2016 Animal Responses to Light Meeting Report

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DISCLAIMER

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Participants

Jim Brodrick	U.S. Department of Energy
Joel Chaddock	National Energy Technology Laboratory
Julie Delabbio	ONCE Inc.
Bob Dauchy	Tulane University
Ben Frater	U.S. Fish and Wildlife Service
Joelle Gehring	Federal Communication Commission
John Hanifin	Thomas Jefferson University
Eric Haugaard	Cree
Tom Katona	California Polytechnic State University, San Luis Obispo
Don Lay	U.S. Department of Agriculture – Agricultural Research Service
Lira Luis	Zoological Lighting Institute
Mark Milby	Midwest Energy Efficiency Alliance
Morgan Pattison	SSLS, Inc.
Jay Penniman	University of Hawaiʻi
Jody Purswell	U.S. Department of Agriculture – Agricultural Research Service
Wouter Soer	Lumileds
Karen Trevino	U.S. National Park Service
Jason Tuenge	Pacific Northwest National Laboratory
Jeremy White	U.S. National Park Service
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Interested Colleagues

Sandra Allan	U.S. Department of Agriculture – Agricultural Research Service
Courtney Daigle	Texas A&M University
James Fischer	Zoological Lighting Institute

Table of Contents

1. Introduction

On April 19th, 2016, ten experts in fields related to animal physiological responses to light gathered with light-emitting diode (LED) manufacturers and the DOE Solid-State Lighting (SSL) Program for a discussion of common research themes, research challenges, and paths forward to better understand the broad topic of animal responses to light. The meeting, hosted by the Midwest Energy Efficiency Alliance (MEEA) in Chicago, Illinois, commenced with "soapbox" presentations, where each participant was invited to give a short presentation describing their field of expertise and forward-looking research concepts. This was followed by a general discussion of research and development opportunities for SSL that potentially benefit productivity and wellbeing of livestock and minimize impacts of light on wildlife and landscape ecology. This report is a summary of the input provided at this meeting and the subsequent discussions.

Key Conclusions

Based on the presentations from the attendees and the subsequent discussion, animal physiological response to light represents a complex interaction that would benefit from dedicated research efforts. The meeting focused on three fields of animal research: livestock productivity and wellbeing, wildlife and landscape ecology, and animal testing for human medical research. While each faces unique challenges, the attendees indicated that SSL research should focus on determining what lighting spectrum, control protocol, distribution, and intensity are necessary for the desired benefit. This understanding would enable development of SSL products that increase wellbeing and productivity of livestock, minimize wildlife and ecological impacts, and improve the effectiveness of human medical research. Potential research topics could include:

- **Applied Research –** Conducting research on: hormonal and eye (visual and/or non-visual) responses to light; light intensity and spectral triggers impacting biological rhythms, ecology, feeding-prey, and/or nesting cycles; new and updated animal eye response curves.
- **Product Development –** Development of correlated color temperature (CCT) tuning and adaptive controls for livestock, wildlife and animal testing for human medical research.
- **Technology Demonstration –** Demonstration of productivity and/or ecological benefits and deployment of adaptive controls to minimize total emitted light for naturally dark settings.

In addition to research needs, it was also emphasized that DOE's facilitation and collaborative presence within these research groups is helpful. It was suggested that DOE help to coordinate lighting education, advocacy and community organization, test methods and standards, as well as demonstration projects to improve understanding of how lighting impacts humans, livestock, plants, and animals.

The following sections summarize attendee presentations and input regarding the critical challenges and suggested research needs for lighting impacts on livestock productivity and wellbeing (section 2), wildlife and landscape ecology (section 3), and human medical research (section 4). Additionally, a group of LED manufacturers and experts provided an overview of the technology, performance metrics, and criteria used to specify lighting applications (section 5).

