1998). It was declared a UNESCO World Heritage Site in 1996. The coastal zone of the lake experiences high touristic and construction loads combined with increased street lighting. Amphipods comprise one of the dominant benthic groups in the lake (354 species and subspecies; Takhteev et al. 2015) and also actively participate at daily vertical migrations (Karnaukhov et al. 2016). Those migrations are especially pronounced in the littoral zone (Takhteev et al. 2019), which is highly affected by human activity.

The light pollution of water bodies has been actively studied during the last decades, yet mostly marine coastal ecosystems have been studied (Depledge et al. 2010; Davies et al. 2014;

Navarro-Barranco and Hughes 2015; Bolton et al. 2017; Sanders et al. 2021). It was discovered that light pollution changes the hydrobionts content (Davies et al. 2012), disorients specimens (Longcore and Rich 2004; Gaston et al. 2013), and concentrates them around light sources (Navarro-Barranco and Hughes 2015). Light pollution near lake ecosystems is much less studied (Moore et al. 2000). By taking into account a number of factors (i.e., high water transparency, daily vertical migrations of amphipods, intense lighting of the coastal zone), we examined the impact of artificial light of the coastal zone on the littoral functions of Lake Baikal. We implemented both visual observations in situ as well as a laboratory experiment. Where it was assumed that fish will see and feed on more amphipods under artificial lighting than at night without lighting, since the light contributes to the predation of fish. Consequently, this can lead to the eating of amphipods by fish in the illuminated areas of the littoral zone of Lake Baikal.

Materials and methods

Observations for nocturnal vertical migrations of amphipods were made on two areas, including Listvyanka village, which has a developed street lighting system and experiences a large traffic volume, and Bolshie Koty village, which is characterized by negligible lighting of the coastal zone (Table 1). In both cases, we selected three sites with similar conditions: no waves, the similar type of lake bottom at the observation points (that is, small pebbles) and a similar depth. At each of the sites, video surveillance was carried out three times, that is, nine video recordings were received near each of the villages. The remote video recording system with one light source was chosen to conduct the observations, and the system was immersed up to 0.5 m and recorded for 15 minutes. The processing of the video record was done according to the previously implemented method (Karnaukhov et al. 2016; Takhteev et al. 2019). The 15-minute video records were divided into 1-minute chunks, and the average number of migrating individuals in the freeze-frame was calculated for each minute. Statistical analysis (including both observations and results of the experiments) was conducted in the program Past 3.x. The data were first checked for normal distribution using the Shapiro-Wilk test. Since the data on the number of amphipods at the points turned out to be nonparametric, we used a combination of the Kruskal-Wallis test with Mann-Whitney's U-test with Bonferroni's correction. For a similar reason, we used a similar combination to analyze the results of the experiment.

Amphipods were caught in the vicinity of the recording system right after the video recording took place in order to quantify the species composition. For this, a Jedi plankton net with an inlet diameter of 0.25 m (mesh diameter of 300 µm) was used.

For the experimental part of the study, five specimens of fish *Leocottus kesslerii* Dybowski,

1874 and many amphipods *Gmelinoides fasciatus* Stebbing, 1899 were caught. All experiments (three parts each) were done after acclimation. Acclimation was carried out at a temperature of 12°C for 10 days. The first part of the experiment was performed in the aquarium: 20 specimens of *G. fasciatus* were planted on each of 5 fish and placed in daylight (860 lux) for one hour (Fig. 1). After that time, the fishes were replaced, and the remaining amphipods were counted. The second and third parts of the experiment were done similarly, but in the second part, we used artificial light (5 lux), and in the third, the experiment was performed without light. This series of experiments was carried out three times (for the second and third times, other fish were used).

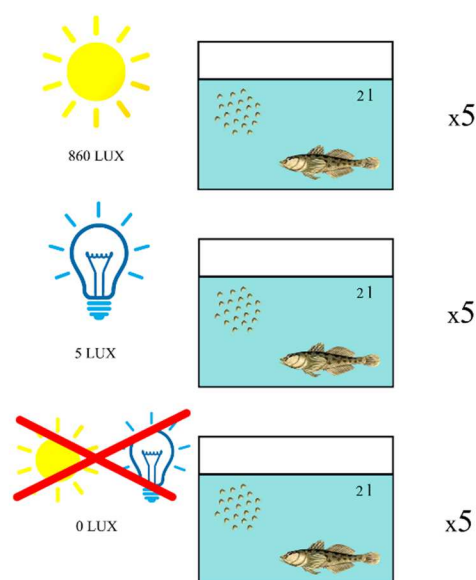


Fig. 1. Scheme of setting up an experiment with fishes and amphipods

For control, the level of illumination during the experiments, as well as to measure artificial illumination in the natural environment, a lux meter (CEM DT-8809A) was used.

