



THE BRIGHT DARKNESS

Assessing Public Attitudes
Towards Light Pollution in
Princeton, MA and Recommending
Approaches to Mitigation

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Abstract

Working with the Environmental Action Committee of Princeton, MA we assessed current outdoor lighting practices in the town, as well as public attitudes towards light pollution through interviews with local officials, members of the town's municipal lighting department, and a town wide survey. We found that lighting technologies used in the town add to the effects of light pollution. We also found that survey respondents were aware of light pollution within the town and care about the night sky. We examined lighting regulation in similar municipalities to find commonalities. From our findings we recommended steps the EAC can take to work with local organizations in promoting awareness of light pollution. We also recommended language for lighting regulation in a zoning bylaw.



Heritage Bible Chapel



Wachusett Mountain Parking Lot

This report represents the work of four WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on its web site without editorial or peer review. The opinions presented in this report do not necessarily represent the opinions of WPI. For more information about the projects program at WPI, see <http://www.wpi.edu/Academics/Projects>

Acknowledgements

Our project goal was to assist Princeton's Environmental Action Committee (EAC) to identify strategies to reduce light pollution, ranging from voluntary measures local residents could take to drafting a light bylaw. Without help from our sponsors, advisors, Princeton town officials, and various dark-sky organizations, this would not have been possible.

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Introduction

Light pollution is the excessive or misdirected use of artificial light outdoors. As artificial light becomes more prevalent over time, the view of the natural night sky has begun to disappear. In 2011, the First Atlas of Artificial Night Sky Brightness found that more than two-thirds of the population in the continental United States no longer can see the Milky Way with the naked eye (Falchi et al, 2011). Light pollution poses a significant threat to the wellbeing of animals. Unnatural illumination disrupts their behavioral habits, feeding and hunting capabilities, and can lead them to stray from traditional migration paths (Chepesiuk, 2007). Studies have shown that for humans light pollution is associated with headaches, stress and anxiety (Khorram et al., 2014), and that the ability to see a truly dark night sky is invaluable to the human psyche (Blair, 2016).

One of the leading methods to mitigate light pollution is to regulate light use. Massachusetts is the only New England state without legislation at the state level to reduce light pollution and preserve the night sky. Towns in Massachusetts have led the efforts to reduce light pollution. As of 2016, 41 towns in the state had developed and adopted a local ordinance or bylaw (MA Towns, 2019). These towns have implemented lighting regulations as stand alone bylaws or, a typically easier path, through their zoning, nuisance, or planning bylaws.

The first step to reducing light pollution in many areas has commonly been taken up by community members who understand the issue from individual concerns, such as local astronomers or environmentalists (Claudio, 2009). “These [grassroots activism] efforts to protect the nighttime environment by informing/educating the public about the use and application of quality artificial lighting have paid off” (Karolina, 2020, pg. 9).

The efforts of small groups have expanded into the existence of many organizations that actively work to spread awareness for protecting the night sky. The International Dark-Sky Association (IDA) is at the forefront of these organizations. The IDA has created outreach materials which touch on each major area effect of light pollution where people may have existing concerns. These include brochures on the health effects on both humans and wildlife, the relationship between light and crime, and the waste of energy and money associated with light pollution (Public outreach materials, 2021).

Princeton, a rural town located in central Massachusetts is home to about 3,500 residents. Figure 1 provides a color-coded overview into the way land is used within Princeton and how that shapes the town’s character. The town’s 2020 Environmental Action Plan seeks to maintain the natural and rural character as a goal of land use and its fourth action there states “Maintaining the town of Princeton’s ‘rural character’ includes ensuring minimal light pollution in the night sky” (Environmental Action Committee, 2020, pg. 77). The extent of light pollution in the town, recent trends, and the attitudes of Princeton residents towards light pollution and different approaches to reduce it are unknown.

The goal of our project is to assist our sponsor, Princeton’s Environmental Action Committee (EAC), to determine the scope of light pollution in the town, assess public attitudes toward it, and identify mitigation strategies. In order to accomplish this goal we identified and interviewed key members of Princeton’s community, a local astronomical society, and the Massachusetts chapter of the International Dark-Sky Association. We compared the lighting regulations of thirteen municipalities which were demographically

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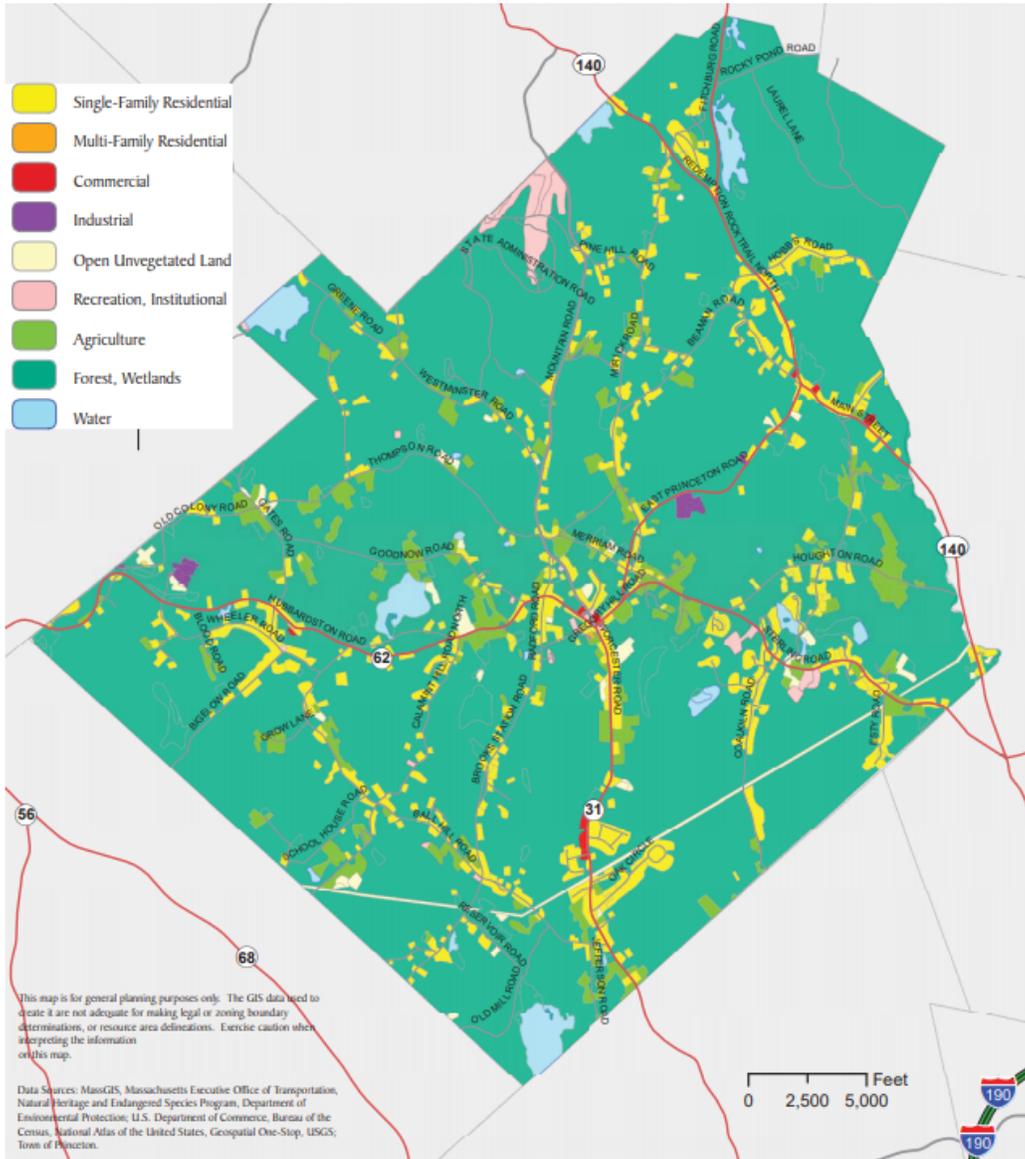


Figure 1. Map of Princeton with color coded land use retrieved from the town’s Master Plan (Town Master Plan, 2007, pg. 42).

similar to Princeton to inform our recommendations for bylaw language. In order to gauge the attitudes of Princeton residents on light pollution, we developed the Princeton Outdoor Lighting survey. With responses from 255 Princeton residents we were able to come to conclusions on how respondents viewed lighting and isolate specific concerns residents held. Following proper protocols, we were able to make two trips to Princeton to conduct field

work, in which we captured photographs of the night sky and a variety of lighting technologies in Princeton.

Background

What is Light Pollution?

Light pollution is the excessive or misdirected use of artificial light outdoors. It causes sky glow, glare, and light trespass, which all prevent the natural glow of stars in the sky from being seen with the naked eye. These effects negatively impact human, plant, and animal life. They are defined below and visually represented in Appendix O.

dysfunction of organs and systems within the body like the heart, lungs, esophagus, and spleen (Luyster, et al. 2012), which causes further side effects like depression and headaches (Khorram et. al, 2014).

	Descriptions
(1) Sky Glow	<ul style="list-style-type: none">• Generally appears over densely populated and developed areas, as a bright illuminated halo
(2) Glare	<ul style="list-style-type: none">• The discomfort or loss of visual senses due to bright artificial lights• Created by light which shines horizontally
(3) Light Trespass	<ul style="list-style-type: none">• Common in any area where compact developments are present• Occurs when unaimed artificial light spills onto nearby property which it was not originally intended to illuminate

Table 1. Table describing the main components of light pollution

What Effects does Light Pollution Pose for Humans?

Excessive exposure to artificial light heavily influences our natural circadian rhythms and our relationship with sleep. Our sleep-wake cycle, which is monitored and maintained by our hypothalamus, or our natural clocks, perceives all light as a signal to remain awake and stay alert. But, as the day carries on and the sky becomes darker, the hypothalamus begins to release signals and hormones throughout the rest of the body which indicates a resting period for our bodies and biological processes. When interrupted by artificial lighting, including light trespass, the body's natural circadian rhythms are unable to distinguish for itself the differences between the waking and sleeping period. Prolonged and repeated disruption causes

Researchers linked some psychological issues, such as feelings of loneliness, anxiety, and depression, as consequences of exposure to light pollution in both young adolescents and adults (Medic, G., Wille, M. and Hemels. M., 2017). The widespread use of LED lights emits a large amount of blue light into the sky. Excessive exposure to these blue lights, which stimulate parts of our brains to keep us alert, can have a drastic effect on an individual's mental health. Since blue light suppresses release of melatonin, chronic interference with the natural circadian rhythms inherently affects an individual's mental health, and mood. "...living in urban settings artificially shifts melatonin production cycles away from natural circadian rhythms, and that spending time in more natural, low-LAN

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settings restores these patterns” (Min, 2018, pg. 19). Urban settings are densely populated, well-developed, and brightly lit. With higher emissions of blue light, more people are going to be affected by light pollution. Along the same lines, an analytical study suggests that missing a natural view of the night sky also affects one’s mental wellness. “Researchers in the field of ecopsychology talk about the ‘missing sky factor’ that is, how light pollution creates the absence of nighttime sky and loss of the grandeur of infinite stars” (Min, 2018, pg. 19). Missing this connection to the universe, people are unable to experience the awe and peace which comes with admiring the night sky. In an environment where the natural celestial sky is not as visible, people are more likely to develop psychological and physiological issues because of their increased exposure to light pollution.

