How does artificial lighting at night (ALAN) influence stream ecosystem metabolism?

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ABSTRACT

Artificial lighting at night (ALAN) has become a pervasive environmental stressor at a global scale. Current research suggests that ALAN may impair individuals and populations in freshwater systems, but little research to date addresses effects of ALAN on stream ecosystem functioning. We examine impacts of a range of nighttime light intensities and spectral compositions on stream metabolism, with goals of: (1) observationally assessing changes in stream metabolism over 12 months in streams exposed to long-term street-lighting, (2) continuing assessments for 6 months after light is experimentally removed at a subset of sites, and (3) identifying mechanisms underlying leaf-litter decomposition changes (laboratory and field experiments). Early data suggest that benthic primary productivity and P:R ratios may increase at relatively high light intensity, as indicated by both a lab study of diatom growth under ALAN and a field study investigating the contribution of aquatically-derived energy to aquatic invertebrate consumers. We anticipate a reduction in respiration and leaf-litter decomposition rates under ALAN (the latter via top-down controls) and a short time lag in convergence with metabolic rates observed in dark (control) systems after light removal. Understanding consequences of ALAN for key ecosystem processes will be critical to developing integrative stream management plans.

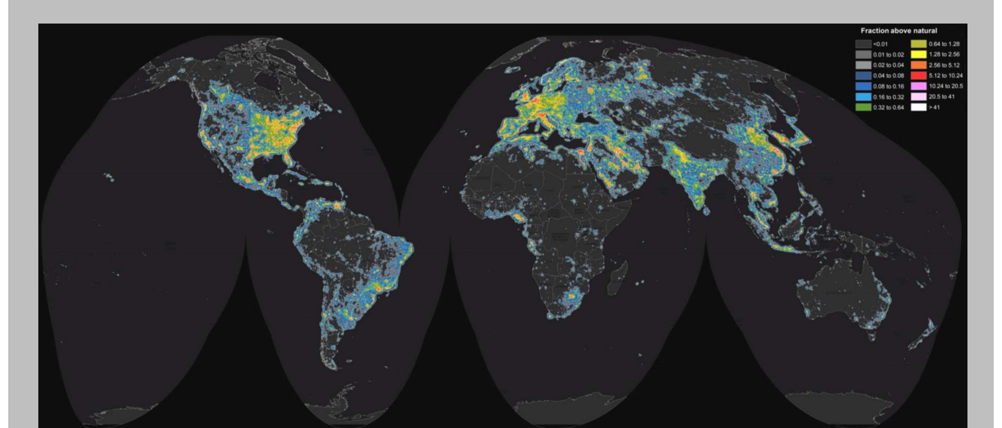


Figure 1. World map of artificial sky brightness relative to average natural sky brightness (assumed to be 174 μcd m^{-2}). Colors indicate fraction above natural brightness.[1]

BACKGROUND

- Artificial light at night (ALAN) is becoming increasingly pervasive worldwide.[1,2]
- ALAN can act as a substantial disturbance to ecological systems, including stream ecosystems.[3,4,5]
- Research suggests that ALAN can cause changes at the individual, population, and community levels,[6,7,8] but little research has addressed ecosystem-level effects.
- ALAN has been shown to alter stream microbial communities and respiration[8,9] and the contribution of aquatically-derived energy to aquatic invertebrate communities,[10] with potential implications for ecosystem production and respiration.

OBJECTIVES & RESEARCH QUESTIONS

Overarching objective
Quantify the effects of ALAN on stream metabolism and identify top-down mechanisms that drive a particular representative of those effects.

Phase 1:
1. Does ALAN influence stream ecosystem metabolism (productivity and respiration)?
2. How long does it take for these values to converge with levels observed in dark systems after lighting is experimentally removed?

Phase 2:
What top-down mechanisms control the effects of ALAN on leaf-litter decomposition?