Table 1. Video recording sites (* intermittent exposure, ** control)

No.	Name of site	Light pollution level at point [Lux]	Coordinates
1	BK1	2.5	51°54'11.4"N 105°04'12.1"E
2	BK2	1.5*	51°54'10.6"N 105°04'14.7"E
3	BK3**	0	51°54'11.5"N 105°04'22.0"E
4	L1	5.2	51°51'04.6"N 104°52'01.1"E
5	L2	5.1	51°50'40.7"N 104°52'33.3"E
6	L3	4.6	51°50'39.3"N 104°52'35.2"E

Results and discussion

Amphipods of Lake Baikal make vertical migrations to the water surface at night (Karnaukhov et al. 2016; Takhteev et al. 2019). As it was suggested, the migratory complex of amphipods of the coastal zone near Bolshie Koty village was richer than near Listvyanka village, both in terms of migrants (Fig. 2) and a number of species. The net-catches showed the following migrating species at the Bolshie Koty site: *G. fasciatus*, *Pallasea canceloides* Gerstfeldt, 1858, *Brandtia parasitica parasitica* Dybowsky, 1874, *Macrohectopus branickii* Dybowsky, 1874 (the influence of light pollution on this species was also established by us earlier; Karnaukhov et al. 2019), *Micruropus* sp. and *Eulimnogammarus* sp. Only *G. fasciatus* and *Micruropus* sp. were caught at the Listvyanka village site. The results of Mann-Whitney's test with Bonferroni's correction (Table 2) showed differences between all video recordings besides L1 and L3 (there are no differences between those points). It should be mentioned that in all three observations in Listvyanka village, the mean number of migrants did not exceed 0.5 specimens per freeze frame.

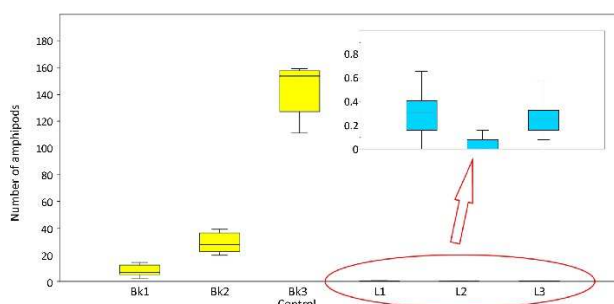


Fig. 2. Mean number of amphipods in front of the camera. BK1, BK2, BK3 – sites in Bolshie Koty; L1, L2, L3 – sites in Listvyanka village

Table 2. Levels of statistical significance (p) of pair wise comparisons calculated with Mann-Whitney's U-test with Bonferroni's correction (* – differences statistically not significant)

	L3	L2	L1	BK3	BK2
BK1	5.53E-05	3.29E-05	6.33E-05	0.003319	0.000278
BK2	3.11E-05	1.92E-05	3.53E-05	0.002694	
BK3	0.001036	0.000544	0.001213		
L1	0.4125*	6.04E-05			
L2	1.37E-05				

It has already been noted for seawater bodies that organisms performing diel vertical migrations are more vulnerable (Navarro-Barranco and Hughes 2015). Organisms leave their daytime shelters when migrating. However, under artificial lighting conditions, they become visible to

potential predators. In such conditions, the transparency of the water will be the factor that will facilitate the penetration of light to big depths at night (Jechow and Hölker 2019).

The explanation of the data obtained by video surveillance is confirmed by the data obtained during the experiment. For the experiment, we used artificial lighting at a level of 5 lux (according to some reports, even 1 lux can affect the behavior of fish; Riley et al. 2015), which approximately corresponds to the light effect on the littoral of the lake near the village of Listvyanka or is comparable to finding a powerful light source at a distance of 15 m from the edge of the lake (Falcon et al. 2020). The experiment results (Fig. 3) showed that without light, fish did not see amphipods and did not eat them, while under daylight conditions, amphipods were eaten. This was confirmed by the results of Mann-Whitney's U-test with Bonferroni's correction that showed significant differences ($p=0.009$) between fish feeding with and without light and for both daylight and artificial lighting conditions. At the same time, there were no significant differences between fish feeding with artificial light and daylight ($p=0.058$).

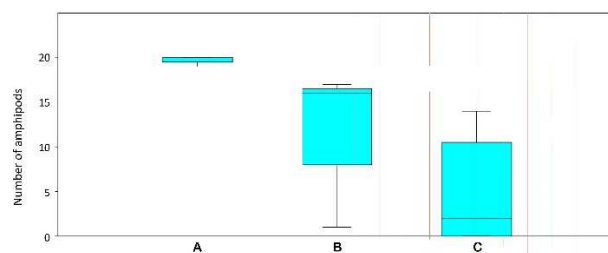


Fig. 3. Number of non-eaten amphipods under different experimental light conditions in the laboratory: A – no light; B – artificial light; C – day light (Scatter of data for remaining amphipods and standard error)

At the moment, light pollution is negatively affecting the Baikal ecosystem. However, there are already examples of using various sources of artificial lighting in aquaculture (Kehayias et al. 2016; Roh et al. 2018). It is possible that over time, aquatic facilities will appear on Lake Baikal, using artificial lighting for good purposes. However, this requires a lot of experimentation in order to study the effect of light pollution in all aspects.

