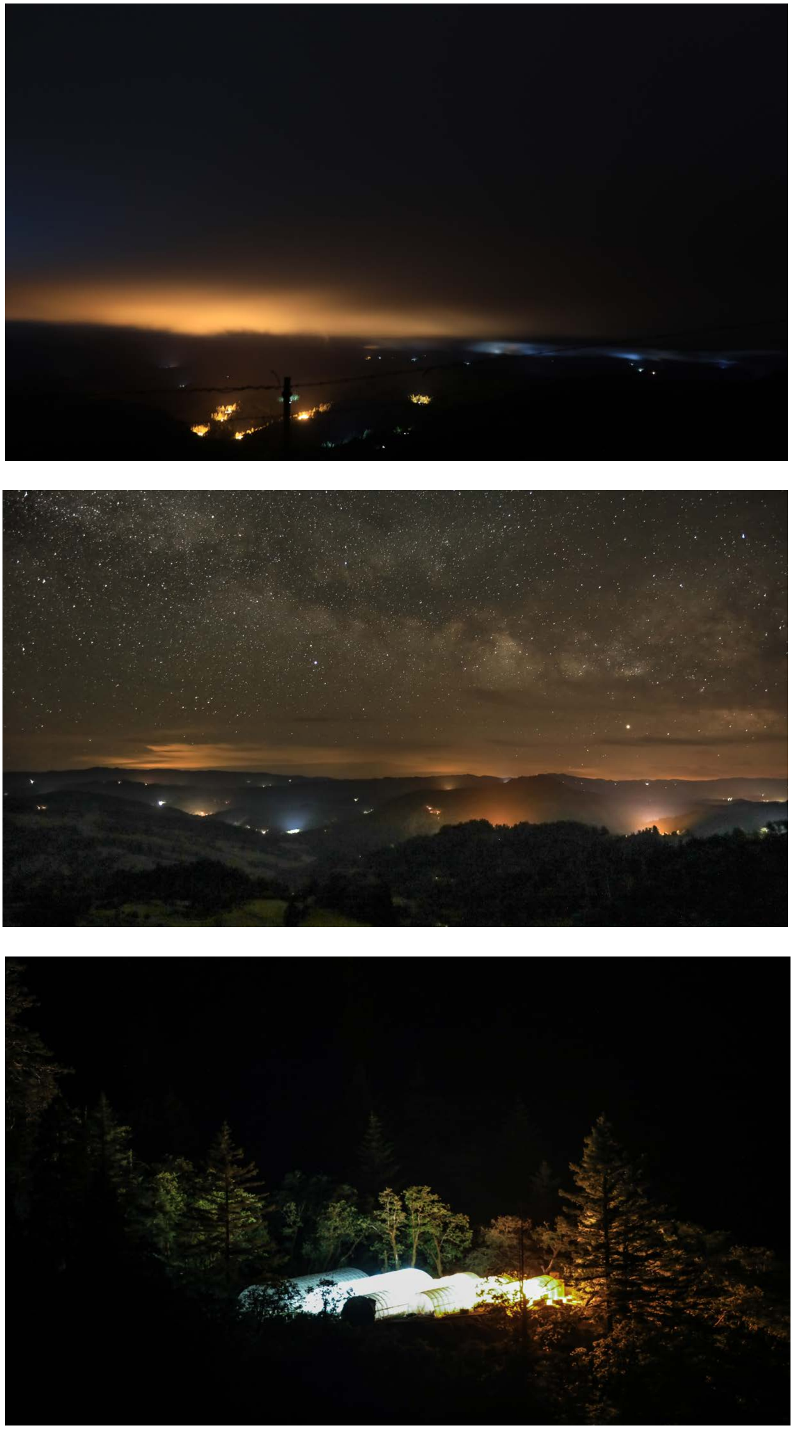

Examples of light pollution from cannabis cultivation operations in southern Humboldt County, 2018–2020. Photo credit: LoMaX

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A review of the potential impacts of artificial lights on fish and wildlife and how this may apply to cannabis cultivation

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Artificial lighting is used at cannabis cultivation sites in California to promote yield, for task lighting, and to provide security. While our understanding of how fish and wildlife respond to the artificial lights associated with cannabis cultivation specifically is in its infancy, studies assessing species' responses to other forms of artificial lighting at night have been ongoing for decades. We provide a review of these studies, with the goal of illuminating how artificial lights may influence the activity, movement, navigation, migration, phenology, and physiology of fish and wildlife populations.