What are the Effects of Light Pollution on Plants and Animals?

In animals, artificial light at night can disorient and cause discomfort to their senses, impact their hunting and foraging patterns, breeding cycles, and symbiotic relationships. Birds are not nocturnal by nature, but as a result of light pollution, they are commonly awake throughout the night and sing when they should be resting. “For example, diurnal animals are active longer than they normally would be, and birds in cities have even been observed to forage at night during the winter” (Da Silva, et al., 2015). Birds will also frequently fly into tall, brightly lit buildings and hurt themselves.

With a bright, night sky, predators that hunt at night such as cougars, have a higher advantage finding food because their prey are unable to hide themselves in true darkness (University of Michigan, 2020). This puts populations of prey at risk, and affects the rest of the food chain causing an imbalance. Breeding and migratory patterns are also heavily impacted by light pollution. Since blue light emissions influence natural time-clocks in all

humans, plants, and animals, increased exposure to this light affects when many animals begin their migration or hibernation (Chepesiuk, 2009). Nocturnal pollinators and insects are heavily impaired and misdirected by light pollution. Distracted by bright lights, many insects will circle illuminated areas for hours throughout the night and die by morning, “...either by being gobbled up by predators or simply from exhaustion” (Daley, 2019, pg. 2).

Plant life which depends on these insects for pollination, or which benefit from their symbiotic relationships are also affected by light pollution because they are frequented less by the pollinators. Comparing the nocturnal visits of wildlife in an artificially lit space to a naturally dark one, researchers discovered a 62% reduction in visits to plants growing in areas that were artificially lit (Knop et al., 2017). This ultimately comes full circle, because animals depend on plant life for food and survival, so that a decrease in their output negatively affects animal life.

What are the Drivers of Light Pollution?

As shown in Figure 2, increasing trends of light pollution began in the 1950s, and are predicted up until the year 2025. “In 2017, researchers found that light pollution has increased nationally at a rate of 2.2 percent per year” (Kearnan, S., 2020). According to Tim Brothers from the MIT Wallace Astrophysicist Observatory, in Massachusetts, the increase in light pollution is closer to 4-6 percent (Kearnan, S., 2020). The increase in light pollution directly correlates to industrial growth, urbanization, and the invention of new technologies.

Background

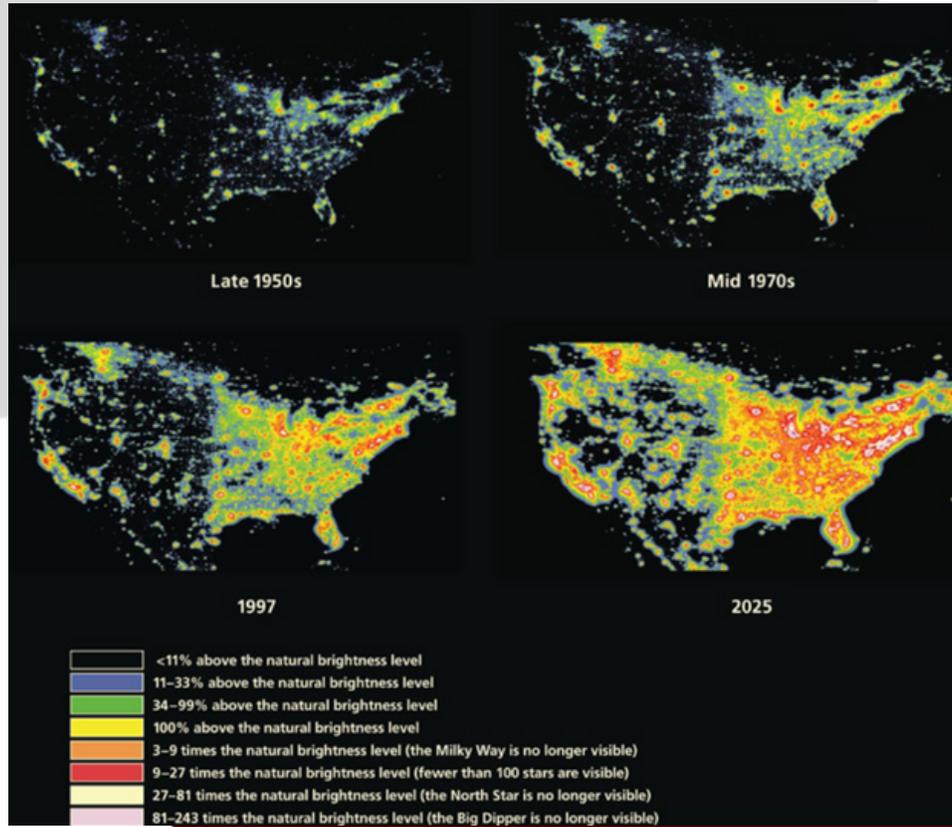


Figure 2. Increasing trends of light pollution

With radiometers and satellite systems, scientists and researchers at the National Oceanic and Atmospheric Administration found that the greatest light pollution is coming from developing countries (Dunham, 2017). As these countries see more industrial and economic growth, as well as increased population migration to urban areas, they will also see an increase in light pollution.

Development has had a similar impact in the U.S. Between the years 2015 and 2020, industry growth in the U.S. was 0.7%, which is mainly composed from roadway lighting. The pie chart in Figure 3 shows a breakdown of different infrastructure which contribute to light pollution. Lighting on roadways, also the leading industrial advancement, contributes approximately 48%. Parking lots contribute approximately 34.3%, and exterior building lights approximately 10.5%.

As development continues, these aspects of lighting will increase, ultimately increasing light pollution levels.

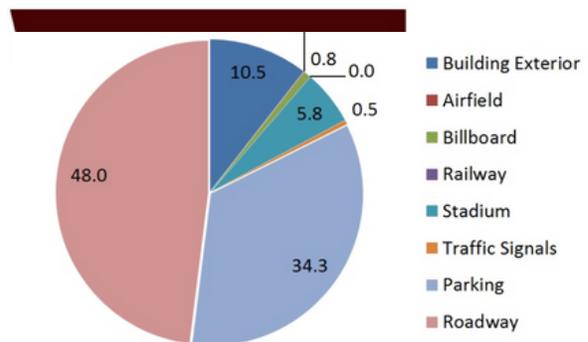


Figure 3. Breakdown of U.S. light pollution contributors (Ashdown, I., 2019)

Background

With increased development comes economic growth and opportunities, drawing more people to urbanized areas. “As rapid urbanization resulted in drastic increase in urban dwellers and economic enhancement, artificial light consumption became ever greater to cater the ceaseless demands. It is estimated that 23% of land area in the USA currently inhabits at least 50% brighter sky than natural at the zenith” (Azman, et al., 2018, 4), or the highest point in Earth's sky. While urbanization is necessary to sustain population growth, it plays a huge part in increasing light pollution levels. Development runs parallel with artificial light installation. With energy and cost efficiencies in mind, cities are more likely to opt for LED lights that emit high levels of blue light into the atmosphere. Such illumination does more harm than good, negatively affecting the surrounding human, animal, and plant life.

Aside from industrial growth, researchers at the U.S. National Oceanic and Atmospheric Administration have also found that new technology, such as blue-light LEDs, are a driving force behind light pollution. In 2008 the LED filament was developed by Ushio Lighting (The Next Generation, 2015). Since then, cost and energy savings, especially government mandates for energy efficiency, have led to the wide acceptance of the LED bulb (Mordor Intelligence, n.d.). While less bright, warm colored LEDs do exist, “an estimated 10 percent of all outdoor lighting in the United States was switched over to an earlier generation of LEDs, which included those problematic blue-rich varieties” (LED Streetlights, n.d., pg. 2). The blue color light has a short, high-energy wavelength and disperses more readily into the sky than the longer-wavelength light emitted by lower color temperature lights. The “brighter and whiter” result of blue LEDs causes the various negative effects associated with light pollution. However, turning away from blue LED’s is not an easy task.

Why is it difficult to address?

Lack of Public Awareness

Other types of pollution gain greater attention from the public than light pollution due to its less noticeable effects. While air pollution kills roughly 2.4 million people a year, and water pollution can lead to visible deformities of plants and animals, the effects of light pollution are not as observable. Light pollution has “no smell, taste, or sound” (Lystrup, 2017, pg. 3), causing it’s existence and negative effects to sometimes go unnoticed all together. Light pollution is not listed as one of the top fifteen U.S environmental concerns, while air and water pollution rank at two and three for 2020 (BioExplorer, 2020).

Economics and Energy Conservation

The dangers of blue light LEDs are difficult to address as their cost and energy efficiency appeal to the eye of consumers, while the dangers of them remain relatively unknown. LEDs are approximately six times cheaper than an incandescent light bulb, and as Figure 4 shows, an LED is at least 80% more energy efficient than a standard, or incandescent, light bulb. Nevertheless, their common bright blue color is still one of the driving forces of light pollution.

EFFICIENCY	Least Most			
	STANDARD	HALOGEN	CFL	LED
BULB TYPE				
LUMENS	450	800	1100	1600
	40 W	29 W	9 W	8 W
	60 W	43 W	14 W	13 W
	75 W	53 W	19 W	17 W
	100 W	72 W	23 W	20 W
RATED LIFE	1 year	1-3 years	6-10 years	15-25 years
SAVINGS	×	up to 30%	up to 75%	up to 80%

Figure 4. The image above depicts energy saving of different types of light bulbs versus the standard light bulb (The benefits of LEDs, 2014)

Background

Inconsistent Enforcement

Even once legislative measures to reduce light pollution have been set, it can be hard to enforce them. Massachusetts does not have a state-wide lighting regulation. Despite this absence, municipalities within the state have independently developed lighting regulations of their own. Regulation between small towns and large cities can vary, causing enforcement to be especially difficult. When small towns with lighting regulations are located next to large unregulated cities which ultimately contribute more to light pollution, small towns can see their efforts as insignificant, and therefore unreasonable to enforce. The passing of a bylaw does not guarantee firm enforcement. According to James Steele, author of “Enforcement of Municipal Bylaws: A Primer”, “The mere passing of a bylaw does not cast any legal duty on the municipality to see to it’s enforcement” (Steele, n.d., pg. 1). Without legislation at the state level, strictness of regulation between neighboring towns presents a challenge, and causes the effectiveness of municipal regulation to be insubstantial.

What has been done Before to Address Light Pollution?