Conclusion

Light pollution strongly affects the coastal zone of Lake Baikal. On the basis of the obtained data, the effect of light pollution might be divided into two categories: the decrease of the species richness

(which requires additional studies) and the decrease of benthic amphipod numbers. The number of villages with developed street lighting systems is not high, but with increasing numbers of tourists and the development of infrastructure in the coastal zone, such pollution will continue to grow. It is likely that the major role in the light pollution rapid development in Lake Baikal belongs to such factors as high water transparency and daily vertical migrations of the major group of zoobenthos (amphipods) that make them flow to the upper water layers, including those that are strongly illuminated where they become easy prey for the predators.

Acknowledgments

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References

- Bolton D., Mayer-Pinto M., Clark G.F., Dafforn K.A., Brassil W.A., Becker A., Johnston E.L., 2017, Coastal urban lighting has ecological consequences for multiple trophic levels under the sea, *Sci. Total Environ.* 576: 1–9.
- Davies T.W., Bennie J., Gaston K.J., 2012, Street lighting changes the composition of invertebrate communities, *Biol. Lett.* 8(5): 764–767.
- Davies T.W., Duffy J.P., Bennie J., Gaston K.J., 2014, The nature, extent, and ecological implications of marine light pollution, *Front. Ecol. Environ.* 12(6): 347–355.
- Depledge M.H., Godard-Coddling C.A.J., Bowen R.E., 2010, Light pollution in the sea, *Mar. Pollut. Bull.* 60(9): 1383–1385.
- Falcón J., Torriglia A., Attia D., Viénot F., Gronfier C., Behar-Cohen F., Martinsons C., Hicks D., 2020, Exposure to artificial light at night and the consequences for flora, fauna, and ecosystems, *Front. Neurosci.* 14: #602796.
- Gaston K.J., Bennie J., Davies T.W., Hopkins J., 2013, The ecological impacts of nighttime light pollution: A mechanistic appraisal, *Biol. Rev. Camb. Philos. Soc.* 88(4): 912–927.
- Jechow A., Hölker F., 2019, How dark is a river? Artificial light at night in aquatic systems and the need for comprehensive night-time light measurements, *WIREs Water.* 6(6): e1388.
- Karnaukhov D.Yu., Bedulina D.S., Kaus A., Prokosov S.O., Sartoris L., Timofeyev M.A., Takhteev V.V., 2016, Behaviour of lake Baikal amphipods as a part of the night migratory complex in the Kluevka settlement region (South-Eastern Baikal), *Crustaceana* 89(4): 419–430.
- Karnaukhov D., Dolinskaya E., Biritskaya S., Teplykh M., Khomich A., Silow E., 2019, effect of artificial light on the migratory activity of the pelagic amphipod *Macrohectopus branickii* during daily vertical migration in Lake Baikal, *Ecol. Environ. Conserv.* 25(4): 1693–1695.
- Kehayias G., Bouliopoulos D., Chiotis N., Koutra, P., 2016, A photovoltaic-battery-LED lamp raft design for purse seine fishery: Application in a large Mediterranean lake, *fish. Res.* 177: 18–23.
- Kozhov M., 1963, Lake Baikal and its life, W. Junk Publishers, Hague, 344 pp.
- Kozhova O., Izmet'seva L., 1998, Lake Baikal: Evolution and biodiversity, Backhuys Publishers, Leiden, 447 pp.
- Longcore T., Rich C., 2004, Ecological light pollution, *Front. Ecol. Environ.* 2(4): 191–198.
- Moore M.V., Pierce S.M., Walsh H.M., Kvalvik S.K., Lim J.D., 2000, Urban light pollution alters the diel vertical migration of *Daphnia*, *Verh. Int. Ver. Theor. Angew. Limnol.* 27(2): 779–782.
- Navarro-Barranco C., Hughes L.E., 2015, Effects of light pollution on the emergent fauna of shallow marine ecosystems: Amphipods as a case study, *Mar. Pollut. Bull.* 94(1-2): 235–240.
- Riley W.D., Davison P.I., Maxwell D.L., Newman R.C., Ives M.J., 2015, A laboratory experiment to determine the dispersal response of Atlantic salmon (*Salmo salar*) fry to street light intensity, *Freshw. Biol.* 60(5): 1016–1028.
- Roh H.J., Kim A., Kang G.S., Kim B.S., Kim D.H., 2018, Blue light-emitting diode light at 405 and 465 nm can inhibit a *Miamiensis avidus* infection in olive flounder, *Paralichthys olivaceus*, *Aquaculture* 493: 176–185.
- Sanders D., Frago E., Kehoe R., Patterson C., Gaston K.J., 2021, A meta-analysis of biological impacts of artificial light at night, *Nat. Ecol. Evol.* 5(1): 74–81.
- Takhteev V.V., Berezina N.A., Sidorov D.A., 2015, Checklist of the Amphipoda (Crustacea) from continental waters of Russia, with data on alien species, *Arthropoda Sel.* 24(3): 335–370.
- Takhteev V.V., Karnaukhov D.Yu., Govorukhina E.B., Misharin A.S., 2019, Diel vertical migrations of hydrobionts in the coastal area of Lake Baikal, *Inland Water Biol.* 12(2): 178–189.