STUDY SYSTEM

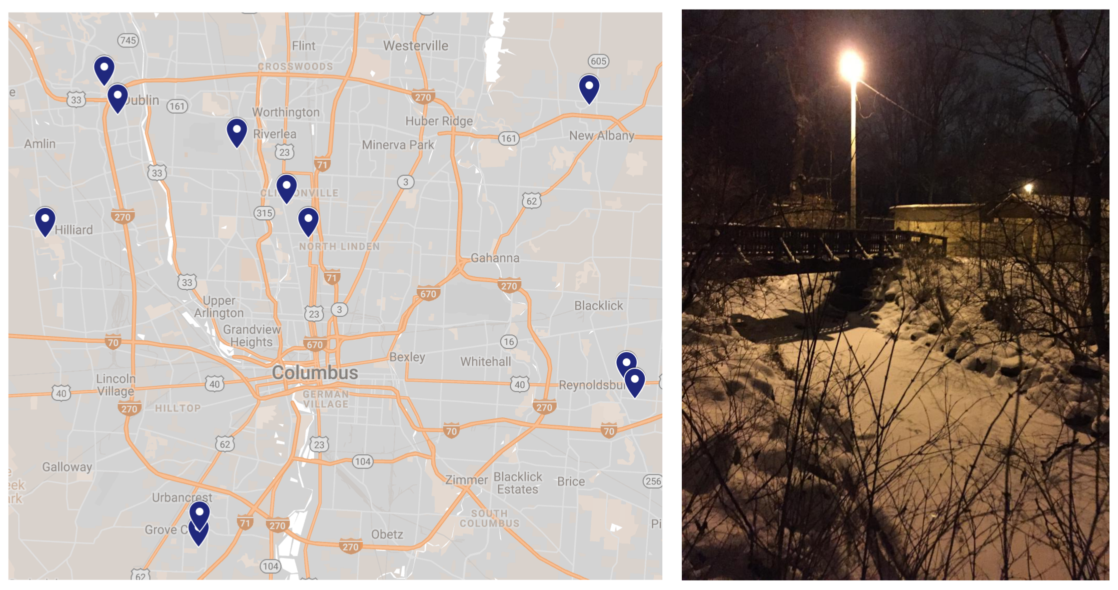


Figure 2. Eleven study sites are distributed throughout the Columbus, OH metropolitan area. Light varies in intensity, type (e.g., LED, HPS), and spectral composition across sites.

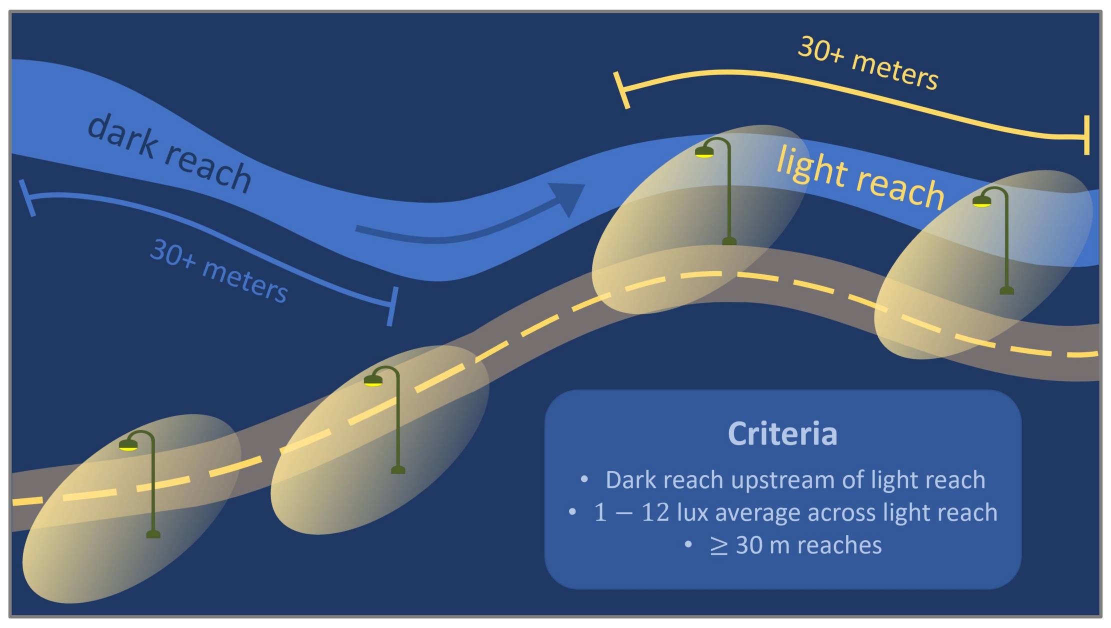


Figure 3. Study sites are exposed to existing light sources (e.g., street lights, parking lot security lights). Unlit upstream reaches and lit downstream reaches are paired for future analysis and comparison.