Determining the Scale of the Problem

For light pollution to be addressed in a meaningful way, it must first be quantified. To this end, astronomers have developed a few methods for analyzing either the wasted light in an area or the brightness of the night sky. Satellite cameras are used to examine the wasted light in an area by detecting visible near-infrared emissions (Chalkias et al., 2006). This allows for the construction of light pollution maps such as the one shown in Figure 5.

The leading non-satellite method for analyzing light pollution is the use of a sky quality meter (SQM). This is a device which measures the difference between the brightness of stars and the brightness of the night sky in units of magnitude per square arc-second (Globe at Night). This method of analyzing light pollution is much easier as it can be

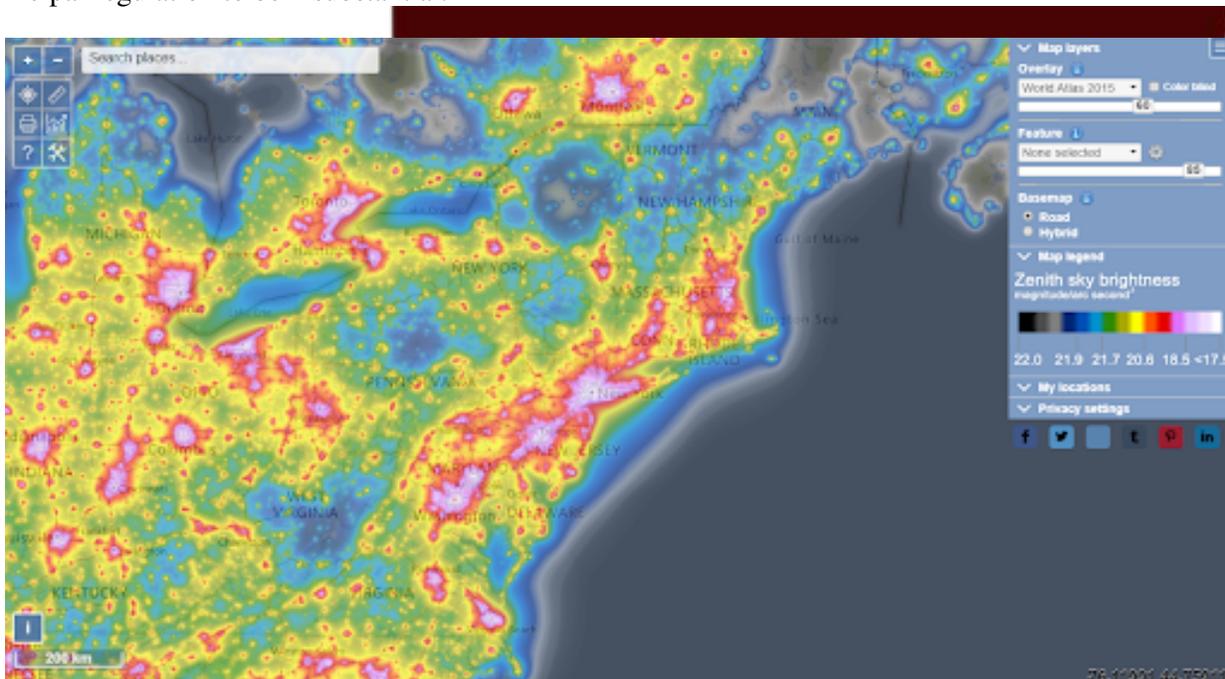


Figure 5. A map which displays light pollution VIIRS/DMSP data over the Northeast part of the US (lightpollutionmap.info, 2020)

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performed from the ground using a relatively inexpensive piece of technology. Resultantly, while satellite imagery is most useful for collecting data to be used for mapping light pollution, SQMs are often used by citizen science initiatives such as Globe at Night. Finally, in cases where neither of the other two methods are available, analysis of pictures of the night sky yields some numerical data regarding light pollution, namely the count of stars visible in the picture and the mean sky brightness. Numerical analysis of light pollution provides concrete evidence that light pollution varies over time and between areas.

Assessing Public Attitudes

Public perception of light pollution is an important consideration when trying to address the issue. In her book *Light Pollution in Metropolises*, Emlyn Goronczy calls light pollution, “one of the most underestimated environmental pollutants ” (Goronczy, 2021, pg. 2). To better understand the public’s understanding of light pollution and their feelings on light, several institutions have conducted surveys. A 2018 survey in “The Irish Times” asked respondents several questions about lighting and the effects of light pollution and organized those responses by geographical location (Coogan, 2020). In that survey, rural respondents identified that residential lighting was the most prevalent source of outdoor nighttime lighting near them. They also identified that light trespass affected their sleep and that the milky way was frequently present in the night sky. A more comprehensive survey was administered in Finland and published in the *Journal of Integrative Sciences*. Over 80% of respondents to that survey indicated that light pollution was an issue and that visibility of the night sky was important to them. Additionally, just under 70% of

that survey’s respondents agreed that everyone should be able to see a starry night sky from their place of residence. Over 50% identified that excessive artificial light affected their neighborhood, and over 70% responded that outdoor commercial lights were disturbing. The Finnish survey also tasked respondents with identifying sources of light pollution. The source identified most by respondents was streetlights, followed by commercial lights and then by city lights and yard lights (Lyytimaki, 2013).

Developing Targeted Awareness Campaigns

The International Dark Sky Association (IDA) is an organization concerned with preserving the night sky. This organization works to decrease light pollution through their own forms of outreach, advocacy, and bylaw consultations. As shown by their statistics in Figure 6, the IDA has supported 23 dark sky communities in adopting strong lighting policies.

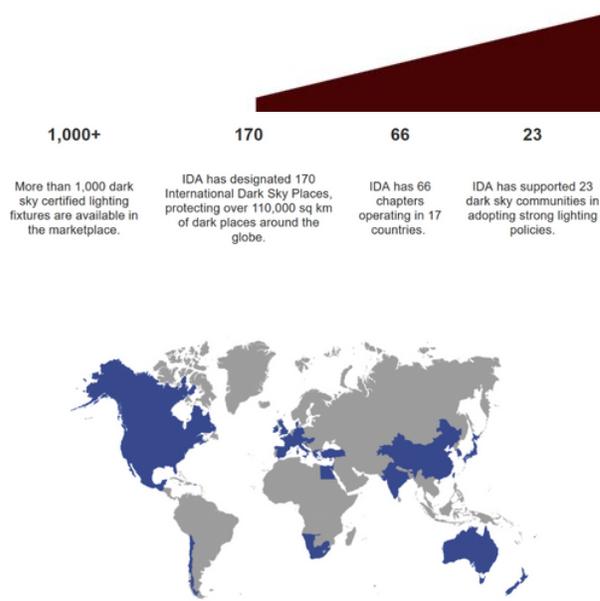


Figure 6. IDA accomplishments (Our work, 2021)

Background

The IDA has also created a host of outreach materials which can be used to spread awareness of light pollution (IDA, 2020). Light pollution is a niche environmental issue, and thus awareness campaigns need to be carefully targeted by linking light pollution to issues in which people are already invested. The simplest outreach promotes enthusiasm for the night sky, focusing on preserving it for future enjoyment. The IDA claims that “in-person events that teach people the value of a naturally dark sky have been some of the most successful programs” (IDA, 2020). Some outreach targets monetary incentives; light is often used unnecessarily, and the energy used to do so can be costly. Other outreach focuses on light pollution’s effects on humans, plants, and animals, discussing disturbed sleep cycles, reduced crop yields, and irregular avian behavior. Additional outreach focuses on correcting commonly-held misconceptions about light, such as the belief that additional nighttime light reduces crime (IDA, 2020). Successful outreach efforts produce increased concern over individuals’ and municipalities’ relationships with light, resulting in more careful use of light and better selection of lighting technologies.

Promoting Technical Advancements in Lighting

Light pollution can be significantly reduced by utilizing better lighting technologies. The IDA suggests several lighting options which serve the same functions as ones already in place but contribute less to light pollution. LEDs with a warm color temperature (the IDA recommends 3000K or less) can be used in place of their 4000K blue-white counterparts. The warmer light which they emit disperses less into the night sky and causes less glare because of the longer-wavelength and correspondingly lower-energy light. Additionally, many LED lights are capable of multiple color temperatures. Installing drivers to lower the color temperature of those LEDs can be hugely impactful,

in many cases lowering the color temperature by as much as 1000K. Equipping lights with shields, opaque barriers which restrict the direction of light, eliminates light shining directly upwards and significantly reduces glare (Outdoor Lighting Basics, 2018).

Light pollution can also be reduced through better use of lighting technologies. Many outdoor lights remain on all night despite not being in use the entire time. The addition of motion sensors to lights ensures that they remain off when not needed. Additionally, outdoor lights are commonly brighter than is necessary for their intended purpose, especially as lights transition from older bulbs to LEDs which are brighter at the same wattage. In many cases, lower-watt bulbs or the installation of dimmers would reduce their brightness without impairing their function. A secondary advantage of using less light, either by dimming or selectively turning off lights, is saving on energy costs. When Cambridge, MA renovated its streetlights in 2014 the newly-installed LEDs were equipped with drivers attached to a wireless control system. Using that system, the lights could be dimmed from their maximum brightness and set to dim further later in the night. Cambridge dimmed over 7,000 streetlights in this manner. In doing so, they found that the effects of light pollution were significantly reduced and that electricity costs were cut by \$500,000 a year (Lenkauskas, S., 2014).

Drafting and Implementing Bylaws

Another method to curb light pollution is to pass outdoor lighting regulation. In New England, every state besides Massachusetts has passed statewide lighting regulation which mandates that publicly-funded lighting meet certain standards. In Massachusetts, however, efforts to pass statewide legislation have repeatedly failed. Those efforts continue with the current bill “An Act to improve

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outdoor lighting, conserve energy, and increase dark-sky visibility” which was proposed by Senator Cynthia Creem and Representative Sean Garballey with input from the Massachusetts Chapter of the IDA. In lieu of statewide legislation, 41 municipalities in Massachusetts have passed their own lighting regulations, either as a standalone bylaw or included in their zoning bylaws (IDA, 2020). These bylaws contain provisions which can be separated into two broad categories. Prescriptive provisions regulate specifications of lighting technologies, such as the lumens and color temperature of lights. Performative provisions regulate lights as they are in use, regulating where lights are aimed and the foot-candle brightness of illuminated surfaces. Bylaws vary in complexity, but most have the performative provision that light should be directed and shielded such that it does not shine across property lines. Additional common provisions include restrictions on the brightness of lights and the maximum height at which they can be mounted. Some bylaws also regulate lights’ color temperature and hours of operation. Most bylaws exempt lights which were installed before the bylaw’s passage.

How can we Characterize Light Pollution in Princeton?