Key words: activity patterns, artificial light, cannabis, fish, migration, movement, phenology, physiology, wildlife, photobiology

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Light plays a vital role in ecosystems by functioning as both an energy and an information source (Gaston et al. 2012, 2013). The addition of artificial light (i.e., light produced by humans) into a landscape can disrupt this role, altering the natural diel, lunar, and seasonal cycles under which species have evolved. This can influence a broad range of system processes including primary productivity in plants, wildlife activity patterns, species interactions, availability and detectability of food resources, movement and migration, timing of phenological events, and physiological functions (Longcore and Rich 2004, Da Silva et al. 2015, Bliss-Ketchum et al. 2016, Spoelstra et al. 2017). Further, because of sky glow (i.e., scattered light in the atmosphere), the reach of artificial light can extend far beyond the area that is directly illuminated (Longcore and Rich 2004). On cloudy nights in urban and suburban areas, for example, the sky glow effect can be of an equivalent or greater magnitude than high-elevation summer moonlight (Kyba and Hölker 2013).

Artificial lighting is increasingly being used in indoor and mixed-light (i.e., greenhouse) cannabis cultivation to promote yield, and for security around the perimeter of cannabis cultivation sites (CDFA 2017). While understanding how fish and wildlife respond to the artificial lights associated with cannabis cultivation, specifically, is an emerging question, studies aimed at assessing species' responses to other forms of artificial light have been ongoing for decades (Rowan 1929, Lashbrook and Livezey 1970, Pedersen and Larsen 1982, Thorpe 1987). Prior knowledge of how artificial light influences fish and wildlife species led the California Department of Food and Agriculture (CDFA), the primary commercial cannabis licensing authority, to require cannabis cultivation licensees to comply with several environmental protection measures pertaining to artificial light (CDFA 2017). These include ensuring that all outdoor lighting used for security purposes is shielded and downward facing, and that all lights used for cultivation are shielded from sunset to sunrise to avoid nighttime glare (CDFA 2017). To elucidate why these protective measures were put into place, and to predict how artificial lights associated with cannabis cultivation may influence fish and wildlife species across California, we review prior studies that assessed the influence of artificial light on species' 1) activity patterns, 2) movement, navigation, and migration, and 3) phenology and physiology. In this paper, we review these potential impacts to fish and wildlife resources, as well as potential approaches for mitigating the impacts of artificial lights.

ACTIVITY PATTERNS

Artificial light improves diurnal and crepuscular species' ability to see at night, allowing them to extend their period of activity into hours of natural darkness (Boujard and Leatherland 1992; Longcore and Rich 2004; Gaston et al. 2013). This activity pattern shift has been predominantly documented in birds, with bird species like the American Robin (*Turdus migratoriusi*) and Northern Mockingbird (*Mimus polyglottos*) beginning morning choruses earlier in the dawn and earlier in the year in areas with artificial lights (Table 1; Derrickson 1988; Miller 2006). For some species, this effect was found to be strongest at higher light intensities (Da Dilva et al. 2014, 2015). Diurnal bird species and salmonid fishes such as Lesser Kestrels (*Falco naumanni*), plover species, European Robins (*Erithacus rubecula*), Blue Tits (*Cyanistes caeruleus*), Rainbow Trout (*Oncorhynchus mykiss*), and Atlantic Salmon (*Salmo salar*) (Boujard and Leatherland 1992; Boeuf and Le Bail 1999; Negro et al. 2000; Santos et al. 2010; Byrkjedal et al. 2012), have also been shown to extend their foraging activities into the night in artificially illuminated areas. In the salmonid species, this extended feeding period led to increased growth rates and muscle mass (Boujard and Leatherland 1992; Boeuf and Le Bail 1999).