2. Livestock Productivity and Wellbeing

Discussion

LED lighting that offers sophisticated control and tunability (i.e., dynamic tailoring of light spectrum, intensity, and distribution) has the potential to significantly impact livestock productivity and wellbeing. Lighting has been shown to reduce stress and increase disease resistance, resulting in happier and healthier animals. However, participants agreed that more research is needed to fully understand the potential behavior and physiological benefits in poultry, swine, cattle, and fish. Research exploring the impacts of natural daily, seasonal, and geographical lighting cycles, and developing LED products that mimic these spectra, could enable increased productivity by stimulating targeted behaviors such as growth or reproduction. Providing customized lighting programs based on the life phase or age of an individual species was also identified as crucial for livestock lighting. In addition, as more of the livestock industry moves towards "light tight" facilities to prevent against bio-security concerns such as avian flu, dependence on artificial lighting that mimics the natural environment increases.

Participant Presentations

Don Lay of the U.S. Department of Agriculture – Agricultural Research Service (USDA-ARS) presented an overview of the Livestock Behavior Research Unit's animal welfare research, expertise and focus. Covering three species (swine, cattle, and poultry), the group studies immunology, physiology, ethology and the neuroscience of these animals to improve their wellbeing. Don indicated that lighting as a treatment for livestock has a big impact and requires further research. Recent projects have considered how light intensity can be used to help mitigate piglet crushing in farrowing rooms. It was found that crushing can be reduced by controlling light and heat lamp interaction.

In addition, Lay presented research conducted by Courtney Daigle of Texas A&M University. Daigle emphasized the importance of providing livestock with a dynamic environment that offers lighting schedules, intensities, and spectrums that will enhance the welfare state of these animals. In particular, the use of LED lighting in agriculture presents an opportunity to develop and create microhabitats that stimulate the performance behaviors where and when they are needed for optimal production.

Julie Delabbio of ONCE Inc. discussed the importance of providing lighting systems that are customized and species-specific to increase the production of livestock. ONCE Inc. focuses on creating spectrum and intensity tunable lighting products that are designed for the agriculture market. LED lighting not only offers energy and cost savings, but can have a tremendous impact on wellbeing and productivity. The controllability of LED systems enables lighting programs and schedules that are optimum for the animal, considering the unique photoreceptors and light history of every species, while also accommodating human care-giver and process needs.

Jody Purswell, of USDA- ARS Poultry Research Unit, Mississippi State, largely focuses his research on how lighting impacts the biological response of broiler chickens. Lighting is the second largest expense in a broiler house behind ventilation, and many have converted from using incandescent to compact fluorescent lamps (CFLs). Unfortunately, in addition to performance issues with CFLs in broiler houses, this lighting technology is not optimized for poultry and has resulted in reduced wellbeing and productivity. As the cost of converting to an LED lighting system has decreased, more and more broiler houses are being retrofitted to utilize LED technology. Purswell cautioned that as more broiler houses move to LED, it is important that these products offer uniform illumination and deliver on their performance claims. Often, advertised productivity benefits are not experienced in the field.

3. Wildlife and Landscape Ecology

Discussion

Outdoor lighting is known to impact a variety of wildlife, including, but not limited to, migratory birds, seabirds, bats, amphibians, sea turtles, and insects. Research has only begun to uncover how artificial lighting distracts certain species. However, the impacts of this distraction are significant, and millions of fatalities for several threatened and endangered species result from disruptions in navigation and prey detection. More research is needed to uncover how lighting can be controlled, and if certain spectra can be used, to minimize interference with wildlife in different settings. In addition to wildlife, outdoor night lighting threatens the natural landscape ecology of our wilderness areas via sky glow. Light pollution from urban areas can be detected hundreds of miles from the source. The optical distribution and spectral control offered by LED technology combined with the use of controls can enable night lighting that is optimized for reduced sky glow and human activity simultaneously. The development of LED lighting solutions offers a tremendous opportunity for conservation of wildlife and landscape ecology. The ability to economically implement adaptive lighting and remote monitoring and control technologies will help biologists react and modify the night lighting spectra based on wildlife behavior documented in the field. In addition, using LED technology as a research tool has given researchers the ability to develop a more refined basic understanding of how different species respond to light.