Princeton is a small town of about 3,500 residents, located in central Massachusetts. It is known for hiking and skiing on Wachusett Mountain. The town would like to maintain its rural character, as described in the land use goals within the 2020 Environmental Action Plan, in part by “ensuring minimal light pollution in the night sky” (Environmental Action Committee, 2020, pg. 77). According to the Environmental Action Committee, our sponsor, “The population of Princeton is changing and increasing, and every new house or new owner is a potential contributor to nighttime light pollution” (EAC project description). With little area in Princeton zoned ideally for commercial

and industrial uses, the majority of new development will be residential. Princeton has already seen an uptick in residential development in the past five years (Gardner, 2020, pg. 14). Outside of land development, Princeton changed their street lights from high pressure sodium technologies to LED technologies in 2017, which resulted in an increase in light pollution. Comparing Figure 7 to Figure 8, there has been an increase in light radiance in Princeton’s center from 2012 to 2020, as well as an increase throughout Princeton’s roadways contributing to the decrease of dark area. The new street lights Princeton implemented can be seen around a rotary in East Princeton in Figure 9, as well as the lights placed in Princeton’s town common in Figure 10. There is also expectation of a new public safety building being constructed within the next five years, which has the potential to increase effects of light pollution.



Figure 7. Satellite imagery from the NOAA’s VIIRS 2012 data, depicting the level of radiance of light pollution (lightpollutionmap.info).

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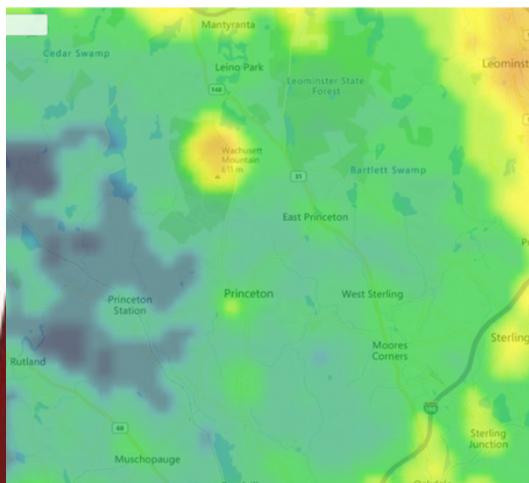


Figure 8. Satellite imagery from the NOAA's VIIRS 2020 data, depicting the level of radiance of light pollution in Princeton (lightpollutionmap.info).

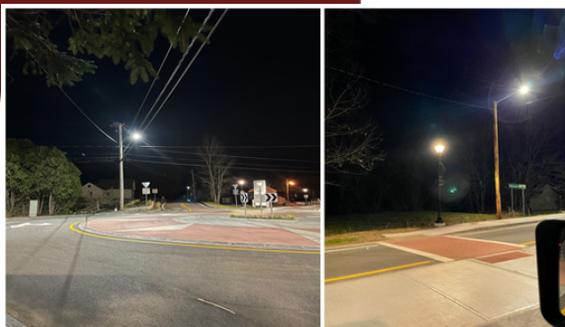


Figure 9. Images of lighting taken near the rotary in East Princeton.



Figure 10. Image taken of Princeton town common.

Wachusett Mountain Ski Area, to the north of the town, is one of Princeton's largest commercial attractions, offering night skiing seven days a week during the winter seasons. The largest impact the Ski Area has on light pollution occurs during the ski season months when night skiing opens to the public. With hours extending into the late night for skiing and grooming slopes, the LED lights illuminating directly towards the snow creates a glow in the night sky that is the prominent contributor to sky glow in Princeton. Figure 8 is an image taken from the light pollution map utilizing the National Oceanic and Atmospheric Administration's (NOAA) Visible Infrared Imaging Radiometer Suite (VIIRS) 2020 data. It shows the level of radiance of light within Princeton and surrounding communities. Comparing this to Figure 7, representing the 2012 data, there has been a clear increase in light radiance on Wachusett Mountain due to the skiing operations. This is partly attributed to the installation of 200W and 400W LED floodlights in 2017, to replace outdated metal halide technology used previously to light the ski slopes (Wachusett Mountain Ski Area History, 2021). In Figure 11 the LED floodlights illuminating the ski slopes can be seen. Light pollution present in Princeton can be attributed in some capacity to all aspects of the town's development and growth, therefore understanding the impacts of existing and potential future lighting is important to curb the effects of light on the night environment.

Background



Figure 11. Image of Wachusett Mountain ski trails lit up at night (Hours of Operation, 2021).

The EAC tasked our WPI IQP team to conduct the initial background and field research to understand the best approaches to mitigate light pollution within Princeton. This includes identifying key sources contributing to light pollution, evaluating the pros and cons of existing methods used to reduce light pollution, and researching current lighting regulations used in Massachusetts municipalities in order to recommend best practices and draft language for a lighting bylaw in Princeton.

Methods

Goal Statement

The goal of this project was to assist Princeton's Environmental Action Committee (EAC) in identifying strategies to reduce light pollution, ranging from voluntary measures local residents could take to drafting a light ordinance. To do so, we identified four objectives:

- Assess current lighting technologies in Princeton
- Assess the views of Princeton residents on light pollution and lighting regulation
- Determine the feasibility of a lighting bylaw specific to Princeton
- Identify strategies to motivate Princeton residents to voluntarily reduce their use of excessive artificial light

Assess Current Lighting Technologies in Princeton

To offer an initial assessment of light pollution evident in Princeton, we assessed current lighting technologies used for municipal, commercial, industrial, or residential purposes. To do so, we photographed different lighting technologies around the town, especially those which we judged to be responsible for the effects of light trespass, glare, or skyglow. We also specifically photographed technologies or commercial properties that were mentioned as contributors to light pollution by residents in a town wide sample survey, which is discussed further below.

Interview Princeton Municipal Light Department

The Princeton Municipal Light Department (PMLD) provided expert knowledge on lighting in Princeton. The two PMLD members we contacted each hold a different position within the department. Sean McKeon is the current manager of the PMLD, who we asked about the types of streetlights used in Princeton and about their dispersion across the town. Rick Rys is the light commissioner of the PMLD, who we

asked about how policy changes occur within the PMLD. Additionally, we asked him questions regarding the prevalence of light pollution within Princeton, as more lighting technologies are used with increasing development. Each of the PLMD interviewees provided us a unique perspective on the inner workings of lighting the town of Princeton.

Assess the Views of Princeton Residents on Light Pollution and Lighting Regulation

We surveyed Princeton residents to determine their attitudes toward dark night skies, light pollution, and possible measures to reduce light pollution. The survey focused on the following topics:

- Light pollution's effects on the night sky
- Light pollution's effects on nighttime wildlife
- Sources of light pollution within Princeton, MA

In order to obtain the most direct perspectives from Princeton residents we implemented a town wide survey. We developed the survey through Google Forms; it was designed to take approximately 5-10 minutes with the majority of questions based on a five point likert scale. One question was open-ended and twelve questions were multiple choice.

The survey was linked on the Environmental Action Committee's newsletter "The Green News", Nextdoor Princeton, Princeton community Facebook pages, and Redemption Rock News. Flyers advertising the survey, with a QR code linked to the survey, were placed in the Post Office, Kwik Stop, and Monti Farm in Princeton. The flyer used can be viewed in Appendix Q. We pre-tested this survey on multiple Princeton residents who provided us with feedback before we revised and released a final copy to the EAC for distribution to the entire town. The survey was open to residents from April 12th to May 1st and can be found in Appendix A.

Methods

The information sourced from Princeton residents through the survey was analyzed after it was converted into google sheets. The eight Likert-scale questions all regarded personal views on light pollution. These questions asked respondents to identify their level of agreement with a given statement on a scale from 1 to 5, with 1 meaning ‘strongly disagree’ and 5 meaning ‘strongly agree’. For these questions, we examined the percentage of respondents who agreed and disagreed with statements, observed the dispersion between the five levels of agreement, and calculated the average and median levels of agreement. Analysis of these level-of-agreement questions showed us the general view on light pollution in Princeton. One checkbox-structured question listed possible sources of light pollution within Princeton. This question was meant to help us understand where residents believe excessive light is coming from. Another checkbox question which asked “Please select any methods for reducing light pollution which you would be willing to support in Princeton.” helped us gauge the level of support residents have for different measures that regulate lighting.

Determine the Feasibility of a Lighting Bylaw in Princeton

<u>Interviewees</u>	<u>Respective Titles</u>
Tom Sullivan	Planning Board Member
John Mirick	Planning Board and Princeton Land Trust Member
James Lowenthal	President of Massachusetts IDA, Professor of Astronomy at Smith College
Tim Brothers	Vice President of Massachusetts IDA, Manager of MIT Wallace Observatory
Tim Hammond	Princeton Representative on Wachusett Mountain Advisory Council

Table 2. Above is a table depicting the people that were interviewed and their relevant and respective titles.

We interviewed Tom Sullivan to understand the perspectives of Princeton residents and the planning board on light pollution. We asked questions focused on the zoning bylaws set by Princeton and how a lighting bylaw could be worked into existing Princeton legislation. We asked Mr. Sullivan about the role of the Wachusett Mountain Advisory Council (WMAC), on which he previously served, and challenges around addressing lighting in Princeton. A more detailed interview script can be found in Appendix D.

In our interview with John Mirick, we inquired about Princeton resident’s attitudes towards maintaining the rural environment, the most feasible path for a lighting bylaw to be placed in town legislation, and how the town's development has changed in the past and may change in the future in relation to lighting. This information helped us gauge public perspective on light pollution and also to identify how a lighting bylaw can be adapted for Princeton. We asked Mr. Mirick questions gauging the impacts of outdoor lighting from existing and potential future residential or commercial developments, the concerns residents have had related to lighting, and changes he has witnessed in lighting in Princeton. A more detailed interview transcript can be found in Appendix E.

We interviewed James Lowenthal to better understand the specific actions the Massachusetts IDA takes to advocate for reducing light pollution and assisting towns in passing lighting regulations. We asked Professor Lowenthal questions regarding his work with the town of Northampton, Massachusetts to assist the town in developing lighting regulations and converting town lighting to LED technology, and about the state of lighting legislations being proposed in the Massachusetts legislative system. A complete interview script can be found in Appendix K.

Methods

We interviewed Tim Brothers because of his involvement with the Massachusetts IDA and his experience with working on lighting legislation. He recently finished a lighting bylaw for his hometown of Pepperell, MA, and is one of four IDA representatives on a committee working on a new Model Lighting Ordinance (MLO) in collaboration with the Illuminating Engineering Society (IES). We asked him questions about his background in light pollution advocacy as well as his experience in writing and then campaigning for light pollution legislation. A complete interview script can be found in Appendix H.

We interviewed Tim Hammond to understand the goals of the Wachusett Mountain Advisory Council (WMAC) and how they work with the local communities to address environmental concerns. The WMAC oversees the use of the conservation area at the mountain, so we asked about the effects of night skiing operations on the mountain and the extent to which they've advocated for reduced lighting. We also were interested in how community members are able to voice their concerns to the WMAC. A complete interview script can be found in Appendix I.