Conversely, other species may have reduced foraging success or reduced nighttime activity in artificially illuminated environments (Vogel and Beauchamp 1999; Gaston et al. 2013). Prey detection in some drift feeding and piscivorous fish species, for example, is dependent on the contrast between prey and background lighting. Consequently, these species exhibit greater visual sensitivity under low light conditions, and their ability to detect prey may be reduced in artificially lit environments (Tanaka 1970; Blaxter 1975). Artificial night lighting has also been found to impact juvenile salmonid overwintering success by delaying the emergence of salmonids from benthic refugia and reducing their ability to feed during the winter (Contor and Griffith 1995; Bradford and Higgins 2001).

A species may reduce their nighttime activity, alternatively, if their vulnerability to predation increases in brighter conditions (Navara and Nelson 2007; Gaston et al. 2013).

Table 1. Examples of changes in activity patterns resulting from artificial nighttime lighting.

Taxa	Species	Response	Source
Birds	Common Blackbird (*Turdus merula*)	Birds residing in the city started their activity before civil twilight, whereas birds residing in a rural forest synchronized their activity to the onset of twilight.	Dominoni et al. 2013
	American Robin (*Turdus migratoriusi*)	Chorus initiation time, relative to twilight, was positively correlated with the amount of artificial light. Mean high, intermediate, and low light levels were 3.91, 1.26, and 0.00 lx, respectively.	Miller 2006
	Northern Mockingbirds (*Mimus polyglottos*)	In an arboretum, mated males rarely sang at night under natural lighting conditions. This pattern was disrupted in more developed areas with artificial lighting.	Derrickson 1988
	Barred Owl (*Strix varia*), Long-Eared Owl (*Asio otus*)	In a laboratory setting, owls detected and attacked mice directly at light intensities comparable to weak daylight and the light given by a full moon. At dim light intensities, conversely, owls were more likely to have to search on foot.	Dice 1945
Mammals	Deer mice (*Peromyscus maniculatus*)	In an indoor habitat chamber, mice decreased their total activity as moonlight increased and were more active in areas with cover. Light bulbs were used to simulate moonlight, with 0.05, 0.17, 0.35, 0.93, and 2.20 lx representing new, quarter, half, three-quarter, and full moons, respectively.	Falkenberg and Clarke 1998
	Merriam's kangaroo rat (*Dipodomys merriami*)	During full moons, rats were more likely to be found in their day burrows and when they emerged, they stayed closer to home. This suppression of nocturnal activity led to an increase in crepuscular activity.	Daly et al. 1992
	Merriam's kangaroo rat	In large outdoor enclosures, rats reduced their foraging in the presence of artificial lighting (i.e., six floodlights set to approximate the light intensity of a full moon).	Brown et al. 1988
	Snowshoe hare (*Lepus americanus*)	Winter track transects showed that hares were less active in open areas during moonlit nights when compared with dark nights.	Gilbert and Boutin 1991

Table 1 continued.