Participant Presentations

Ben Frater of the U.S. Fish and Wildlife Service (FWS) discussed one of the Agency's recent applications of sea turtle lighting in the northern Gulf of Mexico. Hatchling response to visible light was first recognized in the 1950's, and by 1990's this attraction was determined to be for short wavelengths only. Given sea turtle sensitivities to short wavelengths, outdoor amber LED lighting (with longer wavelengths) offers the potential to reduce nesting disturbance and hatchling disorientation in addition to other benefits associated with LED lighting such as better control of light distribution and lower energy and maintenance costs. In Pensacola, Florida metal halide lighting in a shore-side parking lot was replaced by lower intensity amber LEDs, and the reduction in sky glow was significant. While there are still issues with the surrounding commercial metal halide and low pressure sodium lighting, FWS is currently monitoring this amber LED retrofit project, along with several others, to measure the impact on the loggerhead sea turtle population.

Lira Luis, of the Zoological Lighting Institute (ZLI), presented the wildlife lighting and LED research needs identified by the ZLI. The ZLI would like to see further development of narrow band LED products that can be optimized for animal physiology and vision. Luis also stressed the importance of low intensity and low frequency LED light that deliver and control UV-A and UV-B emissions. The development of these characteristics for LED lighting will help to better mimic natural lighting conditions and address the ecological challenges of lighting in wildlife conservation.

Jay Penniman, of the University of Hawai'i, manages a project focused on the recovery of seabirds in Maui County and the state of Hawaii. Over the last ten years this project has responded to more than 1,000 downed seabirds. Research has begun to clarify how artificial light can pose a threat to birds; however, the majority focuses on passerines, or land birds. Seabirds spend most of their lives in the marine environment, and their vision has evolved differently. Brighter, full spectrum outdoor lights disrupt seabird orientation mechanisms causing some to deviate from their flight paths. More research is needed to understand the behavioral responses of seabirds to anthropogenic light sources. This research should not only investigate spectral sensitivity, but also identify the components of light which mimic stimuli for positive behaviors (e.g., bio-luminescence indicating prey availability). Further studies are needed to document effective strategies at reducing or eliminating seabird distraction.

Joelle Gehring, of the Federal Communication Commission (FCC), discussed the issue of bird collisions with tall structures – namely communication towers. Wildlife biologist have determined that migratory birds are attracted to lights used at night to warn pilots of a tower or other hazards, and they appear to be more attracted to steady-burning lights. Estimates indicate that this attraction has led to 7 million migratory songbird collisions with U.S. communications towers. Based on recommendations made by wildlife organizations and the FCC, the Federal Aviation Association (FAA) has issued revised specifications that eliminate the non-flashing lights on towers taller than 150 feet thereby reducing attraction to migratory birds without compromising pilot safety. It is estimated that this new requirement will reduce bird collisions and resulting fatalities by 70% each year. The advancement of LED lighting and the energy savings and controllability benefits over the existing incandescent and xenon lighting systems were all important factors that helped drive the new FAA regulation. While LEDs are the best option for reprograming the non-flashing to flashing FAA requirement, more research is needed to determine which spectra cause disruptive, benign, and beneficial impacts to migratory birds.

Karen Travino and Jeremy White of the National Park Service (NPS) Natural Sounds and Night Skies Division discussed their mission to conserve the natural lightscapes of parks and employ sustainable outdoor lighting practices, as well as the strategies and projects they have implemented in pursuit of this mission. One of the main focuses of the Night Skies Program has been scientific research into the impacts of outdoor lighting and sky quality. This research has involved measuring the photic environment from parks and protected lands to establish baseline night sky quality conditions. This effort has determined that sky glow measured in national parks often results from cities, and sky glow has been measured that originates from cities up to 300 kilometers away. While LED lighting offers energy savings, there is concern that the technology increases glare and sky glow since blue light is thought to scatter more in the atmosphere.

However, it was noted that energy saving LED lighting can be made with reduced blue content (similar to the amber LED seashore installations near loggerhead sea turtle habitat) and can be engineered to limit upward light emission. Additionally, LED technology is inherently controllable, enabling the use of adaptive controls to further minimize the total amount of light emitted into the environment.