In addition to conducting the above interviews, we also analyzed the provisions within existing lighting bylaws around Massachusetts. To do so, we used the IDA's list of Massachusetts municipalities with lighting regulations and isolated twelve that were the most similar demographically and economically to Princeton. We considered the towns' population, average household income, area, and population density. Then, we created a table of common provisions, applicability, and enforcement strategies of those towns. By using this resource and from the information we gained through our interviews, we determined which bylaw components should be featured in a lighting bylaw specific to Princeton and began to adapt language specific for Princeton.

Identify Strategies to Motivate Princeton Residents to Voluntarily Reduce Their use of Excessive Artificial Light

<u>Interviewees</u>	<u>Respective Titles</u>
Gail Walker	Vice-President of Siasconset Civic Association
Peter Morrison	Co-President of Civic League in Nantucket
Kelly Beatty	Member of Massachusetts IDA, Senior Editor for Sky Telescope Magazine
Helga Kuechly	Geospatial Analyst at WWF Germany

Table 3. Above is a table depicting the people that were interviewed and their relevant and respective titles.

We interviewed Gail Walker because she helped to organize the forum on light use in Nantucket. This forum is a great example of successful outreach regarding light pollution, and helped to illuminate the thoughts of Nantucket residents on lighting and the enforcement of Nantucket's lighting bylaw. We asked her about successful approaches to lighting advocacy and about making connections to influential individuals or organizations with outreach. A complete interview script can be found in Appendix L.

Peter Morrison was interviewed due to his role in organizing the public forum held in Nantucket focused on light pollution. The forum was organized with key town informants, lighting enforcement officials, and light pollution experts. We wanted to learn about the process of developing this forum, how it addressed pushbacks and concerns from residents, and how it helped to engage the community with lighting on Nantucket. A complete interview script can be found in Appendix G.

We interviewed Kelly Beatty to gain his perspective on advocating for light pollution awareness, as he has worked with several municipalities in Massachusetts on behalf of the IDA to inform communities of the impacts of light pollution and the best methods to mitigate its effects.

Methods

The Nantucket public forum Mr. Beatty spoke in was of key interest to our project, so we asked about the key aspects of his presentations and others that he's given in local communities. A complete interview script can be found in Appendix J.

Helga Kuechly has experience researching ecology, specifically relationships between wildlife and light pollution, as well as remote sensing and nature conservation. Dr. Kuechly's experience also extends to working on citizen science projects focused on collecting light pollution data. We asked Dr. Kuechly about the primary sources for light pollution, the major health effects associated with light pollution for both wildlife and humans, difficulties associated with light pollution research, and the potential benefits for communities to engage in citizen science projects. A more detailed interview script can be found in Appendix F.

Due to their extensive work on light pollution, Tim Brothers and James Lowenthal provided key insight, not only to regulation but community outreach as well. We asked Tim Brothers, author of a lighting bylaw draft and prolific activist regarding light pollution, questions regarding the best methods he implements to make people aware of the negative impacts of light pollution. We asked similar questions, especially regarding the best strategies to engage community members in conversation of light pollution, of Professor Lowenthal, who has helped officials in the town of Northampton, MA conform town lighting to IDA standards.

Princeton's EAC Monthly Newsletter

In 2020 Princeton's Environmental Action committee created a new monthly newsletter which aims to update its subscribers on current local and global environment actions (Environmental Action Committee has a New Monthly Newsletter, 2020). To alert people of the light pollution issue, in mid-July we added a section in the EAC's newsletter about what light pollution is, how it affects the

environment, and what can be done at home in order to reduce it.

Findings

In this chapter we discuss the information our team collected through interviews with Princeton residents, local officials, light pollution experts, and astronomers, as well as a general light pollution survey that was sent to the Princeton community. We first discuss the state of light pollution in Princeton, which was informed by field work conducted in Princeton, MA and the Princeton Outdoor Lighting survey. The survey assessed residents' views on the effects of light pollution, sources, and reduction methods in Princeton. We then discuss the recommended forms of outreach within a community and plausible paths for Princeton to pass a lighting bylaw.

Light Pollution in Princeton, MA

Public perception of light pollution sources in Princeton aligns closely with recent satellite data on night time light radiance.

Survey respondents perceive the major sources of light pollution in Princeton to be the Wachusett Mountain Ski Area and residential lighting. Some 66% of respondents identified the Wachusett Mountain Ski Area as a contributor to light pollution in Princeton and 44% of respondents identified residential lights as a contributor to light pollution. The increase in light radiance on the mountain, as discussed earlier, could be the result of the ski area switching ski slope lights to LED technology in 2017 and from new LED lighting in parking lots and building exteriors. As Figure 12 shows, flood lights are used to illuminate the ski area's parking lot which is not properly shielded or directed downwards.



Figure 12. Image taken of floodlight used in Wachusett Mountain Ski area parking lot.

Commercial lighting in Princeton is misdirected and inadequately shielded.

Lighting technologies used in Princeton for commercial purposes do not meet all International Dark-sky Association's (IDA) lighting standards. Light technologies used to illuminate commercial signs, such as those in Figure 13, do not properly direct light. Commercial sign lighting should be directed downwards rather than upwards to reduce the amount of wasted light that escapes into the night sky. In Figure 14, a wall pack light, a common technology used for security purposes, is shown emitting a very cool toned light that is scattering in all directions. This light could be replaced with a fully shielded, properly directed wall pack with a warmer color temperature. A replacement wall pack that abides by the IDA standards would provide the same security as the current technology. To view examples of dark-sky friendly lighting technologies a table can be found in Appendix T3. These technologies typically would not reduce energy costs since in most cases commercial lighting is already LED technology. One way for businesses to reduce costs and light pollution is to put lights on timers or dimmers when the lights are not needed, for example, to illuminate signs when the business is closed.

Findings



Figure 13. Image taken of plaza lighting on Route 31 in Princeton.



Figure 14. Image taken of Heritage Bible Church in Princeton.

Princeton's streetlights are designed to minimize the effects of sky glow.

Princeton's current lighting technology does meet some dark sky standards. In 2017 Princeton underwent an LED conversion project to replace most of their sodium vapor lights. Sodium vapor lights produce an orange toned light by running an electric current through pressurized sodium gas. These light technologies were replaced due to their higher operational costs compared to LED technology. After installation, the town's energy cost to operate streetlights decreased due to the greater efficiency of LEDs. Princeton's town-owned lighting consists of 75 light fixtures which include 100, 150, and 250 watt equivalent LED streetlights. The 100 and 150 watt streetlights are Autobahn LED roadway and security series lights, while the 250 watt streetlights are Autobahn LED roadway series lights. Figure 15 shows the Autobahn LED

roadway light. Both series meet the LEED goals and Green Globes criteria for light pollution reduction. These criteria specify that the optical design of the lights must minimize the obtrusive aspects of exterior lighting including glare, light trespass, and skyglow. Specifically the streetlights are designed such that no light is emitted above an imaginary, horizontal plane, passing through the bottom of the LED. Less than 10% of the emitted light shines within 10 degrees below the bottom of the LED's (IAC, n.d., pg. 2). Therefore the lights are rated to provide 0% uplight and restrict backlight to within sidewalk depth.

Findings



Figure 15. Product image of Autobahn ATBM series roadway light (Autobahn, 2021).

Converting to LED streetlights in Princeton has produced excess glare and contributed to light trespass.

The color temperature of both series of streetlights are 4000 Kelvins. The higher color temperature correlates to an increase in blue light that is emitted, which scatters more than other wavelengths of light due to its shorter wavelength and higher energy. Shielding can only limit this scattering to a certain extent, therefore the effects of glare and light trespass are increased with more blue light emissions.

Princeton has just recently installed LED lights, which have an average life span of about 20 years. In order to change the CCT, the LEDs would have to be replaced. In most cases, this replacement of the LED would be just as expensive as replacing the entire light fixture.

Remotely dimming the streetlights would be another viable option to lower the intensity of the streetlights, reduce the effects of glare, and save money as input wattage would be reduced. As discussed in the Background chapter, the city of Cambridge accomplished these effects through dimming streetlights. However, remotely dimming the streetlights in Princeton is not a feasible option now. The process requires the streetlights to be on a mesh internet network, with nodes that connect dimmable drivers from light to light. Princeton's streetlights are too dispersed for connection to a mesh internet network to be economically viable.

The last option to reduce the effects of glare and light trespass would involve manipulating the Field Adjustable Output in each streetlight to reduce the input wattage, which would directly reduce the output lumens. This would result in a less intense light to be emitted, helping to mitigate the effects of glare on drivers, and would slightly reduce energy costs associated with operating the town's streetlights.

Surrounding towns and cities reduce the visibility of the night sky in Princeton.

Light pollution has increased across many parts of Massachusetts at a rate of 4-6 percent per year (Kearnan, S., 2020). Figure 16, satellite imagery from 2012, and Figure 17, satellite imagery from 2020, depict the larger region of Massachusetts with Princeton's town center located by the red arrow. An increase in light radiance is evident across all of Massachusetts, partially from large cities. The effects of light pollution from larger polluters in Massachusetts can disproportionately affect small rural areas. The effects of light pollution from cities including Leominster, Fitchburg, Worcester and even Boston have effects on the night sky in Princeton. Survey respondents identified each of those cities along with the towns of Holden and Sterling as contributors to light pollution in Princeton.

Findings

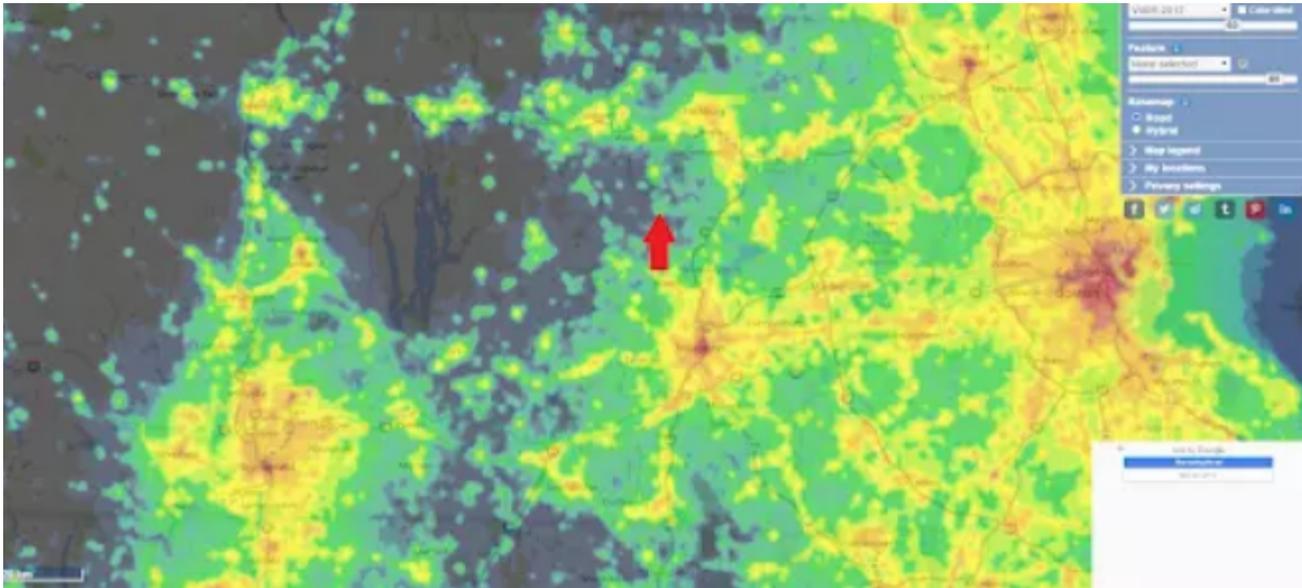


Figure 16. Satellite imagery from the NOAA's VIIRS 2012 data, depicting the level of radiance of light pollution in the larger region of Massachusetts with Princeton's town center labeled by the red arrow (lightpollutionmap.info).