Taxa	Species	Response	Source
Herpetofauna	Prairie Rattlesnake (*Crotalus viridis*)	In a captive setting, light bulbs were used to simulate moonlight, with 0.06, 0.35, 1.00, and 2.10 lx representing new, half, three-quarter, and full moons, respectively. Nocturnal snake activity was greater in new moonlight when compared to three-quarter and full moonlight. Snakes also spent proportionally more time in open areas on darker nights.	Clarke et al. 1996
	Common Toad (*Bufo bufo*)	The toad uses visual cues for prey detection, even at very low light intensities. Light only becomes a limiting factor if it falls below 30.00 µlx (i.e., 30 millionths of a lx).	Pedersen and Larsen 1982
	Long-Nosed Snake (*Rhinocheilus lecontei*)	The snake's small mammal prey has decreased due to light pollution, which may be responsible for the decline of this nocturnal species.	Perry and Fisher 2006
Invertebrates	Aquatic invertebrate (*Daphnia retrocurva*)	In an enclosure experiment, movement was significantly greater in amplitude (2 m higher) and magnitude (10-20% more individuals) in black enclosures that blocked 96% of irradiance vs. open enclosures that had light pollution levels less than that of full moonlight.	Moore et al. 2000
	Drifting aquatic insects	Insects were 37% less abundant at artificially lit sites (mean = 1482.00 lx) than at ambient sites (< 2.00 lx). The effects of light were most notable in large streams, which had a 58% decrease in Simuliidae and 51% decrease in Baetidae (when compared to sites under ambient conditions).	Henn et al. 2014
Fish	Rainbow Trout (*Oncorhynchus mykiss*)	In a laboratory setting, fish exposed to a 24L:0D continuous light cycle had a significantly higher daily growth rate than other experimental photoperiod groups.	Türker and Yildirim 2011
	Rainbow Trout	Trout reaction distance to prey species increased as light levels exceeded 5.00 lx, reaching an observed distance threshold or saturation effect (SIT) around 20.00 lx.	Mazur and Beauchamp 2003
	Rainbow Trout	Prey detection capability decreased when light levels exceeded the SIT (17.80 lx) because visual prey detection is dependent on the contrast between their prey and the background lighting.	Vogel and Beauchamp 1999

This pattern appears to be widespread, having been documented in species ranging from small mammals to snakes to amphibians to invertebrates (Table 1). Insectivorous bat species in Europe, including the lesser horseshoe bat (*Rhinolophus hipposideros*), Geoffroy's bat (*Myotis emarginatus*), and lesser mouse-eared bat (*M. oxygnathus*), for example, showed significantly decreased activity and/or a delay in the start of commuting behavior when exposed to light, likely as a predator avoidance strategy (Stone et al. 1999; Boldogh et al. 2007; Spoelstra et al. 2017).

One species altering its activity patterns due to artificial light can have cascading impacts on numerous other animals, including the species' predators, competitors, and prey. If prey species reduce their nighttime activity in areas with artificial light, for example, it can make prey detection harder and increase the energy demands of the respective predator (Table 1; Buchanan 1993). Alternatively, if prey species are attracted to artificial light, it can make prey detection easier and may result in changes in the movement patterns or distributions of the species' predators (Longcore and Rich 2004; Becker et al. 2013; Gaston et al. 2013). Artificial light tends to attract insects from the orders Lepidoptera, Diptera, Trichoptera, Hemiptera, Coleoptera, and Hymenoptera, for example, which then attract insectivorous bird and bat predators (Table 1; Santos et al. 2010; Longcore et al. 2015; Minnaar et al. 2015; Spoelstra et al. 2017; Welbers et al. 2017). Lastly, artificial light may make prey detection easier for predators that rely on visual cues to locate prey, as has been found with certain species of owls, toads, and salmon (Table 1; Dice 1945; Pedersen and Larsen 1982; Mazur and Beauchamp 2003).

MOVEMENT, NAVIGATION, AND MIGRATION

Artificial light can function as a barrier to connectivity, which may contribute to isolated populations, reduced genetic diversity, increased species' susceptibility to disease, and limited access to resources (Table 2; Bliss-Ketchum et al. 2016). Some mammal species, for example, are less likely to use road under-crossings that are illuminated when compared to those that are dark (Bliss-Ketchum et al. 2016). *Plecotus* and *Myotis* bat species in the Netherlands, alternatively, avoided areas that were illuminated by white or green light, resulting in the loss of these areas as potential habitat (Spoelstra et al. 2017).