METHODS

OBJECTIVE 1 *(ALAN effects on stream productivity and respiration)*

Whole-stream gross primary productivity (GPP) and ecosystem respiration (ER)

- Collect dissolved oxygen (DO) and light intensity data every 5 min for 24-48 h
  - Use DO data or modeling to estimate reaeration coefficient (K)
- Estimate GPP and ER using reverse modeling based on the fundamental metabolism equation:

$$O_i = O_{i-\Delta t} + \left(\frac{GPP}{z} + \frac{ER}{z} + K_O\left(O_{sat(i-\Delta t)} - O_{i-\Delta t}\right)\right)\Delta t$$ [11,12]

using the streamMetabolizer R package[13]

Benthic primary productivity and standing stock

- Estimate benthic algal primary productivity based on rate of periphyton growth on unglazed tiles using ash-free dry mass (AFDM) and chlorophyll-*a* content
- Estimate periphyton standing stock using AFDM and chl-*a* content of samples taken from natural substrate

Substrate-specific microbial respiration

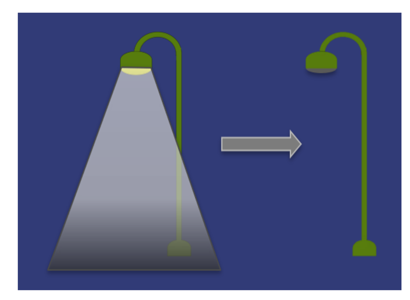
- Measure oxygen consumption rate of leaf litter and fine benthic organic matter samples in the laboratory

Leaf-litter decomposition

- Measure rate of leaf-litter breakdown over the course of 3-6 weeks in the field

Light removal

- Remove or cover light at a subset of sites after 12 months
- Continue to collect all data for an additional 6 months
- Compare to paired unlit reaches



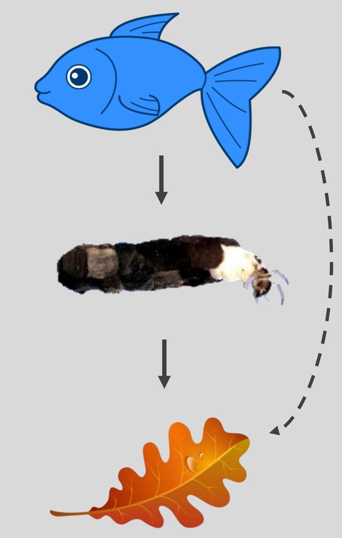
OBJECTIVE 2 *(top-down controls of ALAN effects on leaf-litter decomposition)*

Macroinvertebrate shredders

- Experimentally expose macroinvertebrate shredders to a suite of ALAN light intensities and spectral compositions in the laboratory
- Measure associated rate of leaf litter breakdown by shredders

Insectivorous fish

- Experimentally exclude fish from half of leaf packs in field leaf-litter breakdown study
- Compare breakdown rates across light regimes and fish treatments



PRELIMINARY RESULTS

Primary productivity

- In an experimental laboratory study using a range of LED light intensities (0-12 lux), diatom GPP increased from control levels under the low light level treatment (2-4 lux).[14]

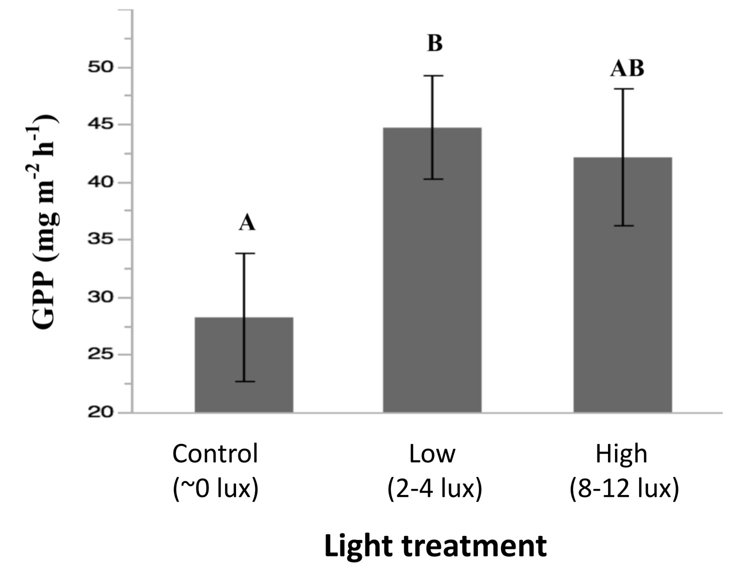


Figure 4. Diatom productivity averaged over the experiment among control (~0 lux), low (2-4 lux), and high (8-12 lux) treatments for GPP ($F_{2,140}$ = 4.78, p = 0.038). Letters over each bar represent linear contrasts, whereby different letters indicate significant differences in GPP. Error bars represent ±1 SE from the mean.[14]

Aquatically-derived energy contribution

- An observational study showed that aquatically-derived (i.e., originating from aquatic primary producers) energy contribution to aquatic invertebrate communities increased at the highest category of light intensity (2.1-4.0 lux).[10]
- This may suggest a shift from stream heterotrophy (P:R<1) to autotrophy (P:R>1) under relatively high-light conditions.