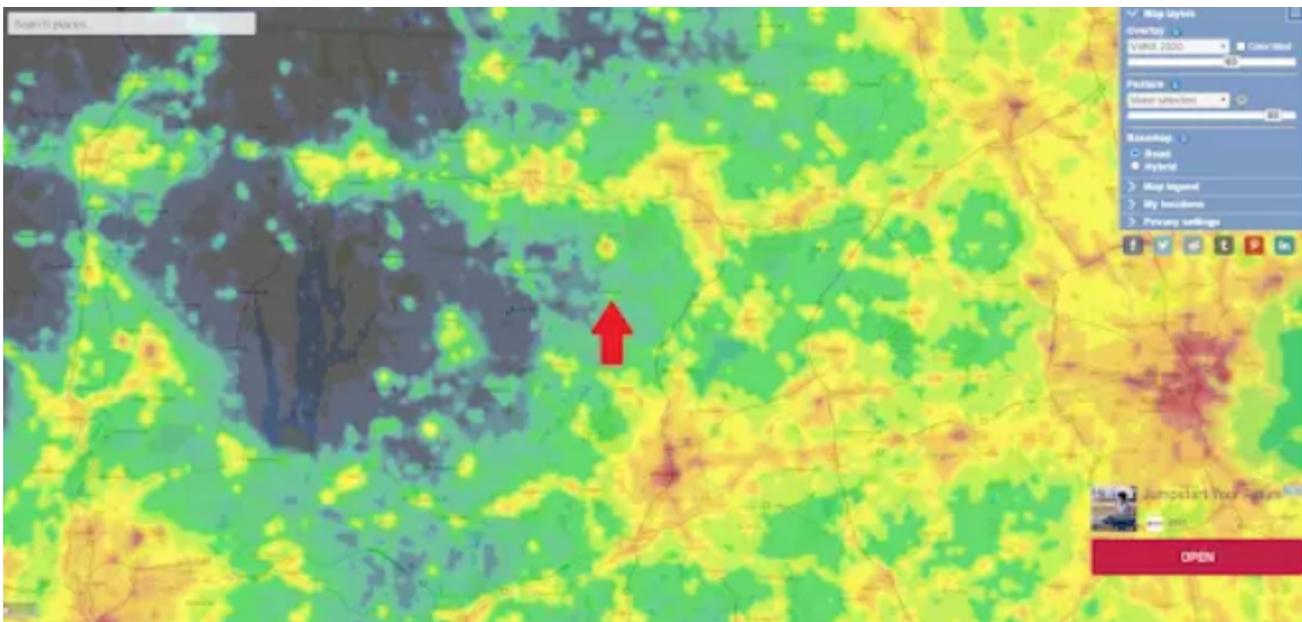


Figure 17. Satellite imagery from the NOAA's VIIRS 2020 data, depicting the level of radiance of light pollution in the larger region of Massachusetts with Princeton's town center labeled by the red arrow (lightpollutionmap.info).

Findings

4. Light pollution affects my enjoyment of the night sky.
254 responses

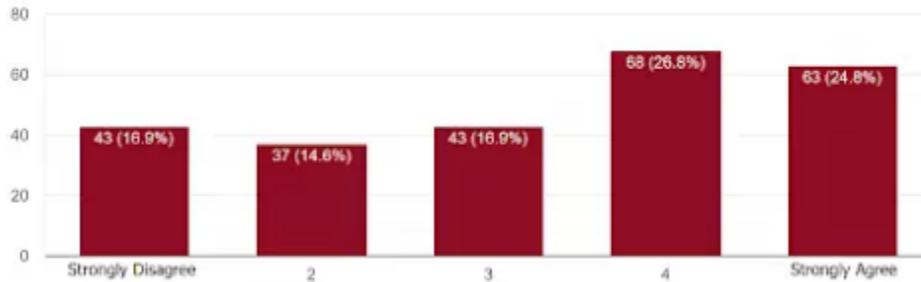


Figure 18. Results of survey question 4.

Princeton Residents' Views on Light Pollution

Our survey ran from April 12th to May 1st. We received 255 responses which is about a 9% response rate.

Survey respondents are affected by light pollution.

We asked Princeton residents several questions about light pollution's presence within the town and its effect on them. A majority of respondents agreed that light pollution was affecting their enjoyment of the night sky, as shown in Figure 18.

was contributing to light trespass or light pollution, shown in Figure 19. These survey responses show that survey respondents believe that light pollution exists within Princeton.

Survey respondents disagree on the effects of light pollution.

In addition to the questions on the presence of light pollution in general, we asked questions about specific types and effects of light pollution within the town. Despite the agreement that light pollution exists, 57.3% of respondents had not noticed a decrease over time in the number of stars visible in

3. Please identify the three examples of light use listed below which you believe contribute the most to light trespass or light pollution in Princeton.
252 responses

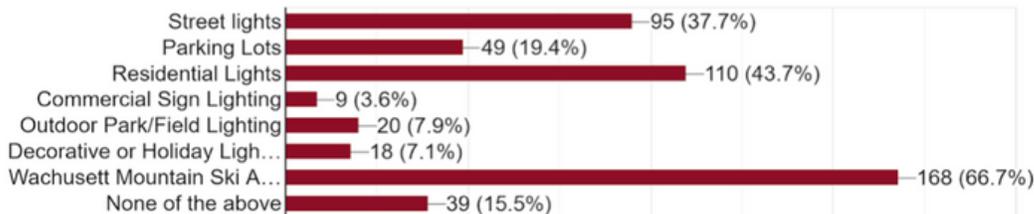


Figure 19. Results of survey question 3.

Survey respondents identify sources of light pollution and trespass.

More than 80% of respondents were able to identify some example of light use within the town which

the night sky (Figure 20) and a 42.6% plurality had not noticed a decrease in the number of fireflies they saw (Figure 21). Additionally, we compared these questions to an earlier question which asked how long survey respondents had lived in Princeton and

Findings

2. In the time that you have lived in Princeton, have you noticed a reduction in the number of stars that are visible in the night sky?
255 responses

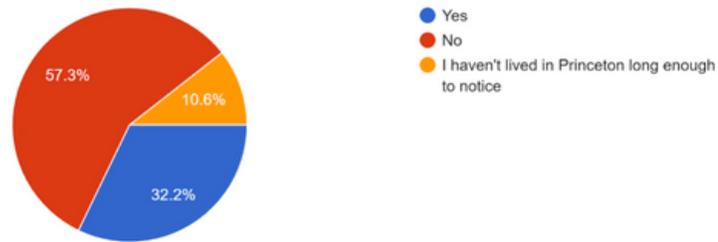


Figure 20. Results of survey question 2.

12. Scientific studies suggest that light pollution may interfere with the behaviors and circadian rhythms of plants and animals. Over the past five years, have you noticed a decrease in the number of fireflies you have seen at night in Princeton?

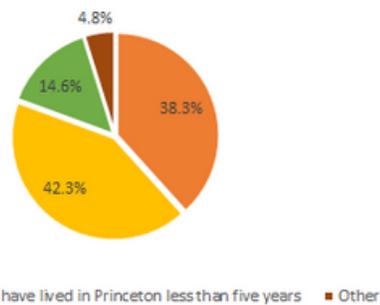


Figure 21. Results of survey question 12.

found that there was no meaningful correlation between how long residents had lived in Princeton and whether they were noticing a decline in the number of stars or fireflies they were observing.

Respondents were largely not affected by glare from streetlights when driving at night. Responses on the existence of light trespass followed an inverted bell curve, with the stronger opinions being the most popular in about equal proportion. The results of this question are shown in Figure 22.

We compared attitudes toward light trespass with length of residency in Princeton to determine whether residents who had lived in Princeton longer were more affected by light trespass. We did not find a meaningful correlation. The number of respondents who agreed that light trespass had personally affected them might explain the difference between the number of respondents who

identified that light pollution was affecting their enjoyment of the night sky and the number of respondents who identified a source of light pollution or light trespass within the town. Alternatively, the overall response that respondents did not experience glare from streetlights, decreasing star count, or shrinking firefly populations could indicate that some respondents who were able to identify sources of light pollution believe that light pollution exists but is not affecting them personally.

Survey respondents overwhelmingly agree that every Princeton resident should be able to see a clear, starry night sky.

Perhaps the most important of the questions we asked Princeton residents, though, are those which looked towards the future. One question in our survey, shown in Figure 23, asked whether seeing a

Findings

10. Light trespass--any light that expands beyond its intended area of use, specifically property lines--has negatively affected me in Princeton.

255 responses

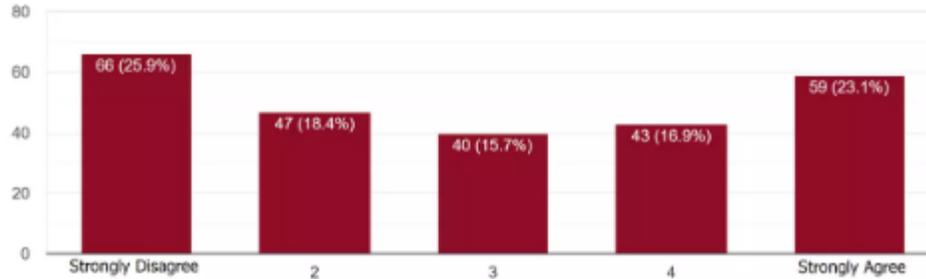


Figure 22. Results of survey question 10.

5. Everyone in Princeton should be able to see a clear, starry night sky.

254 responses

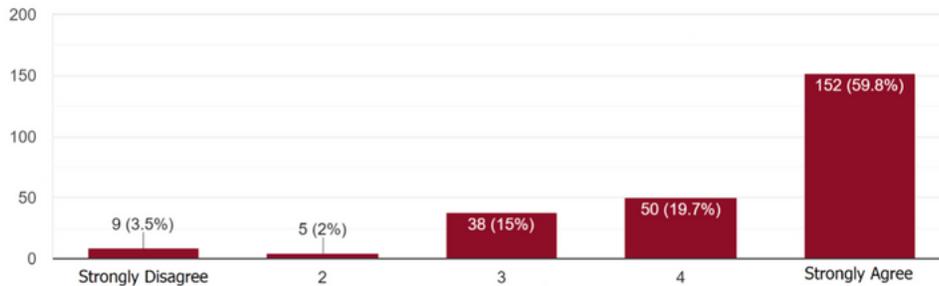


Figure 23. Results of survey question 5.

clear, starry night sky should be a right intrinsic to living in Princeton. Respondents overwhelmingly agreed on this question, with more respondents selecting ‘strongly agree’ than all the other responses combined.