By masking the natural light signals (e.g., through sky glow) that guide species' movements, artificial light can also have major disruptive effects on navigation and migration patterns in a variety of species (Table 2; Rowan 1932; Lowe 1952; Gaston et al. 2013; Bennie et al. 2015). In Pacific salmon (*Oncorhynchus* spp.), for instance, adult migrations and the out-migration of juveniles can be slowed or halted by the presence of artificial lights (Tabor et al. 2004; Nightingale et al. 2006). Similarly, the orientation of nocturnally migrating birds, the homing behavior of Red-Spotted Newts (*Notophthlamus viridescens*), and the vertical migration of larval salamanders (*Ambystoma* spp.), have all been documented to be disrupted by artificial light (Anderson and Graham 1967; Phillips and Borland 1992, 1994; Poot et al. 2008).

PHENOLOGY AND PHYSIOLOGY

Light mediates species' input and interpretation of day length, which can affect the output of certain hormones that regulate physiological events like development, reproduction, hibernation, dormancy, smoltification, and migration (Table 3; Hoffnagle and Fiviz-

Table 2. Examples of altered animal movement or migration patterns associated with artificial nighttime lighting.

Taxa	Species	Response	Source
Mammals	Black-tailed deer (*Odocoileus hemionus columbianus*)	Deer showed sensitivity even to nearby lights, using under-road crossings less often when neighboring sections were lit (high = 172.00 lx; low = 54.00 lx) compared to when none were lit.	Bliss-Ketchum et al. 2016
	Deer mice (*Peromyscus maniculatus*), opossum (*Didelphis virginiana*)	Mice and opossum used under-road crossings significantly more often in ambient conditions than in lit (high = 172.00 lx; low = 54.00 lx).	Bliss-Ketchum et al. 2016
	California bat species	Artificial lights can disturb roosting bats and potentially lead to the abandonment of maternity roosts.	Johnston et al. 2004
Herpetofauna	Common Toad (*Bufo bufo*)	During mass emigration of newly metamorphosed toads away from their aquatic environment, more toads aggregated in areas illuminated by streetlamps than in unlit areas.	Baker 1990
	Larval salamanders (*Ambystoma* spp.)	Vertical migration, which is associated with feeding, was correlated with decreased light intensity.	Anderson and Graham 1967
Invertebrates	Monarch Butterfly (*Danaus plexippus*)	In a lab, Monarch's circadian clock was disrupted when exposed to constant light, likely because they rely on light cues to migrate. Further, they were unable to orient in the correct direction when exposed to advanced light (i.e., sun compass had been advanced by 6 hours).	Froy et al. 2003
Fish	Juvenile Pacific salmonids (*Oncorhynchus sp.*)	Salmon fry migrated downstream at a slower rate under higher light intensities (1.08 and 5.40 lx) than under complete darkness (0.00 lx).	Tabor et al. 2004
	Rainbow Trout (*Oncorhynchus mykiss*) and Atlantic Salmon (*Salmo salar*)	Locomotor activity of salmonids is strongly influenced by an endogenous circadian clock entrained to 12L:12D cycles.	Iigo and Tibata 1997, Richardson and McCleave 1974, Thorpe 1987
	General	Input of artificial light increases species abundance by attracting fish to light sources, potentially concentrating predator and prey fish species. This can cause unnatural top-down regulation of fish populations.	Nightingale et al. 2006, Becker et al. 2013

Table 3. Examples of phenological and physiological changes associated with artificial nighttime lighting.