Going forward, Travino and White stressed the need for more research into the ecological impacts of outdoor lighting. This includes further research into impacts of large area outdoor lighting (e.g., oil and gas platforms and large wind farms), spectral response of invertebrates and other species of concern, and the temporal relationship between the duration of exposure and duration of impact.

4. Human Medical Research

Discussion

Recent research shows that the lighting environment that laboratory rodents experience during testing impacts the results of human medical research. The circadian rhythms entrained by the lighting cycle and spectrum can have measureable impacts on the outcomes of laboratory animals. This creates significant implications for human pharmaceutical research and drug testing since laboratory facilities likely utilize different lighting systems, which could result in different experimental outcomes. This effect also highlights the potential impact of timing therapy delivery within the entrained circadian rhythm.

Participant Presentations

John Hanifin of the Lighting Research Program at Thomas Jefferson University discussed the light spectrum regulation of photoperiodism in laboratory rodents. Early research showed that certain wavelengths appeared to cause a reduction in organ weight and degrade the overall health of exposed rodents; however, the understanding of these mechanisms has only recently been uncovered. The use of LED lighting has expanded this research, and has led to a greater understanding of how the biological and behavioral effects of light are influenced by photoreceptors in the eye. In particular melanopsin-containing intrinsically photosensitive retinal ganglion cells (ipRGCs) play an important role in addition to the conventional rods and cones within the eye. Given this newly described sensory pathway, Hanifin expressed the importance of considering the non-visual effects of light in the design and operation of human environments, as well as those for domesticated research animals. While LEDs provide tremendous potential for energy savings, their spectral tunability also presents new opportunities for care and maintenance of different animal species.

Robert Dauchy with Tulane University School of Medicine presented his research investigating the influence of daytime blue-enriched LED lighting on laboratory animal health and wellbeing. In a study focusing on rodents used for human medical research, Dauchy found that exposure to blue light during the daytime resulted in the amplification of nighttime melatonin. An increase of roughly 6 to 8x was measured for rodents exposed to a 5000K LED system compared to a 4100K fluorescent system. In addition to the rise in nighttime melatonin, the animals also showed improved dietary/water intake, growth rates, circadian rhythms, as well as greater resistance to cancer metabolism.

5. LED Industry and Technology Overview

Discussion

LED lighting technology enables important benefits beyond energy savings and reduced cost of ownership. The optical distribution of LED light sources can be very well controlled, limiting the amount of light outside the target area. LED lighting technology is inherently controllable. It can be turned off and on instantaneously without the need for restrike time and can be dimmed readily. The spectral power distribution of LED lighting can also be engineered based on the requirements of the application and products can even be designed to have a tunable spectrum. These new features enabled by LED technology offer the possibility to develop lighting products that have value beyond just the static provision of light. This new value can be applied to lighting that interacts with animals and the environment, and lighting products can be optimized for specific applications. However, a better understanding of the underlying animal response to light is needed, as well as new metrics and criteria that can be used to communicate the new value presented by LED technology.

Participant Presentations

Wouter Soer of Lumileds provided an overview of how manufacturers are able to optimize the spectrum for various LED applications. Generally, in order for manufactures to meet the lighting needs of a customer, understanding of the lighting requirements (e.g., spectrum, intensity, glare, directionality) is essential. Once these lighting and spectral needs are known, manufacturers can mimic that desired spectrum using a phosphor pump LED, direct emission LEDs, or a hybrid approach using a combination of phosphors and direct emission. Wouter emphasized that current research efforts are focused on the development of narrow-band red phosphors and improving direct green emitters. In addition, manufacturers are also beginning to look more carefully at the lighting science behind ecological and (human and animal) physiological impacts. For plant-based agriculture, Lumileds has developed LED lighting products that meet requirements for different plants/cultivars and growth stages in order to increase productivity, nutritional values, and aesthetics. As an industry, once LED manufacturers understand animal-specific lighting specifications and requirements, then they can design products to service that need.