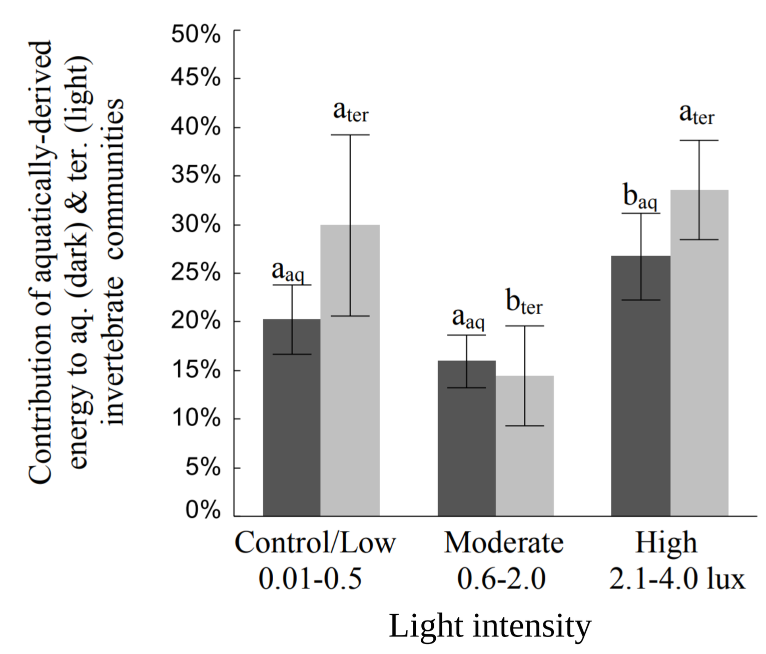


Figure 5. The contribution of aquatically-derived energy to aquatic invertebrate communities increased at high ALAN levels (dark gray bars; χ^2 = 8.27, p = 0.016, df = 2) and decreased at moderate ALAN levels in the terrestrial invertebrate community (light gray bars; χ^2 = 9.38, p = 0.009, df = 2).[10]

ADDITIONAL EXPECTED RESULTS

Respiration

- We expect respiration (in the form of ecosystem respiration, substrate-specific microbial respiration, and leaf-litter decomposition rates) to:
  - decrease with increasing light intensity (due to net suppression of community activity)
  - decrease under LED lights relative to HPS lights (due to broader spectrum and overlap with visual spectra of stream fauna)
- We expect the presence of insectivorous fish to reduce leaf litter decomposition rate under all conditions, and more dramatically under ALAN.

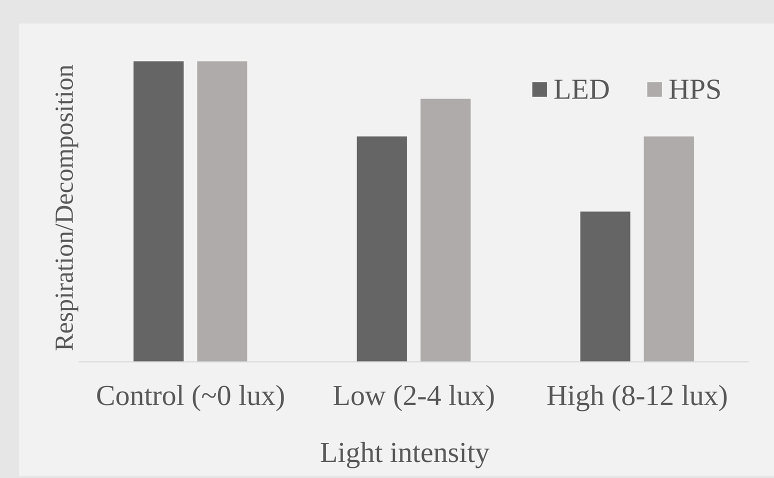


Figure 6. Expected changes in respiration and decomposition rates under a suite of ALAN light regimes.

SIGNIFICANCE & APPLICATION

- Increasingly, research shows that ecosystem functions are better indicators of overall stream integrity and water quality than conventional community and population measures.[15]
- Findings from this study will be translated into best management practices and applied directly to the Ohio Department of Transportation's roadway lighting designs.
  - This partnership provides a model for collaboration between scientists and state agencies to integrate emerging watershed science into urban planning.

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