Taxa	Species	Response	Source
Mammals	Social Voles (*Microtis socialis*)	In a lab setting, night-light pulses (i.e., three 15 min 450 lx light pulses) negatively affected winter acclimization of thermoregulatory mechanisms.	Zubidat et al. 2007
	Deer mice (*Peromyscus maniculatus*)	In a lab setting, mice maintained in long day lengths (16L:8D) were more likely to develop induced tumors when compared to animals maintained in short day lengths (8L:16D); exposure to constant dim light (0.21 lx) significantly increased the growth rate of induced tumors.	Navara and Nelson 2007
Birds	Juncos (*Junco* spp.)	In a lab setting, juncos exposed to artificial light came into reproductive condition out of season.	Rowan 1925
	Common Blackbird (*Turdus merula*)	Nocturnal illumination (0.30 lx) suppressed reproductive activity, which demonstrates that chronic low intensities of light at night can affect the reproductive system.	Dominoni et al. 2013
Herpetofauna	Northern Green Frog (*Rana clamitans melanota*)	Males produced fewer advertisement calls and moved more frequently when illuminated by a maglite flashlight (approximately 1 m surrounding the frog was illuminated), which has the potential to reduce recruitment rates.	Baker and Richardson 2006
	Northern Cricket Frogs (*Acris crepitans*), American Bullfrog (*Lithobates catesbeianus*), Rio Grande Leopard Frog (*L. berlandieri*)	Fewer frogs called when the site was illuminated by a hand-held high-intensity spotlight (~ 38.00 lx at 5 m and 9.00 lx at 10 m) than when kept dark. Frogs also called less intensely during lit conditions vs. unlit.	Longcore and Rich 2004, Hall 2016
	American Toad (*Bufo americanus*)	Toads use photoperiod cues to behaviorally thermoregulate.	Beiswenger 1977
	Western Fence Lizard (*Sceloporus occidentalis*)	In a lab setting, photoperiod influenced the lizard's critical maximum temperature and ability to maintain or depress subdermal temperatures.	Lashbrook and Livezey 1970

Table 3. continued.

Taxa	Species	Response	Source
	Tiger Salamander (*Ambystoma tigrinum*)	Under constant light, the salamander's production of melatonin was disrupted, which altered metabolic rates and required the animal to spend more time foraging.	Perry et al. 2008
Invertebrates	Beetles (family Lampyridae)	Artificial lights may be contributing to the decline of these beetles given they rely on bioluminescence for mate location.	Lloyd 2006
Fish	Chinook Salmon (*Oncorhynchus tshawytscha*)	In an experimental setting, exposure to unnatural photoperiods (24L:0D and 9L:15D) delayed smoltification and decreased body condition when compared to salmon raised under natural light conditions.	Hoffnagle and Fivizzani 1998
	Rainbow Trout (*Oncorhynchus mykiss*)	Fish exposed to artificial photoperiods (14 days at 10L:14D, 60 days at 24L:0D, 30 days at 10L:14D, and 30 days at 12L:12D) experienced immune suppression, and increased levels of cortisol that is indicative of stress.	Leonardi and Klempau 2003
	Rainbow Trout	Exposure to constant photoperiod (24L:0D), created by artificial lighting in a lab setting, advanced spawning timing by 6 weeks to 3 months, and induced a repeat 4-7 month spawning cycle in those fish.	Bromage et al. 1984, Elliot and Bromage 1984
	Rainbow Trout	In a lab setting, alteration of daylength by artificial light manipulation (24L:0D) may indirectly modify growth rate (up to 25%) by increasing food intake and modify muscle mass by increasing exercise.	Taylor et al. 2006

zani 1998; Bradshaw and Holzapfel 2010). Further, photoperiodic control allows species to synchronize reproductive activities and to coordinate key life cycle events with suitable weather conditions (Gaston et al. 2013). When natural photoperiods are disrupted by artificial lights, species may become asynchronous with climatic and environmental conditions (e.g., mismatched reproductive activity with new plant growth or the reproductive activity of prey), which in turn, may negatively impact the species' fitness (Bradshaw and Holzapfel 2010; Bedrosian et al. 2011). The introduction of artificial night lights can shift entire breeding phenologies in temperate zone birds, for example, given that singing behavior, timing of gonadal growth, and egg laying are all proximately controlled by photoperiod (Da Silva et al. 2015). In addition to birds, artificial lights have also been shown to influence the reproductive activities of bats, frogs, fish, and beetles (Table 3).