Tom Katona of California Polytechnic State University, San Luis Obispo emphasized the importance of biological and behavioral effects of light and how these differ by species. Despite these different sensitivities, all living organisms are accustomed to sunlight. The Sun's spectrum changes dramatically over the course of the day, and even though life has evolved in sunlight, our lighting quality metrics are static. Tom highlighted that the LED lighting industry should strive to develop better multi-dimensional performance metrics that are broad-based. Such metrics would not only define a light source in terms of color and photopic efficacy, but also health, productivity, and environmental impacts.

Eric Haugaard of CREE explained the benefits of LED outdoor lighting systems compared to traditional sources such as high pressure sodium (HPS). Even in 2007, when LEDs only offered modest (if any) efficacy improvement over HPS, LED systems were still able to save energy since they could provide more appropriate luminous intensity distributions, thus requiring fewer delivered lumens. Additionally LEDs offered more favorable color quality over HPS. However, cost was an issue with early LED systems costing roughly 10 times that of the typical HPS system. Much has changed in the past decade, and LED outdoor lighting has seen significant performance improvements while costs have dropped dramatically. Haugaard emphasized that expected growth in LED adoption is exponential as municipalities increasingly prioritize LED lighting as a solution for energy use reduction. In order for LED lighting to continue its upward trajectory, color quality metrics should be refined in order to reflect the importance of replicating daylight as opposed to an artificial incandescent source. As an industry we now understand the beneficial impacts of blue wavelengths during the day, and we need performance metrics that reflect the latest science.

6. Closing and Next Steps

Based on the presentations from the attendees and the subsequent discussion, there was widespread agreement that understanding the lighting spectrum, control protocol, distribution, and intensity for livestock production and specific ecological habitats is the key research need to optimize desired animal behaviors and physiological responses. These lighting parameters will differ by animal species, setting, geography, and desired outcomes (e.g., livestock wellbeing and productivity versus light impact minimization). While this represents an extensive research need, existing work can likely be leveraged and organized, and standard research approaches can be applied to maximize useful discoveries. Developing and applying lighting optimized for animal responses could result in significant benefits, including increased livestock productivity, wellbeing, and health (possibly minimizing the application of pharmaceuticals in the process). The ecological and wildlife benefits could also be very compelling and enable drastic improvements in ecosystem health. These advantages can be harnessed while also retaining the standard benefits of LED lighting, i.e., greatly increased energy efficiency and reduced cost of ownership. However, to reap these benefits, testing and characterization approaches need to be develop that assess lighting animal impacts. Various processes from general illumination standards can likely be adapted; however, underlying application demands need to be better understood as a foundation. The development of LED lighting products offering color tuning and adaptive controls that can be used for research and testing in the livestock, wildlife and landscape ecology, and human medical research fields will be essential to help in building this knowledge base.

The conversation surrounding animal physiological response to light has just begun, and several next steps were proposed to help ensure LED energy savings are achieved in tandem with benefits to livestock, wildlife, natural lightscapes, and laboratory animals. The U.S. DOE SSL Program received the following next step suggestions for moving forward from the meeting participants. It was recommended that DOE should help:

- Coordinate lighting education, advocacy and community organization, test methods and standards, as well as demonstration projects to improve understanding of how lighting impacts animals.
- Develop an inventory of existing research on species-specific eye response curves as a resource for the community. The inventory could provide a common format for comparison and include data fields such as type of study, credibility of results, monochromatic response, as well as commonality of eye response and structure, behavior, and ecosystem.
- Engage experts on lighting interferences with bats, insects, and amphibians to further understanding of existing research and impacts on wildlife.
- Create and maintain a list of researchers interested in animal responses to light and communicate new research efforts and developments to the group.

DOE would like to thank all attendees for their participation and for their valuable insights into what needs to be done to help the livestock, wildlife and landscape ecology, and human medical research fields overcome the challenges they face, as well as how the DOE SSL program can

facilitate that process. It is active participation from members of these communities, and collaborative efforts initiated between research groups as a result of this meeting, that will continue to drive LED technology forward.