Over 60% of those we surveyed also responded that they were concerned about the future of light pollution within Princeton and preserving its night sky, shown in Figure 24.

Survey respondents will support action against light pollution.

In a question which asked about support among respondents for different methods to reduce light pollution, over 70% answered that they would support at least one of the methods, with even the least popular method still garnering the support of over 40%. The full breakdown is shown in Figure 25, but the main takeaway is that regulation of

11. I am concerned about how light pollution might negatively impact the night sky in Princeton in the future.

253 responses

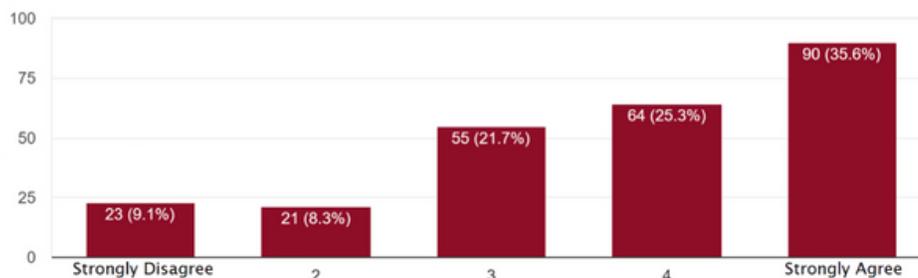


Figure 24. Results of survey question 11.

Findings

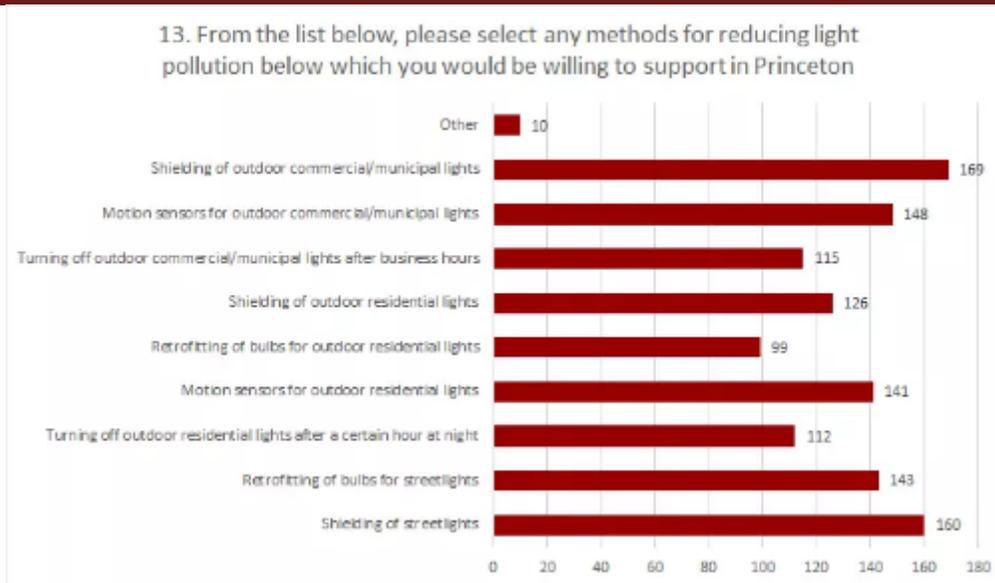


Figure 25. Results of survey question 13.

municipal or commercial lighting would be much more popular than regulation of residential lighting.

This support for alterations to commercial and municipal lighting over residential lighting mirrors what we found when investigating the bylaws of other towns. In most bylaws, outdoor lighting regulations applied only to commercial and municipal lights. The support for shielding is embodied in many lighting bylaws where regulations on the shielding and direction of lights are most common. The full table of towns whose bylaw provisions we examined can be found in Appendix T.

Write-in responses indicated diverse views on light pollution

We also included an open-ended question in our survey which asked about further concerns Princeton residents had related to lighting or light pollution. We received write-in responses both asking for more streetlights and asking for existing streetlights to be removed. Some used the write-in

response to reiterate that residential lights were an issue in the town. We found two respondents' write-ins to this effect particularly poignant:

“Spotlights in residential yards are becoming more common and definitely contribute to light pollution and trespass. I would like to see it regulated with wattage requirements and limitations on hours they can be used. As more people move here from city settings they tend to bring their city light expectations with them and it’s ruining some of our natural rural settings.”

“Noticed with my neighbors they want to light the exterior of their house with blinding lights. Post lights as well as spot lights. All the lights I install are pointed at the ground and shielded like they do in dark sky communities”

Findings

Both of these respondents seemed to take issue with their neighbors' outdoor lights. One references their compliance with dark-sky standards, while the other asks for regulation on residential lighting and notes that new residents in Princeton who move to the town from more urban areas light their homes more aggressively.

Outside of discussing residential lights, some respondents suggested the EAC focus its light pollution reduction efforts, at Wachusett Mountain Ski Area or at other towns and cities whose brighter and more prevalent lighting contributes more to light pollution. Five respondents told us that light pollution is not an issue in Princeton. These responses call into question the necessity of reducing light pollution in Princeton and suggest that at least some portion of Princeton residents are unaware of the presence of light pollution in the town. Additionally, some respondents expressed concerns over the rights of residents and an aversion to new regulations which suggest the EAC may face some pushback against lighting regulation.

Options to Mitigate Light Pollution in Princeton

Community Outreach

Efforts to reduce light pollution are most effective when linked to community concerns about lighting nuisances.

We looked to Nantucket, MA as a guide to identifying successful and less successful strategies to motivate communities to reduce light pollution. Local activists organized a Night-Sky Watch Party, which encouraged the community to gather at the beach and stargaze. Though it was an interactive method for connecting the community to the night sky, the turnout was much less than anticipated. This was due to residents not having an established

interest in enjoying the night sky beforehand. An effort to spread awareness of the effects and impacts of light pollution was carried out through a low-lumen bulb giveaway. Despite there being free items involved, residents were not interested. The organizers concluded that the community simply was not invested enough to go out of its way for these programs so they had to be approached from where their concerns and interests already lied.

What proved to be most effective was advocacy about existing lighting concerns. Residents emphasized light trespass or glare issues. The advocacy group amplified this message to town officials who would work collaboratively to resolve problems. Facilitating these discussions on a personal level not only conveyed to residents that they could trust the group, and enabled the group to more effectively link individual lighting concerns to the large issue of light pollution and night skies.

To build on early success, the light pollution advocates designed a virtual public forum to discuss light pollution in depth, to distinguish good from bad lighting practices, as well as providing astrophotography to display the presence of light pollution in the area. This forum was important because it served as an opportunity for community members to learn more about light pollution on their own accord.

Strategic and sustained outreach to three main groups is most effective.

A few of our key informants broke down outreach to local communities in a concise, pyramidal approach. The first group to reach out to are the town officials and energy coordinators. Outreach to both of these groups could be done through brief presentations during regularly held public meetings, which run through the basics of what light pollution is, its effects on the humans and the environment, and some lighting alternatives which can be considered.

Findings

If this outreach is carried out, town officials and energy coordinators could make more informed decisions that help efforts combating light pollution (Beatty, Personal Communications, April 29, 2021). They also have the ability to make impactful decisions within the town, so spreading awareness to them will help them make more informed decisions on lighting alternatives and approaches.

Second in the breakdown are businesses and homeowners within the town. Informing them of light pollution issues could motivate them to opt for better lighting alternatives within their own business and homes, and thereby encourage other individuals to do the same. As an incentive, one of our key informants advised bringing in discussions of cost efficiency. He drew on the commercial Dunkin Donuts chain which opened up within his town of Pepperell, MA. “They had nothing to do with our town, when they shut all of their lights off at night except for one indoor light. And their interest was just money, right? They just wanted to save energy, but it’s really beautiful because you can actually see very well if someone was trying to break in. You don’t need that extra light....if Dunkin Donuts can do it, so can you” (Brothers, Personal Communication, April 30, 2021). Besides preserving the night sky, these residents could also save money on electricity by keeping lights off through the night, or choosing better lighting technologies the next time they change their lights. These incentives and actions benefit both the business owners, homeowners and the night environment.

Lastly, outreach to the general public should be carried out. This could be done through local organizations like the public library, local schools, and any environmental or agricultural groups (Brothers, Personal Communication, April 30, 2021) which residents interact with more regularly. Since this outreach is less tailored to a specific group in town, and is meant to reach the whole community, the options for outreach approaches are much greater.

Community activists use passion as a driving force to work against light pollution.

The Massachusetts Chapter of the IDA was formed by a group of passionate, and knowledgeable activists who cared strongly for the preservation of the night sky. Making instant connections at the light pollution convention, they formed the Massachusetts chapter of the IDA. Since then, they have been able to spread light pollution awareness to many towns and cities within Massachusetts, as well as helping towns like Nantucket, Siasconset, and Pepperell draft their own bylaws (Lowenthal, Personal Communication, April 23, 2021). In addition, they have instituted their own programs and efforts against light pollution within their own communities.

The start of this organization is exemplary of an outreach expert’s advice to form a group of well-knowledgeable and respected individuals to spearhead the effort against light pollution in Princeton. It worked in Nantucket to help pass the bylaw and draw attention to the cause; And worked overall in Massachusetts when advocates networked with other advocates. Through these collaborations, they were able to spread wider and more effective outreach.

Findings

Lighting Bylaw

The way a lighting bylaw is implemented varies from one town to another.

Forty one towns in Massachusetts have created lighting bylaws. We studied 13 municipalities that have demographics similar to Princeton in relation to population size, annual income, square area, and square area per person (shown in Appendix S). Results of this study are shown in Table 4.

The highlighted columns show regulations which are the most common between the thirteen towns. Out of 13 towns, we found that 10 applied regulations through a zoning bylaw. A zoning bylaw is a town law that controls use of land and development on land. We also found that regulations on commercial and municipal infrastructure were common, as 9 out of the 13 towns did this. All 13 municipalities included regulation on shielding, 12 of them included regulation on direction of light, and 8 of them included regulation on lumen output. Under the grandfathering column in Table 4, we found that for 5 out of the 13 towns, new lighting regulations would not apply to any previously existing lighting. 1 of the 13 towns gave residents 5 years to update their lighting in accordance with new regulations, 1 town called any lighting that existed before 2001 acceptable where post-2001, non-abiding lights needed to be replaced. Grandfathering terms for the

remaining towns are unknown. By studying these bylaws, while also keeping survey regulation responses in mind, we were able to identify plausible bylaw language for Princeton; this can be found in Appendix T1.