Continuous periods of darkness also play an important role in controlling the repair and recovery of certain physiological functions (Gaston et al. 2013). Darkness is vital to the production of melatonin, the hormone that orchestrates changes in body mass, metabolic rates, hormone synthesis, and immunity that, in turn, influence processes ranging from reproductive development to skin coloration to thermoregulation (Table 3; Zubidat et al. 2007; Da Silva et al. 2015; Dominoni et al. 2016). By disrupting the production of melatonin, artificial light can suppress species' immune responses, alter species' perception of day length, or change a species' metabolic rate requiring them to spend more time foraging (Leonardi and Klempau 2003; Navara and Nelson 2007; Perry et al. 2008; Da Silva et al. 2015). Constant illumination may even cause results as extreme as altering a species' gene expression (Perry et al. 2008).

MITIGATING THE IMPACTS OF ARTIFICIAL LIGHT

The impacts of artificial lighting on ecosystems can be mitigated using numerous approaches of varying intensity (Gaston et al. 2012). The most effective option would be to prohibit the use of artificial night lighting or restrict its use. Restrictions may include, for example, limiting the use of artificial lights to 1-2 hours following sunset and 1-2 hours preceding sunrise (vs. all night), switching lights off or dimming lights during critical times of the year such as when foraging, breeding, or dispersal and migratory activities are happening, or only allowing the use of motion-activated lights (Gaston et al. 2012; International Dark Sky Association- IDA 2019). Less restrictive options for mitigating the impacts of artificial night lighting are to ensure 1) lights are only used where they are needed, 2) lights are only illuminated when they are useful, 3) lights only illuminate the target area (i.e., trespass of light is minimized), and 4) lights are no brighter than necessary (IDA 2019). Trespass of light typically happens when lights are unshielded, which includes when light fixtures have an exposed bulb, and can be addressed by fully shielding fixtures and ensuring they are downward facing, as is required by CDFA for commercial cannabis cultivators (CDFA 2017; IDA 2019).

The impacts of artificial lighting may also be mitigated by changing the intensity or spectrum of the lighting (Gaston et al. 2012). Each type of lamp has a unique spectral signature, emitting light at differing intensities and over distinctive ranges of wavelengths (Gaston et al. 2013). This is true of both artificial light and natural light. In a natural photoperiod, for example, blue light increases as dusk falls, especially when the moon is new or absent (Sweeney et al. 2011). Blue light is then replaced by moonlight and/or starlight, which is red-shifted relative to sunlight (Sweeney et al. 2011). These spectral characteristics are used by wildlife species as sources of information regarding their location and the time of day, triggering numerous behavioral and physiological processes (Sweeney et al. 2011; Longcore et al. 2015). White light-emitting diodes (LEDs), which emit a large fraction of their energy as blue light, have rapidly become the most common type of outdoor lighting, with higher Color Correlated Temperature (CCT) LEDs emitting more blue light than lower CCT LEDs (e.g. a 4000° Kelvin CCT LED typically emits more than a 2700° Kelvin CCT LED). This may be problematic for local wildlife populations as blue light produces more sky glow than lower color temperatures (e.g., yellow or red light) and contains the most biologically active wavelengths for physiological processes like hormone production and daily activity (Gaston et al. 2012; Kyba and Hölker 2013; Brainard et al. 2015; IDA 2019).

The spectral composition of LEDs can be custom-built, however, to mitigate the effects of artificial night light on ecosystems (Table 4; Poot et al. 2008; Gaston et al. 2012; Ouyang et al. 2015; De Yong et al. 2018). The IDA (2019) recommends using LEDs with color temperatures less than 3000 Kelvins when white lighting is needed and there are no specific wildlife concerns. When there are wildlife concerns, the recommended spectral composition of LEDs is species-specific. Green, yellow, phosphor-coated amber, and white LEDs with filters that remove blue wavelengths have all been found to help minimize the responses of certain wildlife species to artificial light (Longcore and Rich 2016; Longcore et al. 2018).

FUTURE DIRECTIONS

Artificial lights associated with cannabis cultivation may differ from lights associated with other forms of human development both temporally and spatially. They may differ temporally if lights are on continuously during nighttime hours, as compared to motion-activated lights or lights that are only on in the daytime. They may differ spatially if lights are operating in areas that are predominantly rural and forested, as compared to lights that are clustered in housing developments or in large agricultural areas. As of August 2019, 43% of commercial cannabis cultivation licenses issued by CDFA have been for mixed-light cannabis cultivation, which uses artificial lights to extend the number of growing hours in a day and the number of growing days in a year (i.e., the lights function during nighttime hours). The majority of these mixed-light licenses have been issued in Humboldt and Mendocino counties in northwestern California, one of the least developed regions of the state, with most cannabis-related development in this region occurring in areas previously covered in natural vegetation, notably old growth and second growth forests (Butsic et al. 2018). While this suggests that artificial lighting associated with cannabis cultivation may be distributed differently across the landscape than other types of artificial lighting, empirical data are desperately needed. Thus, in relation to cannabis cultivation, we encourage assessments on 1) the proportion of cultivators using artificial light in an outdoor or mixed light setting, and whether these lights are fully contained (i.e., such that no light escapes), 2) the number of nighttime hours when artificial lights are illuminated and how this varies throughout the year, and 3) the spatial distribution of artificial light sources and resulting skyglow at both local (e.g., within a forested or urban environment) and statewide scales. This information is imperative for developing our understanding of how artificial lighting is used in cannabis cultivation, how it may be impacting fish and wildlife populations in California, and how we can proactively mitigate any potential impacts.

Table 4. Examples of how different light colors impact wildlife.

Color	Species	Response	Source
White	Nocturnally migrating birds	60.5 – 80.8% of observed birds were disoriented by and attracted to white light.	Poot et al. 2008
	Plecotus and *Myotis* bat species	These bat species avoided transects illuminated by white light (via light posts).	Spoelstra et al. 2017
	Pipistrellus bat species	These bat species were more abundant in transects illuminated by white light (via light posts) than in darkness, likely because of the accumulation of insects.	Spoelstra et al. 2017
	Common toads	Toads avoided sections of road illuminated in white light.	Grunsven et al. 2016
Red	Nocturnally migrating birds	53.8 – 54.2% of birds were disoriented by and attracted to red light.	Poot et al. 2008
	Common toads	The toads showed no response if the road was illuminated in red light.	Grunsven et al. 2016
	Plecotus, *Myotis*, and *Pipistrellus* bat species	Bats were equally abundant in transects illuminated by red light (via light posts) and in darkness, which suggests they were least disturbed by red light.	Spoelstra et al. 2017
	House flies	Flies were attracted to red light.	Longcore et al. 2015
Green	Nocturnally migrating birds	Birds were less disoriented by green light than by red and white light, with only 12.5 – 27.3% of observed birds reacting to green light.	Poot et al. 2008
	Plecotus and *Myotis* bat species	These bat species avoided transects illuminated by green light (via light posts).	Spoelstra et al. 2017
	Mosquitos, midges, house flies	These insects are attracted to green light.	Longcore et al. 2015
Blue	Nocturnally migrating birds	Birds were the least disoriented by blue light (2.7 – 5.3% of observed birds reacted), when compared to red, white, and green light.	Poot et al. 2008
	Most insects	Many insects are attracted to blue light.	Longcore et al. 2015
	Coho Salmon (*Oncorhynchus kisutch*) and Chinook Salmon (*Oncorhynchus tshawytscha*)	In a lab setting, salmonids were more active (90% increase in activity) under lights in the blue and ultraviolet spectrum (mercury vapor lamps), when compared to strobe lights.	Puckett and Anderson 1988, Nemeth and Anderson 1992

Author Contributions

Conceived and designed the study: LNR, EF, ADB
Collected the data: LNR, EF, ADB
Performed the analysis of the data: LNR, EF, ADB
Authored the manuscript: LNR, EF, ADB, EC
Provided critical revision of the manuscript: EF, ADB, EC

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