Unlike many of the other municipalities shown in Table 5, Pepperell, Massachusetts drafted a lighting bylaw in the form of a general bylaw. We spoke to Tim Brothers, the author of this bylaw. While requiring less supportive votes from the town was an advantage, deciding between a general bylaw and zoning bylaw was predominantly determined by who would be responsible for enforcing it. From Tim Brothers' perspective, planning boards, who would be responsible for enforcing a zoning bylaw in Pepperell, "tend to be made up of builders who are reluctant to enforce strict regulations" (Brothers, Personal Communication, April 30, 2021). This general bylaw will instead be enforced by a building inspector or any town Police officer, which Brothers believes is more likely to be enforced in Pepperell. The benefits of a general bylaw versus a zoning bylaw can vary from one municipality to another. Tim Brothers also made suggestions for the content within a bylaw. When he designed Pepperell's lighting bylaw, he did so from a prescriptive stance, but cautiously, meaning that exact specifications are discreet. His reason for using some exemptions from the prescriptive approach came from the conclusion that light pollution, especially light trespass and sky glow,

Town	Light Type	Shielding	Direction	Lumens	Kelvin	Hours of Operation	Pole Height	Residential	Streetlights	Commercial	Municipal	Zoning or General	Grandfathering
Truro		x	x	x			x	x		x	x	General	5 years to update
Boxborough	x	x	x	l		x	x	x	l	x	x	Zoning	Anything predating
Rowley		x	x	x		x	x	l		x	x		Pre-2001
Dalton		x										Zoning	
Lincoln	x	x	x									Zoning	
Blackstone		x	x				x	x	x	x	x	Zoning	
Georgetown		l	l									Zoning	
Plainville		x	x	l								Zoning	Anything predating
Lancaster	x	x	x	x	x	x	x	l		x	x	Zoning	Anything predating
Littleton	x	x	x				x			x	x	Zoning	
Middleton	x	x	x	l		x		x		x	x	Zoning	
Townsend	x	x	x	x	x	x		l	x	x	x	Zoning	Anything predating
Pepperell	x	x	l	l	x	x	x	x	x	x	x	General	Anything predating
Key:		Symbol	Meaning										
		x	This provision is present in the bylaw										
		l	This provision is present in the bylaw, but is irregular in some way										

Table 4. Comparative table of towns in Massachusetts with lighting bylaws.

Findings

are difficult to quantify. He used an example regarding Wachusett Mountain Ski Area and made the point that a picture of the mountain with the lights off will be evidently different from the mountain with their lights on. Leaving the attainment of this quantified data up to inspectors though will not be as straightforward. Specifically, he stated, “we can easily call balls and strikes without having to actually break out a Sky Quality Meter and make a quantitative measurement” (Brothers, Personal Communication, April 30, 2021). It is easiest for the enforcers to regulate lighting specifications such as direction and lumens if the conditions are kept broad and not qualitative.

Public awareness correlates with the effectiveness of a bylaw.

Bylaw existence does not ensure enforcement or effectiveness. Awareness campaigns focused on what light pollution is, its negative effects, and the feasible ways it can be mitigated, will increase enforcement and effectiveness of a bylaw. Nantucket, Massachusetts passed a lighting zoning bylaw in 2005 that had minimal effectiveness. A violator of Nantucket’s lighting bylaw will receive a warning from the Lighting Enforcement Officer of the town, and have a grace period of thirty days. If the violation continues after these thirty days, a fine of one hundred dollars will be applied for each additional day until resolution. Despite these seemingly strict penalties, many Nantucket residents were unaware that the bylaw existed. We spoke with Peter Morrison Co-President of the Nantucket Civic League who was involved in light pollution outreach approximately fifteen years after the passing of the bylaw. Town survey results showed that before the outreach forum, less than 50% of respondents within the Nantucket community were aware of the town’s existing lighting bylaw.

Recommendations

Community Outreach

- Many Princeton residents have complained about light trespass and glare from nearby streetlights, flood lights or porch lights. A community outreach campaign to reduce light pollution should make these concerns the starting point.
- The EAC can also appeal to residents about light pollution by sparking conversations through topics which may appeal to the community, such as protecting wildlife or conserving the rural character of the town.
- When delivering outreach more directly, the EAC could break down the outreach to three main groups of people:
 1. Town officials and energy coordinators
 - a. This group includes: Town Selectboard, the Planning Board, and the Princeton Municipal Light Department.
 - b. Outreaching first to these individuals in town is important, since they have the abilities to make decisions within the town in terms of lighting decisions between energy coordinators and the implementation or consideration of guidelines.
 - c. Outreach to them would include attending public board meetings, and presenting a brief presentation on what light pollution is, and how it affects the environment and the people in Princeton.
 2. Businesses and Homeowners
 - a. Bringing awareness to business owners in town could allow them to make more informed decisions for available lighting alternatives the next time they change their lights.
 - b. Incentives: Saving on electricity costs, by turning off lights after operational hours.
 3. General community
 - a. Fostering partnerships with:
 - i. The Aldrich Astronomical Society (AAS)
 1. Astrophotography: Similar to direct engagement through the Adopt a Library Telescope program, spreading astrophotography to the community and showing residents that the stars and the moon are present above their heads could spark care in residents and encourage further engagement with the movement. The AAS holds many Astrophotography presentations, now easily accessible over zoom for anyone to log onto and view. They also have a lot of available astrophotographs on their site for anyone to view.
 2. Scouts, STEM and Seniors: The AAS has also volunteered with the Boy and Girl Scouts, helping many meet requirements in their scouting program by sharing “...all about telescopes, science imaging, light pollution and constellations” (Aldrich.club, 2021). Through these programs, they are able to spark interests for astronomy in young students who can go on to share this interest with others. The AAS also volunteers for after school enrichment programs, bringing a similar program structure as with the scouts to these students, and also exploring “...current events and topics in astronomy, space science, telescopes, and telescope making. Audio visual presentations are tailored to the unique needs of each group” (Aldrich.club, 2021). Lastly, connecting with Senior citizens, the AAS also has well developed programs which spreads light pollution awareness and provides opportunities for them to appreciate and engage with the night sky.

Recommendations

3. The International Dark-Sky Association (IDA)

- a. Has many public outreach materials available for anyone to download and share. These educational public outreach materials include brochures offered in English, Spanish and Arabic which covers content such as:
 - i. “Protecting Night Skies for Present and Future Generations” (IDA)
 - ii. “Light Pollution Can Put Your Health at Risk” (IDA)
 - iii. “Light Pollution Can Harm Wildlife” (IDA)
 - iv. “Outdoor Lighting, Crime, and Safety” (IDA)
 - v. “Light Pollution Wastes Energy and Money” (IDA)
- b. They also have postcards and infographics with a quick summary of light pollution as an issue, which can be shared to the community.
- c. Globe At Night: This is a citizen-science program which works to bring awareness to the impacts of light pollution by encouraging residents from all over the world to log their observations and visibility of the night sky onto the site (accessible through laptop or mobile phone). Each month, a different constellation is selected for program users to identify in the night sky from where they are, and users could log in to track their overall night sky visibility.

4. Outreaching through local institutions

These organizations below have been contacted by our team to develop outreach programs with, however we have only received a response from the library. Our recommendations for the EAC is to work in partnership with the AAS, to spread advocacy to these institutions with programs listed beneath the AAS section. We also recommend expanding outreach to these groups through the resources listed beneath the IDA section above. Please refer to Appendix T1.1 to see a detailed breakdown of communications between our group and these institutions below, as well as their contact information for the EAC to build connections with them.

- i. Princeton Public Library
- ii. Thomas Prince Elementary School
- iii. Audubon Wildlife Sanctuary

By presenting these opportunities to the community for residents to learn more, not only can they be made aware of the impacts of light pollution on the environment and their lives, but it also allows for voluntary action of good lighting practices within their own homes. Outreach can also help nurture any interest they have in preserving the night sky, and connect them to larger groups like the AAS or Massachusetts IDA. Light pollution is a big issue, but by reaching out to the community about its impact and encouraging people to take action against it, they can work collaboratively against its effects.

Recommendations

Developing a Bylaw

We recommend that a lighting bylaw in Princeton:

- Be passed as a zoning bylaw
 - This was the most common approach in the lighting bylaws we examined
- Contain an intent statement
- Apply to commercial and municipal lights
 - Bylaws which applied to commercial and municipal lights were the most common in our research, and alterations to commercial and municipal lights were the most common in our survey
- Apply to residential lights
 - Bylaws which applied to residential lights were not as common in our research, but a bulk of Princeton's lighting is residential
 - If the bylaw does apply to residential lights, we recommend that lights which were installed prior to the passage of the bylaw be exempt, as was the case in most bylaws we examined which dealt with residential lights
- Contain a provision regarding shielding and direction of lights
 - This was the most common provision in our research
- Contain a provision regulating the lumens of lights used
 - This was the next most common provision in our research
- Contain a provision regulating the correlated color temperature of lights
 - Though uncommon in our research, this provision was strongly recommended by experts we interviewed

Recommendations

Further Contacts

We recommend that the EAC reach out and make connections with individuals/organizations who expressed interest in helping address light pollution within Princeton, whether that be through outreach programs or developing a bylaw. These individuals/organizations include:

- Individuals who expressed interest in Speaking
 - Kelly Beatty, *Senior Editor for Sky & Telescope Magazine, and an officer for the IDA-MA as a speaker.*
 - James Lowenthal, *President of the IDA-MA, Professor of Astronomy at Smith College*
 - Tim Brothers, *Vice President of the IDA-MA, MIT Wallace Observatory Manager*
- Institutions who expressed interest in hosting outreach events
 - Princeton Public Library (director Erin Redihan) who was willing to schedule an event almost immediately.
- Organizations who expressed interest in participating in outreach events
 - Aldrich Astronomical Society who suggested the EAC utilize the “Adopt a Library” program.
 - Jim Zebrowski, *President of AAS*
 - Steven Gallo, *Construction Coordinator of AAS*
 - Kevin Boucher, *the Information Technology and Membership Database Manager of AAS*
- Individuals who could offer bylaw structure and content suggestions
 - Tim Brothers, *Vice President of the IDA-MA, author of the Pepperell, MA lighting bylaw.*

Limitations

One limitation of our project was the distribution method of our survey. We primarily distributed the survey online through Princeton Facebook pages, Nextdoor Princeton, and “The Green News”. Therefore, the results which we received were biased towards Princeton residents who are active online and up to date with town news. The next limitation of our project was our ability to collect evidence of lighting technologies used in Princeton, as well as quantitative measurements of light pollution in Princeton’s night sky. Due to WPI’s Covid-19 protocols, our team was limited in the amount of field work we could conduct. We made it to Princeton on two occasions, but encountered further limitations from disruptive weather conditions. We had planned to obtain images of the night sky from multiple locations throughout Princeton to compare the levels of light pollution using PixInsight software but this was not possible.

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